Luminescent growth banding and stable isotope stratigraphy in a stalagmite from northern Norway: preliminary results for the period AD 1734 to 955 BC

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Abstract

Luminescent organic matter in a stalagmite from northern Norway is found to display characteristic patterns of annual and sub-annual bands for the period AD 1734 to 955 BC. The stable isotope stratigraphy, with a temporal resolution of 10 to 30 years/mm, shows large-scale fluctuations with time similar to the variation in annual band width. Preliminary results suggest that, in one annual layer, the main luminescent lamina is deposited in the spring in relation to flushing of organic matter from the soil zone during snowmelt, and that minor laminae (of lower intensity and thickness) are formed during the autumn. Moreover, this indicates a strong relation between summer soil zone conditions and stalagmite growth rate, thus information from studies of annual bands are expected to improve the understanding of stable isotopes in high latitude speleothems.

Introduction

Calcite speleothems provide a multitude of archives of paleoenvironmental change (see reviews by SCHWARCZ, 1986; GASCOYNE, 1993; LAURITZEN & LUNDBERG, 1999a) which can be accurately dated by the uranium series (^{238}U-^{234}U-^{230}Th) method (SCHWARCZ, 1986). In this work we report preliminary records of variation in annual luminescent growth banding and stable isotopes from the period from AD 1734 to 955 BC provided by the L-03 stalagmite from northern Norway.

Speleothem luminescence is mainly caused by organic, acidic compounds with aromatic or conjugated π-bonds derived from the overlying soil and trapped within the calcite (BAKER et al., 1993; SHOPOV et al., 1994). Mechanisms controlling speleothem growth rate are related to climate change, through precipitation, temperature, carbonate precipitation process, but also to local factors causing changes in percolation water flow route (BAKER et al., 1998; DREYBRODT, 1999).

Changes in $\delta^{18}O_c$ along the growth axis of a stalagmite may reflect changes in the ^{18}O content of the dripwater which, in turn, can reflect surface temperature. The $\delta^{13}C_c$ signal is related to changes in the source of carbon and/or the calcite precipitation process (GASCOYNE, 1992). In order to use $\delta^{18}O_c$ as a paleotemperature proxy it must verified that the speleothem calcite was deposited in isotopic equilibrium with its parent dripwater, a condition recognized by insignificant variation in $\delta^{18}O_c$ along a growth horizon, and where any slight changes in $\delta^{18}O_c$ does not correspond to changes in $\delta^{13}C_c$ (HENDY, 1971; SCHWARCZ, 1986). Such measurements are usually referred to as the "Hendy-test".

Site and sample description

The L-03 stalagmite was collected from Larshullet, a cave situated in the Rana area, approximately 20 km south of the Svartisen ice cap and the Arctic Circle, northern Norway (Figure 1; inset). The area is characterized by mean annual temperatures of +3 to +4 °C and mean annual atmospheric precipitation of about 1500 mm.

Only a centre section of the L-03 stalagmite exists after previous analyses (α-dating); this slice was again split in the centre yielding two opposite facing slices (Figure 1). The stalagmite is beige of colour, has visible banding, and measures 144 mm along the vertical growth axis. The apex area of the stalagmite display zones of less massive calcite with non-coalescing crystals and large amounts of fine grained detritus.

Methods

Six subsamples of 2 to 3 mm vertical thickness (grey areas, Figure 1), weighing 0.3 to 1.0 g, were dated by the TIMS uranium-series technique with tailored chemical and instrumental procedures (LAURITZEN & LUNDBERG, 1997; 1999), at the University of Bergen using a Finnigan MAT 262 mass spectrometer.

For the analysis of luminescent laminae, a polished sample slice (right slice, Figure 1) was investigated under microscope at 20x and 50x magnification. Overlapping images from top to base of the stalagmite were collected using a Zeiss Axiotech reflected light microscope with mercury vapour light source, and a black and white CCD camera, and continuously analysed using Image Pro Plus/Express image analysis software. The distances between observed luminescent laminae were measured between the centres of each of the laminae. The detritus rich zones forced us to place the traverse for image analysis to the far right side of the sample slice (broken vertical line, Figure 1).

A 0.5 mm dental drill was used to sample along the vertical growth axis at 0.5 mm intervals (right slice, side view, Figure 1). More than 270 subsamples of 88 to 100 μg were analyzed for stable oxygen and carbon isotopic composition. Subsamples were also measured at 1.5 to 10 mm intervals along three individual growth horizons (A-C) for the 'Hendy' tests. The analyses were done at the GMS Laboratory, University of Bergen, using a Finnigan MAT 251 mass spectrometer and an automatic on-line carbonate preparation device ('Kiel device'). Standard carbonate samples have an analytical reproducibility of ±0.06 and ±0.07 ‰, for $\delta^{13}C$ and $\delta^{18}O$ respectively. Results are reported as ‰ versus PDB, using the NIST (NBS) 19 standard as a reference.

Figure 1 The L-03 stalagmite. Sample slice viewed from the front; grey areas to the left indicate positions of TIMS dates, vertical broken line on right side gives position of traverse for luminescent laminae analysis. Sample slice (right part) viewed from the side; growth axis with mm scale is identical with traverse analysed for stable isotopes. Inset: map of Scandinavia, arrow indicates location of the sample site just south of the Arctic circle.

Lab. no.	mm from base	mm from top (luminesc. traverse.)	^{238}U conc. (ppm)	^{232}Th conc. (ppm)	$^{234}U/^{238}U$	$^{230}Th/^{234}U$	$^{230}Th/^{232}Th$	$^{234}U/^{232}Th$	**Age** (yr before AD 2000)
334	12-14	129.5	5.755 ±0.014	0.695	1.1132 ±0.0067	0.03297 ±0.00083	82.86 ±2.84	2513 ±107	3644 ±93
339	36-39	106.0	2.830 ±0.010	0.647	1.1152 ±0.0085	0.02692 ±0.00041	35.69 ±0.69	1326 ±33	2967 ±46
323	53-56	88.5	3.359 ±0.004	0.601	1.1111 ±0.0029	0.02296 ±0.00009	38.6 ±0.36	1683 ±17	2525 ±10
336	111-114	31.5	5.205 ±0.007	0.766	1.1172 ±0.0044	0.01146 ±0.00006	23.66 ±0.19	2065 ±19	1253 ±6
304	120-123	24.5	4.930 ±0.006	0.690	1.1259 ±0.0034	0.00983 ±0.00006	21.92 ±0.21	2229 ±25	1075 ±7
333	135-138	8.5	3.714 ±0.002	0.486	1.1260 ±0.0021	0.00647 ±0.00010	15.17 ±0.03	2345 ±58	705 ±12

Table 1 TIMS uranium-series dating results from sample L-03

Results

TIMS uranium-series dating:

Table 1 shows the TIMS uranium-series dating results from the six subsamples with positions indicated as grey areas in Figure 1. The results show ^{238}U concentrations higher than 2.8 ppm, ^{232}Th concentrations lower than 0.8 ppm, and with ages in chronostratigraphic order. The growth period of the stalagmite commenced before 3600 yr ago (1600 BC), and terminated after 705 yr ago (AD 1295).

Figure 2 a) The distance between recorded laminae from the top surface (0 mm) to 110.6 mm below the top surface. b) The distance (=band width) between laminae with annual status.

Characteristics of luminescence laminae:

The L-03 speleothem sample is found to be continuously banded in the analysed interval, i.e. from 144 mm (top surface) to about 34 mm above sample base. Growth is also believed to have been continuous as no evidence of hiatuses are observed in microscope.

Figure 2a shows the variation in distance between observed laminae from the top surface to 110.6 mm below the top surface (i.e. 144 to ~34 mm above the sample base). A total of 3570 laminae were recorded in this interval. Two characteristic patterns of luminescence laminae are observed: 1) zones with

Figure 4 Upper curve: Variation in $\delta^{18}O_c$ from base to top of the sample. Middle curve; variation in annual band thickness (grey curve - annual data, black curve – 29 yr running mean). Lower curve; variation in $\delta^{13}C_c$.

Figure 3 Hendy-tests for the horizons A, B and C. $\delta^{18}O_c$ is plotted against distance from the growth axis (mm), and against $\delta^{13}C_c$. Minor variation in $\delta^{18}O_c$ is observed along the horizons and no obvious correlation is evident between $\delta^{18}O_c$ and $\delta^{13}C_c$.

closely spaced and highly intense luminescent laminae (< 20 μm between individual laminae), corresponding to white, visible bands in the speleothem calcite, and 2) zones with one high-intensity luminescent lamina followed by another low-intensity lamina, or in rare cases two, and then again a high-intensity lamina. The distances between these three features are typically 10 to 20 μm (high to low) and 30 to 50 μm (low to high).

The low-intensity laminae are believed to be subannual (seasonal), the high-intensity laminae represent the main annual organic depositional event (i.e. flushing of organics from the soil zone), and the distance between two high-intensity laminae represents the annual band thickness. Figure 2b shows the thickness of the interpreted 2690 annual bands from the top surface to ~ 34 mm above sample base (0 to 110.6 mm from top). To confirm the annual nature of the banding in Figure 2b, the difference in age between two dated positions (see Table 1) is compared with the number of laminae between the same positions:

Between 8.5 and 24.5 mm below the top surface a total of 491 luminescent laminae are recorded, 114 of these are considered to be subannual. The number of interpreted annual bands, 377, compares well with the difference in age of 370 ±14 yr from the TIMS dates. 231 laminae are observed between 24.5 and 31.5 mm below the top surface and 80 of these are interpreted to be seasonal laminae, giving 151 annual bands compared to the age difference from TIMS on 178 ±9 yr. Between 31.5 and 88.5 mm below the top surface a total of 1718 laminae are recorded, of which 530 are considered to be subannual, yielding 1188 bands of annual status compared with a TIMS age difference of 1272 ±12 yr. Between the 88.5 and 106.0 mm below the top surface, the total number of laminae is 562, of these 125 are subannual. The number of annual bands, 437, which compares very well with the 442 ±47 yr difference between the dates. The age of the topmost calcite is unknown, being impossible to date with the uranium-series method due to the very high content of ^{232}Th. However, between the top and 8.5 mm below the top surface 459 laminae are recorded, only 20 of these are convincingly of a subannual character, giving 439 annual bands in the topmost interval. By subtracting this from the topmost TIMS date an age of 266 yr B2K or AD 1734 is obtained for the top surface.

The top 20 mm has been counted twice and there is little uncertainty on the number of bands and their status in this upper interval. From the comparison with the TIMS dates, about one hundred bands seem to be missing between 31.5 and 88.5 mm below the top surface, and a recount is required. However, as a preliminary result, the comparison between the band counting and the TIMS dates are considered to be quite good.

If the annual growth rate is assumed to be constant, the distance between annual and subannual laminae may be used as an indicator of the duration of the seasons. For example, if the thickness of an annual band, as measured between lamina #1 and the overlying lamina #2, is 46 μm, the monthly growth rate is 3.8 μm. If then the distance between lamina #1 and lamina #1a (subannual status) is 12 μm, this can be taken as representing 3.2 months of growth. Each luminescent laminae is produced by hydrological "events" flushing organic material from the soil zone to the percolation zone. We therefore suggest that the main laminae or luminescent band is deposited in spring/early summer in relation to snowmelt (May-June), while the less intense, subannual laminae result from heavy autumn rainstorms.

Stable isotopes:

Figure 3 shows the Hendy tests made at horizons A, B and C, 23.0, 86.0 and 116.5 mm above sample base respectively. The internal variation for each horizon is less than 0.3 ‰ for $\delta^{18}O_c$ and 0.2 ‰ for $\delta^{13}C_c$. The variation is considered to be insignificant and as no evident correlation is found between $\delta^{18}O_c$ and $\delta^{13}C_c$ the sample is considered to be deposited in isotopic (quasi-) equilibrium with its parent dripwater.

As the L-03 stalagmite ceased to grow hundreds of years ago, comparisons cannot be made between the stable isotope data and instrumental temperature records. A negative relationship between temperature and $\delta^{18}O_c$ is therefore assumed based on previous findings (e.g. LAURITZEN & LUNDBERG, 1999b), i.e. a decrease in the cave temperature is accompanied by enrichment in the $\delta^{18}O_c$ signal. The oxygen and carbon isotope measurements (Figure 4) are plotted on a calendar year timescale derived from the TIMS dates in Table 1, and on the interpreted annual bands between the upper TIMS date and the stalagmite surface. The temporal resolution is 10 to 14 yrs per measurement except between the upper TIMS date and the top surface were the resolution is 30 yr per measurement.

Conclusions

The L-03 stalagmite is shown to display annual luminescent banding. The variation in annual band thickness is believed to be related to climate through the biological activity in the soil zone. Further work on annual and sub-annual banding may improve our understanding of seasonal processes in the soil zone and how they affect the chemistry of the dripwater.

Moreover, a positive correlation is evident from the large scale trends of annual band thickness data, the stable oxygen isotopes, and to a lesser degree, the stable carbon isotopes. This relationship is expected to enhance the knowledge on all three proxies.

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