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MORPHOLOGIC AND DIMENSIONAL LINKAGE BETWEEN RECENTLY DEPOSITED SPELEOTHEMS AND DRIP WATER FROM BROWNS FOLLY MINE, WILTSHIRE, ENGLAND

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Dimensional measurements of juvenile speleothems from Browns Folly Mine, Wiltshire, SW England, indicate that rapid drips preferentially deposit calcite on the stalagmite rather than the stalactite. The ratio of stalagmite volume to stalactite volume, termed a speleothem volume ratio (SVR), increases with increasing drip rate. Rapid drip rates result in a reduced period of CO_2 degassing on the ceiling, and consequently less calcite deposition and smaller stalactites. However, extremely low drip rates appear to have an insufficient flux of HCO_3^- and Ca^{2+} to deposit significant amounts of calcite on the roof of the cave. The drip rate most conducive to stalactite deposition is 0.02 mL/min. A positive feedback mechanism resulting in a preferential increase in calcite deposition on the stalactite through time is hypothesized to exist. The relationship between stalagmite basal diameter and drip rate is very significant (r^2 = 0.44, p = 6.31 x 10^{-14}, n = 99). It may, therefore, be possible to reconstruct paleo-drip rates and subsequently infer paleoclimate.

The internal structure of stalagmites has been scrutinized intensely over the past few decades because of the potential paleoclimatic records contained within (Allison 1926; Gascoyne *et al.* 1981; Genty & Quinif 1996; McDermott *et al.* 1999; Railsback *et al.* 1994). However, understanding the external morphology may assist in the elucidation of the processes responsible for speleothem development and consequently aid in the establishment of linkages between climate and speleothem climate proxies. Few recent studies have focused on the morphology of speleothems.

Allison (1923) attempted to classify stalagmites into 32 different types according to drip rate, air circulation, solute concentration, temperature, and relative humidity. Allison (1923) postulated that drip rates that allow the drop of water to equilibrate with the cave atmosphere on the ceiling of a cave would preclude stalagmite formation. Franke (1965) attempted to classify different stalagmites according to temporal changes in the drip rate. Franke also recognized that changes in a speleothem's morphology could reflect climatic change. Curl (1972, 1973) formulated mathematical relationships predicting the minimum diameter of stalagmites and stalactites. Gams (1981) recognized that progressive increase in size of a stalactite would result in a corresponding decrease in stalagmite size due to the increased surface area on the stalactite from which degassing could occur. Dreybrodt (1996) used a computer program to model stalagmite growth and morphology.

With the exceptions of Allison, Franke, Gams, Curl, and Dreybrodt, previous researchers have considered stalactites and stalagmites separately and have largely ignored the external morphologies of speleothems. This study attempts to view stalactites and stalagmites as an integrated system where changes in stalactite morphology directly affect the formation of the stalagmite. Because the dimensions of the stalagmite are dependant on the drip rate and chemistry of the water feeding it, the size and nature of the stalactite might affect the morphology of the associated stalagmite. The principal objective of this study is to establish relationships between the dimensions of recently deposited speleothems with the characteristics of the precipitating water.

LOCATION

This study was conducted at Browns Folly Mine, Bathford, Wiltshire, in southwestern England (Fig. 1). Browns Folly Mine was opened in 1836 for extraction of building stone. The mine was worked until 1886, when all of its entrances were closed. Mining in nearby mines ceased in 1904, and vegetation re-established itself at that time. For the last 94 years, the secondary woodland that developed was left undisturbed as part of a local nature reserve. The entrances to Browns Folly Mine remained closed until cavers re-opened them in the 1970s, ensuring that speleothems inside the mine developed without human interference for a long period during their growth (Baker *et al.* 1998).

The mine is located at the crest of Bathford Hill at ~150 m msl. The mine was excavated at a uniform depth below the surface (5-15 m), increasing the likelihood that all drip water is meteoric percolation water rather than water derived from fracture flow within the aquifer. Precipitation is almost evenly distributed throughout the year, although increased evapotranspiration during the summer results in reduced water infiltration and lower drip rates (Baker *et al.* 1999). The surface above the mine is covered by a thin brown rendzina soil (Genty *et al.* 2001).

The sampling site is a series of rooms located ~300 m from the nearest entrance (Fig. 2). The area is replete with thousands

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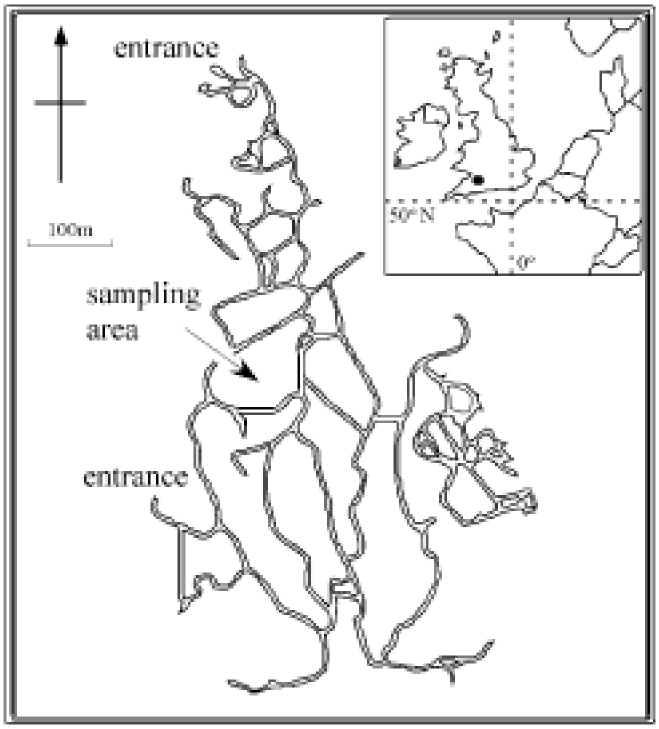

Figure 1. Location and map of Browns Folly Mine in southwestern Great Britain (51°23' N, 2°22' E; Baker & Genty 1999). Only major passages are represented on this map. Several rooms exist adjacent to these major passages that are not shown on the map. The study area is in one of these rooms.

of actively growing stalactites and stalagmites (Fig. 3). The air temperature at the sampling site has been recorded as 10.0 ± 0.4°C with no seasonal variability, and the humidity close to 100%. P_{CO2} within the mine has been measured in the range of 0.0035-0.0040 atm, with no significant seasonal variations (Baker *et al.* 1998).

The host bedrock is the Bath Oolite limestone, a subdivision of the Jurassic Great Oolite Series. It is an oolitic grainstone composed predominantly of calcite with much primary porosity and localized well-developed secondary porosity. Miners referred to the stone as “freestone” because of its lack of fossils and flaws, and because it can be cut freely in any direction without fear of splitting in an undesired fashion (Price 1984).

Browns Folly Mine was chosen for this study for three reasons: 1) The speleothems within the mine have formed within the last 152 years. This removes many of the problems inherent in speleothem studies, such as the possibility of significant climate change; 2) The history of the surface vegetation is known. The ages of the speleothems are not certain, but because vegetation re-established itself in 1904, vegetation has probably been constant for most of their development; 3) The sheer abundance of juvenile speleothems increases the likelihood of obtaining a wide array of drip rates and water chemistries.

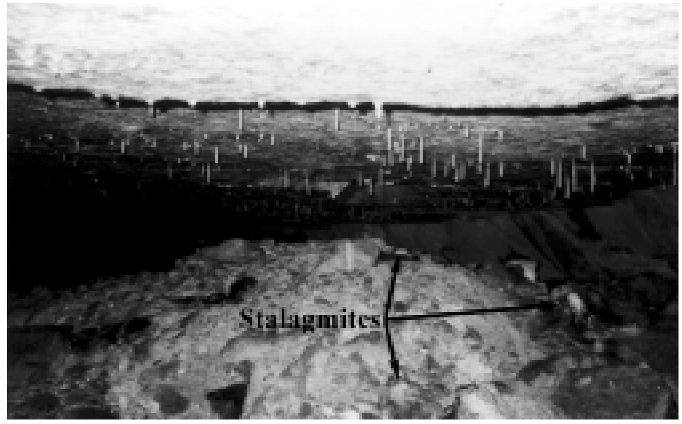

Figure 2. Photograph of stalagmites growing on clasts left in the mine when mining ceased. Stalactites are extremely abundant and are randomly distributed on the ceiling. No preferential development of stalactites along joints was noted.

METHODOLOGY

SPELEOTHEM DIMENSIONS

Speleothem dimensions were measured using a caliper. The diameters were measured at the base (the point of attachment of the speleothem to the roof or floor), at the place where the most conspicuous width change took place, and near the tip of the speleothem. The height of each speleothem was also measured with a caliper. Stalactites showing evidence of breakage were noted as such. A very fragile, translucent framework of calcite with euhedral crystal terminations was assumed to represent undisturbed stalactites, while an unusually thick layer of calcite with no crystal terminations suggested that the stalactite had been broken at some point in time. A few small curtains were present, and because they had roughly boxlike shapes, the length, width, and height were measured. Any other slightly anomalous formations were noted and appropriate measurements were taken. The vast majority of stalactites were soda straws (Fig. 3a), and most of the stalagmites had well-developed cylindrical shapes (Fig. 3b).

The volume of calcite contained within the stalagmites and stalactites was calculated using equation 1, derived from the volume formula for a truncated cone. This equation was determined to best quantify the volume of a speleothem using a reasonable number of measurements.

$$\begin{aligned} \textit{volume} = \; & 1/3\,\pi\,(h_1)(R^2_{base} + R_1^2 + R_{base}R_1) \\ & + 1/3\,\pi\,(h_2 - h_1)(R_1^2 + R_2^2 + R_1R_2) \\ & + (1/3\,\pi\,(h_{total} - h_2)R_2^2) \end{aligned} \qquad (1)$$

Where: h_1 = *height from base to first radius measurement (mm)*

h_2 = *height from base to second radius measurement (mm)*

R_{base} = *radius at the base of speleothem (mm)*

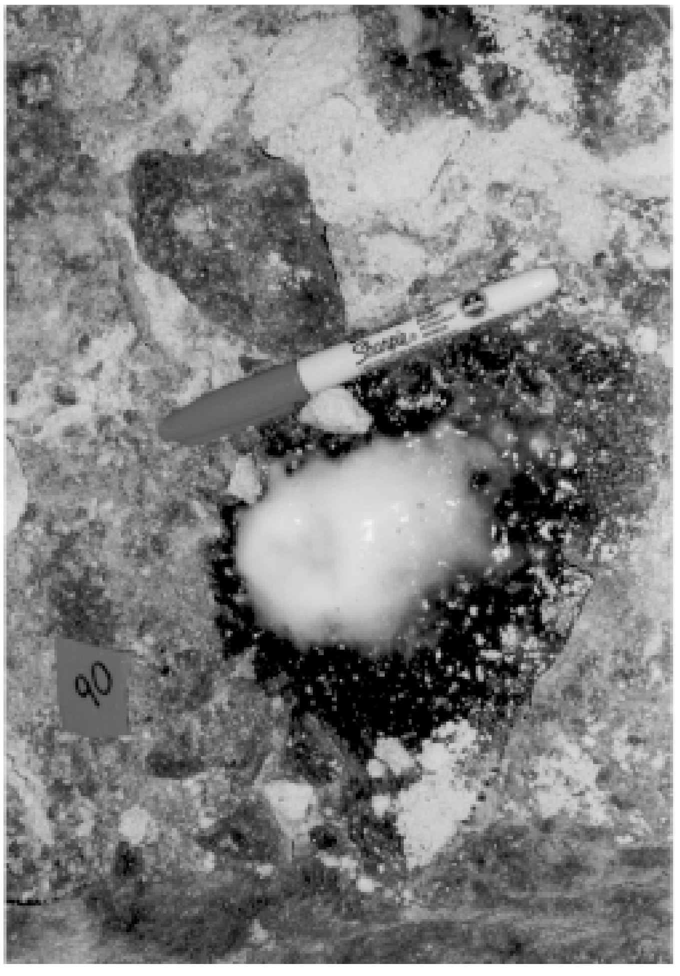

Figure 3a (left). View looking down on a typical stalagmite in Browns Folly Mine.
Figure 3b (right). Photograph of typical stalactites found within the mine. Very thin, crystalline calcite at the tips of soda straws indicated that the stalactite had not been broken. A small ribbon stalactite can be seen on the bottom right of the picture.

R_1 = first radius measurement, at height h_1 (mm)
R_2 = second radius measurement, at height h_2 (mm)

Most of the stalactites are soda-straws and have the characteristic hollow central cavity. The approximate volume of this void has been subtracted from the volume derived using equation 4.1 to arrive at the actual volume of carbonate deposited. The central canal is assumed to be a cylinder with a diameter of 3.0 mm extending the length of the stalactite. The mean value for stalactite volume after the correction for the central canal was 91% of the mean value for the uncorrected data set.

DRIP WATER COLLECTION

Drip water samples were collected from Browns Folly Mine June 25-30, 1998, using a collection device constructed of a small polyethylene funnel inserted through a slit in the base of a waxed paper drinking cup. The cup acted as a support and brace for the funnel. A clear plastic bowl (15 cm diameter, 5 cm height) was used as a stand in order to provide a horizontal surface on which a 10 dram (36.9 mL) glass collection vial could be placed. The waxed cup was placed over the plastic stand and the collection vial, with the bottom of the funnel suspended over the collection vial. The device was placed directly underneath the stalactite, usually directly over the stalagmite. Occasionally the stalagmite was in a precarious position, so a pile of rocks was used to support the device. The stalactite was observed until a drop of water formed on the tip, and then the drop was followed through the air into the collection device to ensure the device was in fact directly underneath the correct stalactite. Upon verification of the functionality of the device, the time of placement was recorded in a logbook.

The device was left undisturbed for several hours. The time of collection and the height of water in the vial were noted. In several instances, the collection device was left too long, resulting in the vial overflowing. In these cases, the actual time between consecutive drips was counted using a stopwatch. Times between drips were also obtained for speleothem pairs, defined as a stalactite and its corresponding stalagmite, whose

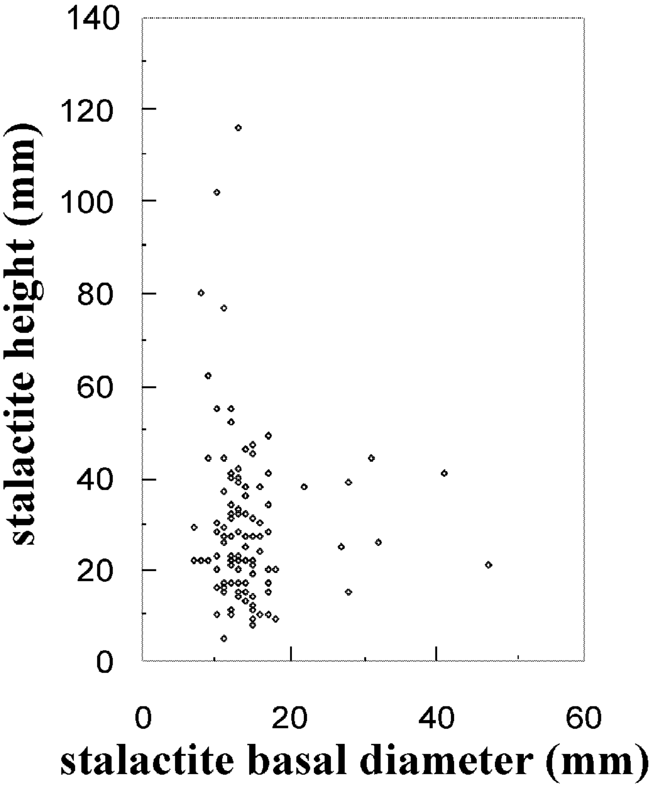

Figure 4a. Stalactite height plotted against stalactite basal diameter. Stalactites apparently can either be wide or tall, but not both simultaneously.

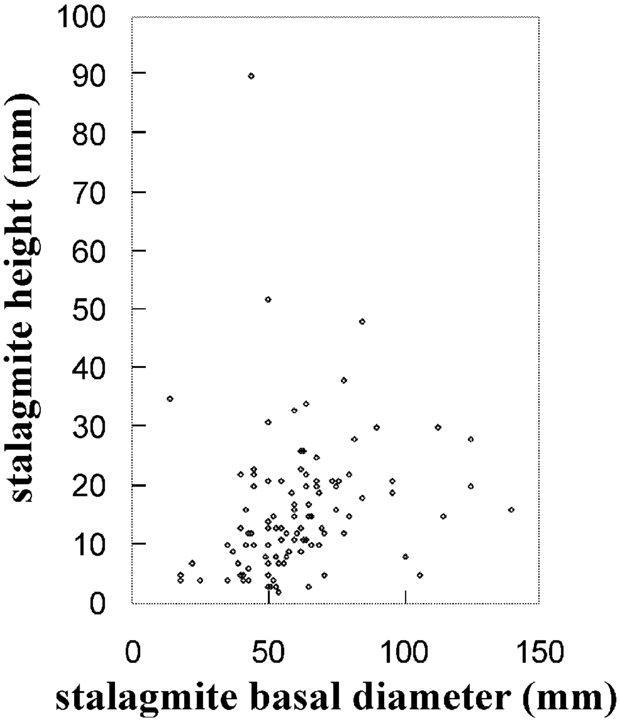

Figure 4b. Stalagmite height plotted against stalagmite basal diameter. No clear trend is evident.

collection vials had not overflowed, thus allowing the volume per drip to be calculated. From the volume per drip, determined to be a constant 0.0749 mL/drop (n = 18, S.D.=7.04 x 10^{-5}), the drip rate in mL/min was calculated for the overflow vials.

For the vials that did not overflow, the volume of the water collected was determined using the volume formula for a cylinder, volume = radius^2 x height x π. The radius was the radius of the collection vials, a constant 12 mm, and the height was the height of the collected water within the vial.

This volume was then divided by the appropriate time to determine the drip rate. Drip rates are expressed in milliliters/minute instead of the commonly used drips/minute in order to report more clearly the volume of water that actually reaches the speleothems.

Total hardness, pH, and alkalinity were measured after the collection of the sample vials using Aquachek test paper having the following ranges: total hardness 0-425 ppm, pH 6.4-8.8, total alkalinity 0-240 ppm. The test strips precluded obtaining very precise measurements, resulting in a large number of identical values. However, the accuracy may have benefited from the test strips because the measurements were obtained *in situ*.

The water samples were treated with hydrochloric acid and then analysed for cations using a Thermo Jarrell-Ash 965 Atomcorp ICP spectrophotometer at the University of Georgia. All water chemistries were extremely constant throughout the suite of waters sampled, and no meaningful relationships were drawn between water chemistry and any other parameters. Thus, the water chemistry will not be discussed in detail in this paper (tabulated as an internet archive on the JCKS website: http:www.caves.org/pub/journal/volume63).

RESULTS

SPELEOTHEM DIMENSIONS

Stalactites in Browns Folly Mine have a mean basal diameter, defined as the diameter of the stalactite at the attachment point to the ceiling, of 14.31 mm (S.D. = 5.943) and a mean height of 28.1 mm (S.D. = 18.561) (Fig. 4a). Stalagmites have a larger mean basal diameter of 60.170 mm (S.D. = 22.056), and are shorter (mean height = 15.641 mm, S.D.=11.987) (Fig. 4b). The stalagmites have highly variable basal diameters, while the stalactites have relatively constant diameters. The diameter of the stalactites tips is extremely uniform, with a mean of 5.491 mm and a standard deviation of 0.791 mm.

DRIP RATES

Drip samples were obtained during a precipitation event three days in duration during an otherwise dry summer. The average drip rate for actively dripping speleothems was 0.768 mL/min (S.D.=5.33), and is highly skewed to the right. The maximum drip rate recorded was 54.29 mL/min. There were five speleothem pairs that were dry during the sampling period.

The average volume of a drop of water was obtained by using the following formula:

$$volume = R \times T/60 \quad (2)$$

Where: R = drip rate calculated from collected water in vial (mL/min)
T = time between consecutive drips (sec/drop)

The average drop of water had a volume of 0.0749 mL (n = 18, S.D.=7.04 x 10^{-5}), not including two values of 0.1393 mL and 0.0987 mL that were clear outliers in the data set. The precision of this average is remarkable, and serves as a good quality control for the collection of drip water. The only variable in the preceding equation that could have any significant error associated with it is the R term, derived from the amount of drip water captured by the collection device. If significant amounts of drip water had missed the collection funnel or splashed out, the numbers obtained for the volume of a drop of water would be too low. The extremely low standard deviation is an indication that essentially no drip water was lost during collection.

Calcite Saturation Indices

Saturation indices for calcite for the drip water were calculated using the field alkalinities and the Ca^{2+} concentrations. The mean saturation index for calcite for the sampled drip waters was 0.7 ± .5 with a standard deviation of 1.0, where equilibrium for calcite is at a saturation index of 0.0. The highest saturation index was 1.8, and the lowest was –0.9. Water that was supersaturated with respect to calcite composed 64 of the 96 samples. The mean Ca^{2+} concentrations of all the drips sampled was 1.28 mmol/L (n = 93, C.V. = 21.7%), which is 40% lower than the mean Ca^{2+} concentrations obtained for seventeen drips in the mine by Baker *et al.* (1998) of 2.20 mmol/L and a C.V. of 15%. This may be due to the greater number of samples and the wider range of drip types observed in this study.

Relationships within the data

Dimensional Relationships

Empirical observations within Browns Folly Mine suggest that the most rapid drip rates produce the largest speleothems. Drip rate appears to exert considerable control on stalagmite volume. The p-value for a regression line through the log-transformed data (Fig. 5) indicates that the relationship between stalagmite volume and drip rate is significant (r^2 = 0.304, n = 105, p = 1.09 x 10^{-9}). Stalagmite volume (τ) is therefore approximated with:

$$\tau = 10^{(0.503(\log R) + 5.116)} \quad (3)$$

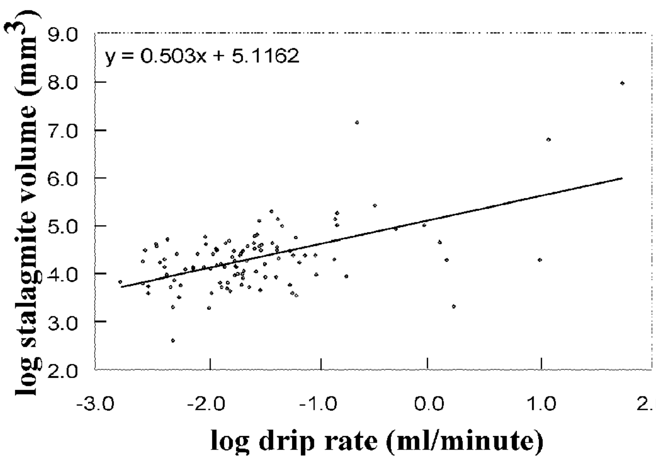

Figure 5. Log stalagmite volume versus log drip rate (r^2 = 0.30, p = 1.09 x 10^{-9}, n = 105).

where: R = drip rate in mL/minute

During the first day of sampling, some large flowstone deposits were observed underneath dry stalactites. During the precipitation event that began on the second day, these large stalagmites were no longer dry but were being fed by rapidly dripping water. Sites that exhibited this sort of flashy discharge were avoided in the drip sampling in order to minimize uncertainty due to temporal variations in drip rates.

Stalagmites formed under lower drip rates, less than ~0.1 mL/min, tended to be elongated cylinders. Conversely, the five stalagmites formed by the most rapidly dripping water (>1 mL/min) were broad and flat, the largest being over a meter wide. Stalagmite basal diameter (w) does increase with increasing drip rate (Fig. 6) according to equation 4 (r^2 = 0.44, p = 6.31 x 10^{-14}, n = 99):

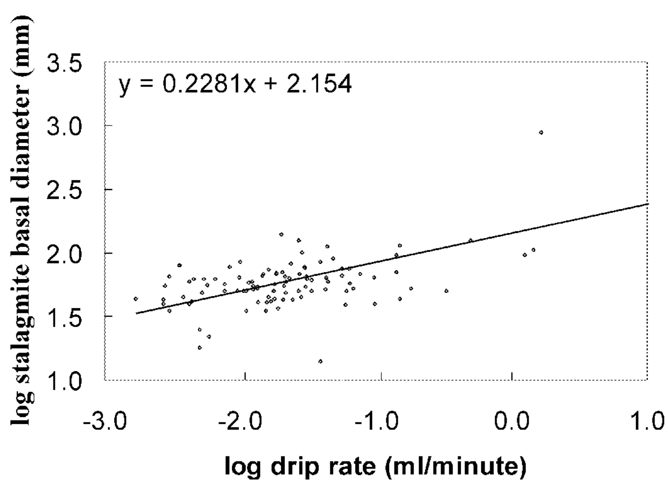

Figure 6. Log stalagmite width versus log drip rate (r^2 = 0.44, p = 6.31 x 10^{-14}, n = 99). Stalagmites with problematic dimensions are not included in this chart.

$$w = 10^{(19.3(\log R) + 67.5)} \quad (4)$$

The stalagmite basal diameter indicates the lateral extent drip water flows along the floor of the mine before completely equilibrating with CO_2 in the mine air. The more rapid the drip rate, the more rapidly the water flows from the center and onto the flanks of the stalagmite, resulting in a wider stalagmite. The drip water will degas completely on the stalagmite, depositing carbonate until the water is no longer saturated with respect to calcite. Therefore, the volume of a stalagmite is predominantly dependent on the amount of Ca^{2+} and HCO_3^- transported to it through time. If drip water chemistry remains constant, a larger volume stalagmite is clearly the result of more rapid drip rates. In some situations the drip may be sufficiently rapid to cause the resultant speleothem to deviate from the classic stalagmite morphology and become a flowstone. The large flowstones observed underneath dry drips are likely to have extremely rapid, ephemeral discharges during precipitation events.

Derivation of paleo-drip rates for ancient stalagmites may be possible utilizing equation 4. Drip rates are often correlative with net amounts of meteoric precipitation or infiltration (Baker *et al.* 1997; Genty & Deflandre 1998; Sanz & Lopez 2000), therefore equation 4 may also have applications for paleoclimatic reconstruction.

The distribution of calcite in stalactites is apparently more complex than in stalagmites (Fig. 4 a,b). An incipient soda straw develops by the degassing of CO_2 from the periphery of a drop of water. Upon reaching a critical mass determined by gravity, fluid density, surface tension, and drop volume (Curl 1972), the drop falls, breaking the thin veneer of calcite at its lowermost point (Allison 1922). The same sequence is repeated with successive drips, until a soda straw stalactite is formed. Blockages of the central canal diffuse water radially along crystal boundaries and subsequently result in lateral growth. Figure 4a demonstrates that stalactites are either long or wide, suggesting that insufficient calcite deposition has occurred to produce a stalactite that is both. Either vertical stalactite growth continues unimpeded, or a blockage of the central canal preferentially encourages lateral over vertical growth.

Previous research (Baker *et al.* 1999; Genty *et al.* 2001) has demonstrated that the drips within Browns Folly Mine vary seasonally depending on water availability, and different drips have different response times to rainfall events. Good statistical correlations exist between speleothem morphology and drip rate despite using drip rates measured only once, in June. This may be because many of the drips sampled had a low coefficient of variation during the course of the year. Some that responded rapidly to a rainfall event were sampled during the period of rapid flow, when most calcite deposition would take place, explaining the correlation with morphology. More drip rate measurements, particularly in the winter, would be very useful and may raise the r^2 values.

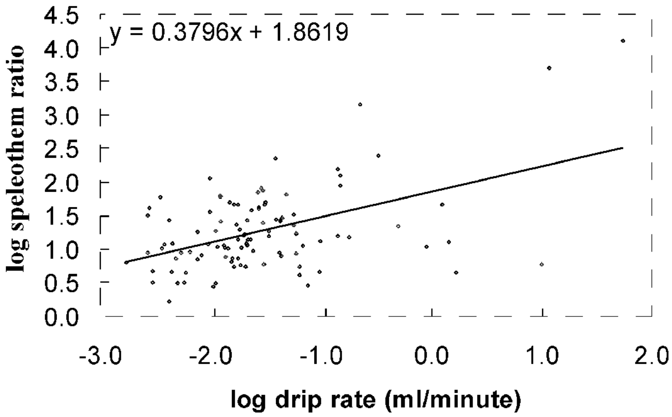

Figure 7. Log speleothem ratio versus log drip rate (r^2 = 0.237, p = 1.85 x 10^{-7}, n = 103). If either the stalagmite or the stalactite was not present in a speleothem pair, that "pair" is not included in the chart. Speleothems with drip rates of 0.00 ml/minute are not included in this chart.

SPELEOTHEM VOLUME RATIOS

The ratio of stalagmite volume to stalactite volume, henceforth known as the speleothem volume ratio (SVR), quantifies the spatial distribution of precipitated carbonate in a speleothem pair. The speleothem volume ratio increases with increasing drip rate ($r^2 = 0.237$, $p = 1.85 \times 10^{-7}$, $n = 103$) (Fig. 7), suggesting that a reduction in the amount of time water spends on the stalactite increases the amount of carbonate deposited on the stalagmite. Carbonate deposition on the stalactite removes Ca^{+2} and CO_3^{-2} from the drip water, reducing the amount of raw materials that will reach the stalagmite, consequently producing a smaller stalagmite. As drip rates increase, the amounts of raw materials that can be potentially deposited on the stalagmite also increase, creating a larger stalagmite.

The average measured stalagmite in the mine was 214 times larger than the average measured stalactite. It has been proposed that the rate of stalactite growth increases throughout their development (Gams 1981), while stalagmite growth rates must necessarily decrease. Increased stalactite volume increases the period of drip degassing on the stalactite resulting in more calcite deposition. This is essentially a positive feedback mechanism that culminates in large stalactites whose drips are already equilibrated with respect to calcite when they reach the stalagmite, precluding any further stalagmite growth. Support for this hypothesis would be provided if measured SVRs of ancient speleothems in caves are less than 214. If this hypothesis is correct, paleoclimatic interpretations based on stalagmite stable isotopes, trace elements, or layer thicknesses must be corrected for the gradual, systematic decrease in calcite deposition on the stalagmite.

STALACTITE MORPHOLOGY

The vast majority of the stalactites in the mine are of the soda-straw variety; therefore, the only dimension that differs

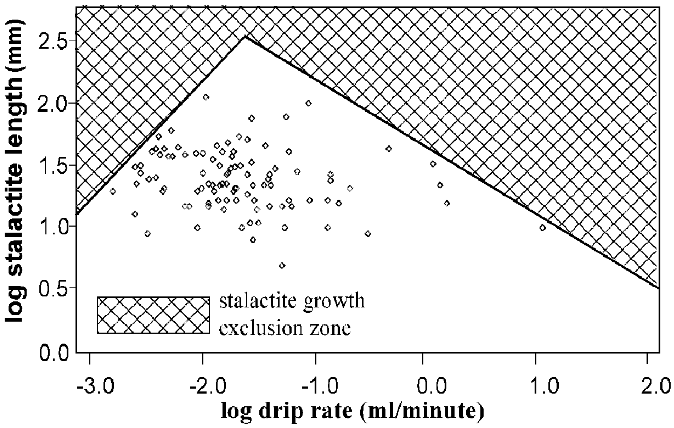

Figure 8. Stalactite length plotted against drip rate. The stippled area is a stalactite growth exclusion zone, which represents stalactite lengths that are impossible given the drip rates, water chemistries, and age of the stalactites. Extremely high drip rates do not seem to favor the formation of long stalactites. A longer period of degassing on the roof of the mine is believed to be responsible for the increase in stalactite length with decrease in drip rate. Drip rates that are too low, however, do not transport enough carbonate and Ca^{2+} to the roof to favor the deposition of long stalactites.

greatly from one stalactite to another is the height. When height is plotted against drip rate, a weakly significant (p-value = 0.03987) inverse relationship is evident (Fig. 8). The data as a whole indicate a decrease in stalactite height with increasing drip rate.

Limits as to how long a stalactite can form at certain drip rates appear to exist (Fig. 8). Low drip rates produce a short stalactite because, although most of the degassing occurs on the stalactite, not enough carbonate has been transported to the stalactite during the course of its existence to create a long stalactite. As drip rate increases, the amount of Ca^{2+} and dissolved CO_2 transported to the stalactite increases, creating a longer stalactite. However, eventually a drip rate is reached that moves water away from the stalactite prior to significant degassing of CO_2, reducing the amount of carbonate precipitated on the stalactite. The drip rate that seems to most favor the longest stalactites is ~0.02 mL/minute.

Stalactites measured in Browns Folly Mine have an average diameter of 5.49 mm (S.D. = 0.79 mm) at their tip, a number wholly consistent with the theory that the smallest possible diameter of calcite soda-straw stalactites on earth is 5.1 mm (Curl 1972). The smallest consistently measured diameter of a soda-straw was 5.0 ± 0.5 mm across the tip. Soda-straw stalactites with this tip diameter comprise a majority of the specimens sampled (66%). Only one soda-straw measuring less than 5.0 mm was found, and it measures 4.0 mm across the tip. The reasons for this anomaly are unknown; no egregious differences between this stalactite and others were noted.

CONCLUSIONS

Evidence obtained from Browns Folly Mine suggests that degassing of CO_2 and subsequent deposition of $CaCO_3$ on a stalactite reduce a spelean drip water's ability to further deposit calcium carbonate on the stalagmite. Slower drip rates increase the amount of time that a drop spends on a stalactite, resulting in increased stalactite sizes and decreased stalagmite sizes.

Speleothem volume ratios, defined as the ratio of stalagmite volume to stalactite volume, increase in value with increasing drip rates, supporting the hypothesis that slow drip rates favor deposition of available $CaCO_3$ on the stalactite. The existence of a positive feedback mechanism resulting in increased stalactite growth rates and decreased stalagmite growth rates through time is hypothesized. Therefore, speleothem volume ratios in ancient caves should be lower than those of younger speleothems, though an exhaustive study is clearly necessary. Paleo-drip rate estimates based on speleothem volume ratios of ancient speleothems in natural caves may have applications in paleoclimatological studies.

Stalactite height is at its greatest at drip rates of ~0.02 mL/minute, suggesting this drip rate is sufficiently rapid to transport raw materials to the growing lattice, and is sufficiently slow to allow for enough degassing of CO_2 to deposit calcite. A stalactite growth exclusion zone demarcating the limits for stalactite heights is a result of drip rate, drip chemistry, and the maximum possible age of the stalactites.

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REFERENCES

Allison, V.C., 1923, The growth of stalagmites and stalactites: Journal of Geology, v. 31, p. 106-125.

Allison, V.C., 1926, The antiquity of the deposit in Jacob's Cavern: American Museum of Natural History, Anthropological Papers, v. 19, p. 204-225.

Baker, A., Barnes, W.L. & Smart, P.L., 1997, Variations in the discharge and organic matter content of stalagmite drip waters in Lower Cave, Bristol: Hydrological Processes, v. 11, p. 1541-1555.

Baker, A., Genty, D., Dreybrodt, W., Grapes, J., & Mockler, N.J., 1998, Testing theoretically predicted stalagmite growth rates with Recent annually laminated samples: Implications for past stalagmite deposition: Geochimica et Cosmochimica Acta, v. 62, p. 393-404.

Baker, A., Mockler, N.J., & Barnes, W.L., 1999, Fluorescence intensity of speleothem forming groundwaters: Implications for palaeoclimate reconstruction: Water Resources Research, v. 35, p. 407-413.

Baker, A. & Genty, D., 1999, Fluorescence wavelength and intensity variations of cave waters: Journal of Hydrology, v. 217, p. 19-34.

Curl, R.L., 1972, Minimum diameter stalactites: Bulletin of the National Speleological Society, v. 34, p. 129-136.

Curl, R.L., 1973, Minimum diameter stalagmites: Bulletin of the National Speleological Society, v. 35, p. 1-9.

Dreybrodt, W., 1996, Chemical kinetics, speleothem growth, and climate, *in* Lauritzen, S-E (ed.) Climate change: The karst record: Karst Waters Institute Special Publication #2.

Franke, H.W., 1965, The theory behind stalagmite shapes: Studies in Speleology, v. 1, p. 89-95.

Gams, I., 1981, Contributions to morphometrics of stalagmites: Proceedings of the International Congress of Speleology, v. 8, p. 276-278.

Gascoyne, M., Ford, D.C., & Schwarz, H.P., 1981, Late Pleistocene chronology and paleoclimate of Vancouver Island determined from cave deposits: Canadian Journal of Earth Science, v. 18, p. 1643-1652.

Genty, D., Baker, A., & Vokal, B., 2001, Intra- and inter-annual growth rate of modern stalagmites: Chemical Geology, v. 176, p. 191-212.

Genty, D.D. & Deflandre, G., 1998, Drip flow variations under a stalactite of the Pere Noel cave (Belgium): Evidence of seasonal variations and air pressure constraints: Journal of Hydrology, v. 211, p. 208-232.

Genty, D. & Quinif, Y., 1996, Annually laminated sequences in the internal structure of some Belgian speleothems: Journal of Sedimentary Research, v. 66, p. 275-288.

McDermott, F., Frisia, S., Huang, Y., Longinelli, A., Spiro, B., Heaton, T.H.E., Hawksworth, C.J., Borsato, A., Keppens, E., Fairchild, I.J., van der Borg, K., Verheyden, S., & Selmo, E., 1999, Holocene climate variability in Europe: Evidence from δ-18O, textural and extension-rate variations in three speleothems: Quaternary Science Reviews, v. 18, p. 1021-1038.

Price, E., 1984, The Bath Freestone Workings: Bath, U.K., The Resurgence Press.

Railsback, L.B., Brook G.A., Chen, J., Kalin, R., & Fleisher, C., 1994, Environmental controls on the petrology of a late Holocene speleothem from Botswana with annual layers of aragonite and calcite: Journal of Sedimentary Research, v. A64, p. 147-155.

Sanz, E. & Lopez, J.J., 2000, Infiltration measured by the drip of stalactites: Ground Water, v. 38, no. 2, p. 247-253.