18 Speleothems from Lebanon


18.1 INTRODUCTION

The Levant region has a long history of human settlement and migration. Water and food availability have been, and still are, major factors influencing the complex social and political situation in the region. In this region with strong north–south and east–west topographic, temperature, and precipitation gradients (e.g. Avni, Chapter 2; Kushnir et al., Chapter 4 of this volume), subtle changes in regional climate patterns may induce huge changes over short spatial and temporal scales. During the past decade, several palaeoclimatic studies of this region (Fig. 18.1) using marine (Rossignol-Strick et al. 1999; Kallel et al. 2000; Emeis et al. 2003) and continental palaeoclimate records (e.g. Frumkin et al. 2000; Bar-Matthews et al. 2003, Bar-Matthews 2014, and Chapter 17 of this volume; Kolodny et al. 2005; Verheyden et al. 2008; Develle et al. 2011; Ayalon et al. 2013; Vaks et al. 2013; Gasse et al. 2015, and Chapter 19 of this volume; Stein & Goldstein, Chapter 12 of this volume; Torfstein & Enzel, Chapter 13 of this volume) have revealed a complex regional climatic pattern, and more particularly, distinct north–south differences in precipitation variability. In a region where a drier climate is expected in the context of global warming, a robust understanding of past precipitation patterns is particularly important to understand future water stress. Hence, the Levant is an ideal region to study the impact of climate as one of the potential factors influencing societal change.

The δ18O records of speleothems from Israel have demonstrated the ability of these archives to record past decadal to millennial climate changes. They show good agreement with marine δ18O records from the eastern Mediterranean (Bar-Matthews et al. 2003; Kolodny et al. 2005), a source region for rainwater. Speleothems, which form by cave dripwaters, i.e. rainwater minus water lost by evapotranspiration, recorded glacial–interglacial changes (Frumkin et al. 1999; Enzel et al. 2008) as well as episodes of sapropel development, linked to increased freshwater influx from the Nile River (Rohling et al. 2002, 2004; Scrivner et al. 2004). Besides these source variations, lower δ18O values of speleothem calcite (δ18O_S) are also suggested to be linked to higher amounts of rainfall (Bar-Matthews et al. 1997, 1999) with potential quantitative precipitation reconstructions based on δ18O_S (Bar-Matthews et al. 2003). This quantitative reconstruction was challenged by Frumkin et al. (1999, 2000), Kolodny et al. (2005), and Enzel et al. (2008).

Changes in the carbon isotopic composition of speleothems, in the Levant and elsewhere, depend on several factors, including the C3/C4 vegetation changes (Frumkin 1999, 2000) and the contribution of soil CO2. The latter is controlled by the vegetation activity and soil development, and consequently by the contribution of soil CO2 relative to that derived from the host rock. In these southern regions, soil activity and subsequent soil CO2 contribution is more directly linked to precipitation amounts than to temperature.

In this chapter, we summarize the palaeoclimatic data for the Holocene and Last Interglacial intervals recorded in speleothems obtained from the Jeita and Kanaan caves in Lebanon.

18.2 SETTINGS OF THE CAVE SITES AND DESCRIPTION OF THE SPELEOTHEMS

The Jeita (N 32° 56′; E 035° 38′) and Kanaan (N 33° 54′; E 35° 36′) caves are within the western flank of central Mount Lebanon at ~100 m above sea level and 2–5 km from the Mediterranean coastline. The caves are therefore strongly influenced by the maritime Mediterranean climate. Jeita Cave is ~15 km north of Beirut and ~5 km north of Kanaan Cave (Fig. 18.1). Both caves developed entirely in the middle Jurassic Kesrouane Formation limestone (Dubertret 1975; Walley 2001; Nader 2004).

The stalagmite JeG-stm-1 (Fig. 18.2) was retrieved in 2005 from the upper gallery of the Jeita show cave, some 200 m from the entrance. The passage roof at this location is 16.5 m high, and the thickness of the overburden micritic limestone is around 100 m. At the sample site, the cave temperature is 22.0±0.5 °C, and water drips from the high ceiling during winter and spring, with possible short-term dry spells during the summer months. The sampled JeG-stm-1 stalagmite specimen is 121.5 cm long and was deposited from ~12 ka to ~1 ka. Its longitudinal inner profile displays a
regular deposition of dense calcite, ranging in colour from dark grey to light yellow-beige. The stalagmite along its entire length displays a typical ‘dish-stack’ structure. An important change in crystallographic habit coupled with a reduction in speleothem diameter occurs around 6.0 ka (Verheyden et al. 2008).

Kanaan Cave is a 162 m long relict conduit discovered during quarrying in 1997. A stalagmite 23 cm long and up to 10 cm wide, sample K1 (Fig. 18.3), was collected in 2010 (K1–2010) at ~20 m from the formerly closed cave entrance. The passage height at this location is 2.4 m with approximately 50 m of limestone overburden. At present, the stalagmite receives no dripping water, although drip water is present in other parts of the cave during winter and spring. The cave is generally dry during the summer months. The cave air temperature is 20±1 °C. The speleothem collected from Kanaan Cave grew from approximately 129.7±0.8 (2σ) ka to 85.3±0.7 ka and displays regular layers of dense calcite ranging in colour from dark brown to light yellow with a regular thin (<0.2 mm) lamination in places. It presents two growth phases divided by an abrupt hiatus at 108.8–103.5 ka where the stalagmite was tilted ~45°, probably owing to settlement of the underlying boulder floor (Nehme et al. 2015).

18.3 TWO-STEP DRYING AT ~6 KA AS RECORDED IN THE JEIJA JEG-STM-1 STALAGMITE

The Jeg-stm-1 record (Verheyden et al. 2008) confirmed the occurrence of a generally wet early Holocene interval with increased speleothem growth between ~9.0 ka and ~6.0 ka (Fig. 18.2). The general δ18O pattern during this time interval more likely reflects a change in source δ18O, while the trends in δ13C and Sr/Ca (Cheng et al. 2015) indicate increasing groundwater recharge, and thus probably precipitation, towards 6.0–7.0 ka. From ~6.0 ka, increased speleothem δ18O- and δ13C-values, decreased speleothem diameter, and a change in crystallographic habit indicate a decline to dry conditions marking an end to this local ‘Holocene
and a dry southern Levant during an interval with Northern Hemisphere summer insolation maxima. This north–south difference is also observed during the penultimate glacial–interglacial and during the transition towards the Last Glacial (glacial inception) (Nehme et al. 2015; Cheng et al. 2015).

18.4 THE LAST INTERGLACIAL AND ITS DEMISE – THE KANAAN CAVE RECORD

The general pattern of the Last Interglacial as registered by δ¹⁸O and δ¹³C in the K1–2010 stalagmite (Nehme et al. 2015) suggests wet conditions at the glacial–interglacial transition around 130 ka with a rather active vegetation (Fig. 18.3). The local settings of the stalagmite on a tilted rock, which explains the later tilting of the stalagmite, combined with the presence of clay layers despite high growth rates before and after the hiatus, suggest a period of flooding of this part of the cave. Between 126.3 ± 0.9 and 120.3 ka (uncertainties of <1 ka), a remarkable δ¹⁸O increase occurs which may indicate a change in isotopic composition of the source or a severe drying. The δ¹³CST does not display important changes; the continuous rather negative values indicate that the vegetation growth is still active. During the glacial inception, decreased δ¹⁸O values and changing growth rates at 108.8 ka (extrapolated) to 99.9±0.7 ka, and at ~93 to ~90 ka (interpolated), are interpreted as two wet intervals, corresponding well with sapropel 4 and possibly linked to pre-sapropel 3 (Ziegler et al. 2010), respectively.

Warm and humid conditions prevailed during the Last Interglacial as recorded in the Kanaan speleothem, and are also identified in Lake Van (Litt et al. 2014; Stockhecke et al. 2014) in northeastern Turkey and in speleothem proxies from Soreq and Peqi’in Caves (Ayalon et al. 2002; Bar-Matthews et al. 2003) in central and northern Israel (Fig. 18.4). The Soreq and Peqi’in speleothems exhibit high δ¹³C and low δ¹⁸O values interpreted as linked to massive rainstorms (Bar-Matthews et al. 2003). The pollen records of Yammouneh palaeolake (e.g. Gasse et al., Chapter 19 of this volume) in northern Levant indicate sufficient humidity to enable forests to develop (Develle et al. 2011) during the second part of the Last Interglacial, although chronologies in the early Last Interglacial are less robust. During the glacial–interglacial transition, most of these archives as well as the K1–2010 stalagmite indicate these wet conditions, which contrast with an arid southern Dead Sea Basin (Torfstein et al. 2015). The situation is similar with the last glacial/present interglacial transition (Verheyden et al. 2008; Cheng et al. 2015), and is in agreement with previous suggestions of contrasting climate variability between northern and southern Levant (Almogi-Labin et al. 2009; Develle et al. 2011). The contrasting behaviour at millennial scale is demonstrated for the Holocene between the Jeita Cave record and the Dead Sea basin (Cheng et al. 2015). During the Last Interglacial (Marine Isotope Stage 5e), however, wet conditions seem general over the Levant, as Neugebauer et al. (2015) and Torfstein et al. (2015) have revisited data of the Dead Sea basin lakes and demonstrated a somewhat more humid Last Interglacial than previously thought. These authors suggest that
Figure 18.3 A: Cut face of the K1–2010 speleothem and sketch showing the position of the U–Th ages (see Stein et al., Chapter 8 of this volume). B: Growth rate of the stalagmite with respect to distance (in mm) from the top, assuming linear growth rates between two consecutive ages, except in the middle part where a discontinuity (hiatus) is identified. Based on Nehme et al. (2015).
tropical Africa sources could have moderated the dryness during 5e. The inverse behaviour of the δ^{13}C in speleothems from Kanaan, with a rather constant δ^{13}C, and speleothems from Soreq and Peqi’in caves, with negative δ^{13}C anomalies, remains puzzling and suggests different local settings or different precipitation systems influencing the cave locations. The strongly enriched δ^{13}C values in speleothems of Soreq and Peqi’in caves were linked to storms and could be in agreement with the influence of tropical moisture, which would not have reached Kanaan Cave. However, Soreq and Peqi’in caves are located to the north of the supposed monsoonal influence as displayed in recent general circulation models (e.g. discussion in Torfstein et al. 2015 and in Torfstein and Enzel, this volume). Another possibility is that the Soreq and Peqi’in speleothems reflect seasonal deposition of calcite during wet months in an otherwise dry area with poor soil development, suggesting a north–south precipitation gradient with higher precipitation seasonality in the southern Levant than in the northern Levant. At present, the influence of Mount Lebanon on the observed precipitation gradients remains uncertain, but could probably be constrained through further studies focusing on caves at higher altitudes.

At ~126 ka, the important δ^{18}O increase between 126.3 and 120.3 ka (uncertainties of ~1 ka) in the Kanaan speleothem seems to be mostly due to a ‘source’ effect (Nehme et al. 2015), reflecting the δ^{18}O composition of Mediterranean Sea surface water, since the δ^{18}O_{ST} change is synchronous with the eastern Mediterranean isotopic increase at ~126 ka during the sapropel S5 event (Emeis et al. 2003; Grant et al. 2012). Several studies (Rohling et al. 2002, 2004; Schmiedl et al. 2003; Scrivner et al. 2004) suggest a coincidence between Mediterranean cooling and enhanced aridity around the Mediterranean, and the interruption of the insolation-driven monsoon maximum during the S5 event. Schmiedl et al. (2003) argue that this episode marked the onset of a regional climate deterioration (glacial inception) following the ‘Last Interglacial optimum’ (early S5). The K1–2010 isotope change dated between 126.3 and 120.3 ka confirms and refines the chronology of the δ^{18}O change as published by Grant et al. (2012). Although the first part (~2‰ increase) of the δ^{18}O_{ST} change can be attributed to the source effect, the second part, combined with lower growth rates and slightly higher δ^{13}C, may reflect drier conditions related to a regional climatic deterioration. The change towards dry conditions at ~126 ka,
i.e. ~6 ka after the start of the Last Interglacial, mimics the changes observed during the present interglacial. However, the climate deterioration does not seem to have had much impact on the vegetation in this part of Lebanon, in contrast to the change at ~6 ka during the present interglacial. The change at ~126 ka observed in the Kanaan Cave speleothem was recorded differently in other places. In northern Levant, the transition seems to be more progressive (cf. the Yammouneh palaeovegetation signal; Gasse et al. 2015), while in southern Lebanon, the change seems more abrupt and occurs later around ~118 ka (Bar-Matthews et al. 2003) in Soreq Cave (or ~122 ka, when using the refined chronology of Grant et al. 2012), ~122 ka in Peqi’in Cave (Bar-Matthews et al. 2000, 2003) and between 122 and 116 ka in Dead Sea basin lakes (Torfstein et al. 2015).

During the glacial inception, two wet periods are defined based on changing growth rates and low $\delta^{18}$O values at 108.8 ka (extrapolated) to 99.9±0.7 ka, corresponding well with sapropel 4 and at ~93 to ~90 ka (interpolated), possibly linked to pre-sapropel 3 (Ziegler et al. 2010). Regarding the rapid changes and current uncertainties on the chronology, it is not evident whether the wet periods in the north are synchronous with the low water levels of southern lakes at 110–108 ka and 93–87 ka (Neugebauer et al. 2015).

18.5 CONCLUSION

The Jeita and Kanaan Cave records contributed to describe and precisely date the two-step change from a wet Early Holocene to a dryer period at ~6 ka and a similar but less severe change at ~126 ka. The amplitude of the associated $\delta^{18}$O change is high because of the cumulative effect of the source and the precipitation amount. The $\delta^{18}$O change at ~126 ka in the Kanaan speleothem seems to occur more progressively and probably earlier than in southern regions. Both speleothems clearly demonstrate the wet conditions during glacial–interglacial transitions (for Present and Last Interglacial) in this part of the Levant and its contrast with the aridity of the Dead Sea basin. Intervals such as the ~7 ka interval in the Jeita Cave speleothem and the glacial–interglacial transitions of the Last Interglacial and present interglacial in Jeita and Kanaan speleothems, respectively, suggest a general north–south gradient with contrasting dry/wet variability between northern and southern Levant. The contrast during other intervals, such as the first part of the Last Interglacial or the glacial inception (MIS 5–MIS 4 transition) is less obvious. A better understanding of the different signals from the intermediate regions in the Levant, i.e. speleothem proxies and especially the $\delta^{13}$C signal, derived from the Jeita, Kanaan, Peqi’in and Soreq Caves, is essential to figure out north–south palaeoclimatic gradients and possible decoupling as well as the implication of precipitation seasonality in speleothem signals. Moreover, Lebanon is an ideal place to investigate the effects of topography (i.e. Mount Lebanon) on the observed climatic gradients.

Recent additional dating led to a more constrained age model. Based on these new data, the change from wet to dry conditions at 126 ka occurs gradually up to 122 ka, followed by a more rapid change to 120 ka. The wet–dry change, therefore, seems contemporaneous within uncertainties to the change observed in more southern areas of the Levant. The record does not show a clear out-of-phase climate variability during MIS 5 as demonstrated for the last 20 ka in the Jeita record (Cheng et al. 2015).

REFERENCES


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