LECTURE

Caves: dark dank holes in the ground, or geological treasure troves?

Summary of the lecture given to the Society on Saturday 14th January 2006 by Dr Andy Farrant of the British Geological Survey.

Mention caves, and most people think of dark, wet holes in the ground, or maybe a show cave. But caves are more than that; they have benefits for geoscientists.

Not only do caves enable the geologist to see the rocks from the inside and provide first hand knowledge of underground drainage patterns, but they are also superb repositories of geological information. Unlike surface exposures, caves are protected environments. They are less susceptible to erosion, weathering and bioturbation than surface environments. Over time, underground streams cut new routes at lower levels, leaving former conduits high and dry. Old stream routes are preserved as relict passages, unlike rivers which erode their former flow stages. The morphology of these relict passages contains clues to their function.

Flow direction within the relict passages can be determined by sediment ripples and cross bedding and by scallops on the passage walls. Scallops are shallow, asymmetric, dissolutional, scoop-shaped hollows that are etched into the bedrock with their steeper sides facing downstream. Their size is inversely proportional to flow velocity, and an empirical equation can be used to determine flow velocity, and hence discharge, if the passage cross section is known.

In addition, former base-levels can be identified from passage morphology. Vadose passages, formed above the water-table, are easily distinguished from sub-water-table phreatic passages. A vadose passage is often canyon-shaped, with small irregular scallops indicative of rapid flow, whereas phreatic passages have an elliptical or circular, smooth, sculpted morphology, generally with large rounded scallops. Former water-table elevations can be constrained by noting where a vadose passages changes into a phreatic passage. In addition, the water-table is often marked by concordant loop crests in an undulating phreatic passage, notably where a phreatic cave cuts across dipping strata. Relict passages can thus be used to build up a picture of how a cave system evolved over time, which can then be related to changes in surface environments or base-level changes.

Dating techniques

Cave deposits, both sediments and speleothems, can be dated using a variety of techniques, the most common of which is dating of speleothem calcite using uranium series disequilibria. This uses the radioactive decay of uranium (notably ^{234}U) into thorium (^{230}Th). Uranium is soluble in water, whereas thorium is not. Thus when stalagmites form from water percolating through the rock, the drip-water contains uranium, but no thorium. Once the stalagmite has formed, the uranium isotope ^{234}U gradually decays into the thorium isotope ^{230}Th, at a known and constant rate. As time passes, the amount of thorium in the stalagmite therefore increases. By measuring the ratio of ^{234}U and ^{230}Th, using a mass spectrometer, the age of the stalagmite can be calculated. This method works for stalagmites up to about 500,000 years old. In stalagmites older than this, thorium also begins to decay and tends towards secular equilibrium, and the U/Th ratio becomes unreliable.

An alternative method of determining the relative age of a cave is palaeomagnetic dating. This technique utilises known changes in the Earth's magnetic field. Through time, the Earth's magnetic north pole has 'wandered' around by several degrees, periodically 'flipping' from north to south and back again. These fluctuations in the magnetic field have been independently dated using other methods. The last time the magnetic pole reversed was 780,000 years ago, and before that, approximately 910,000 years ago. These changes in the Earth's magnetic field may be recorded in cave sediments. Clay particles deposited in still water preferentially align themselves to the prevailing magnetic field at the time of deposition. So by taking carefully oriented cores of fine-grained, clay-rich sediment, it is possible with a magnetometer to determine the direction (and polarity) of the magnetic pole when the sediment was deposited. The most recent sediments are aligned towards the current North Pole. However, older sediments preserved in high-level, abandoned caves may preserve evidence of former pole positions. By taking a suite of 'fossil' sediment samples at progressively higher elevations, it may be possible to work back through time to when the sediments were deposited during the last period of reversed polarity. Various cave systems, including Masson Cave, at Matlock, have been dated in this way.

Folded Black Rock Limestone in Swildon's Hole, Mendip.

Uranium-lead dating is a similar technique to U-Th methods and relies on the decay of ^{238}U to ^{206}Pb. However, this dating method is still in its infancy, and the initial state of ^{238}U disequilibrium in Quaternary and Tertiary samples needs to be assessed; also, it can only be used for samples with high U/Pb ratios.

Cosmogenic isotopes have also been used date cave deposits. The ratio of the isotopes of ^{10}Be and ^{26}Al, both produced by cosmic rays, is constant at the Earth's surface. However, below ground, where samples are shielded from cosmic rays, ^{26}Al decays faster than ^{10}Be so their changing ratio can be used to calculate age since burial. This technique has been successfully applied to cave sediments in Mammoth Cave, Kentucky, and elsewhere.

Landscape evolution

Caves are an integral part of the landscape and are affected by changes in the surface environment. Base-level decline, driven by uplift or valley incision, causes changes in cave systems. A period of valley incision, perhaps by glacial erosion, causes a cave system to adjust to the new base-level by developing a new lower level set of passages. Over time, valley incision results in a vertically stacked series of cave passages. Dating of the deposits preserved within these caves can give an estimate of rates of base-level lowering. A series of cave levels in Cheddar Gorge has been dated, and gives a rate of about 20 mm per 1000 years. Similar calculations have been made for cave systems elsewhere in Britain and overseas. The oldest caves in the Peak District pre-date the last magnetic reversal 780,000 years ago.

Palaeoclimate

As well as being tools with which caves can be dated, speleothem deposits (mainly stalagmites) are versatile, datable, proxy palaeoclimate indicators in their own right. A slice though a stalagmite reveals many growth layers, hiatuses and erosional events. Dating these layers, using high-precision U-Th techniques, can constrain when and how fast they grew, and when growth was curtailed. Speleothem growth is controlled by external factors such as rainfall and temperature, and generally only form if the climate is relatively warm and wet. Thus by dating enough stalagmite deposits over a suitable time span, periods of speleothem deposition and non-deposition can be identified and correlated with glacial, interglacial and interstadial cycles, or with periods of aridity. As with tree rings, examining speleothem growth bands (using luminescence techniques combined with dating) has demonstrated that some speleothems contain annual banding. The thickness of these bands can be related to external changes in climate and environment, sunspot cycles and even volcanic eruptions.

Most speleothem deposits form from drip-waters in subaerial caves. However, in many parts of the world, there are submarine caves that are filled with fabulous arrays of speleothems. Excellent examples occur around the Bahamas and in Florida where they are known as Blue Holes, and in the Yucatan peninsula in Mexico where their entrances are the well-known cenotes. These submarine caves often form at the mixing zone between salt and fresh water, and can be very extensive. Speleothems deposits can only form in these caves when sea-level falls during glacial periods that leave the caves high and dry. Sea-level rise at the end of a glacial period drowns any speleothems, and stops their growth. Thus by constraining when these submerged speleothems grew and at what depth, palaeo-sea-level curves can be constructed.

Phreatic tube in Peak Cavern, formed beneath a water-table level with an old contemporary higher floor of Hope Valley

As well as information gained from the presence or absence of speleothem growth, analysis of material contained within speleothems, such as isotopes ($\delta^{13}C$ and $\delta^{18}O$), trace elements, pollen and spores, can also provide clues about the palaeo-environment. Pollen trapped within speleothem calcite can record information about the vegetation history of the cave surroundings at the time of deposition. Analysis of $\delta^{13}C$ in calcite can do the same. Different types of plant use isotopes of carbon in different ways. C4 type plants, mainly warm season grasses adapted to high temperature have higher (less negative) $\delta^{13}C$ than C3 plants, mostly trees and shrubs, and cool season grasses. This differential isotopic uptake in plants affects the amount of $\delta^{13}C$ in the drip-waters feeding the speleothem. Similarly, changes in the $\delta^{18}O$ of rainfall caused by changes in global ice volume are reflected in $\delta^{18}O$ values preserved in speleothem calcite which can be accurately measured and dated.

Ongoing advances in dating techniques and palaeo-evironmental analysis will continue to provide geoscientists new tools with which to study past climates and environments. Caves provide excellent, undisturbed and relatively unstudied field laboratories for a whole host of disciplines across the Earth Sciences. As such, even the darkest, dankest cave may still contain material of interest to the geoscientist.