Karst and caves: an introduction

Karst terrains

Karst is defined as a landscape whose features are dependant on the presence of efficient underground drainage. Except in deserts, this is only completely achieved where there are caves large enough to carry streams and rivers, and cave passages are only formed naturally in soluble rocks where the groundwater can dissolve away the walls of narrow fissures to turn them into large caves. So karst is a feature of soluble rocks, of which limestone is by far the most important (but is not the only one). Named after the Kras of Slovenia, karst terrains are found all over the world, and the Yorkshire Dales have one of the finest.

Limestone dissolves in water in the presence of carbon dioxide, which combines with it to make the soluble calcium bicarbonate. The classic schooldays formula [$CaCO_3 + H_2O + CO_2 = Ca(HCO_3)_2$] simplifies a complex process but clearly demonstrates the key components. Limestone is the calcium carbonate, water is the rainfall, and air provides the carbon dioxide. But CO_2 is only a small part of the normal atmosphere, and the major source of this gas component is soil air that has been enriched in it by the breakdown of dead plant material and oxidation of its carbon. This biogenic carbon dioxide is picked up by rainwater as it percolates through the soil before it reaches the limestone - which it can then dissolve so much more effectively.

Where it seeps down into fractures in the limestone, this aggressive, CO_2-rich soil water progressively develops caves of increasing size, and a karst landscape can develop. Besides the caves, the obvious signs of a karst landscape are bare rock, dolines, dry valleys and perhaps some distinctive hill shapes.

Bare rock characterises karst because total dissolution of the rock leaves no mineral residue that can form a soil. Nearly all soils on karst have been transported in - aeolian silt, fluvial alluvium or glacial till. Bare rock survives little-changed since it was scraped clean by Pleistocene glaciers, notably as limestone pavements and their intervening scars and cliffs.

Dolines are closed depressions formed where water sinks underground; they are the diagnostic karst landform (and may also be known as sinkholes). Each a metre to a kilometre across, dolines can be isolated features, or high densities of them can dominate a karst landscape. Subsidence dolines form within the soil profile where soil has been washed down into an underlying bedrock fissure; there are thousands in the Dales, all locally known as shakeholes. Dolines in

Bare limestone in a karst terrain in southern China.

Subsidence dolines in alluvium, in Guizhou, China.

Pinnacle karst of the Shilin Stone Forest, China.

Doline karst on the Sinkhole Plain, Kentucky, USA.

bedrock range between two types named after their processes of formation; solution dolines are essentially valleys with no outlets except underground whereby the rock has been carried away in solution, while collapse dolines have steep sides left by rock collapse into voids originally created by dissolution.

Dry valleys in karst include some carved by streams before the bedrock had caves large enough to swallow the drainage. Others were formed by meltwater when caves and fissures were blocked by ice in permafrost ground; various periods of such periglacial environment (near to the glaciers but not covered by them) during the Pleistocene, notably in the Peak District, which is therefore a fine example of fluviokarst..

Because limestone dissolution rates relate directly to the amounts of available biogenic carbon dioxide, and these depend almost entirely on the levels of plant activity, karst landforms are significantly influenced by climate. Different types develop in different environments, and this is particularly noticeable on the large scale.

Hot-and-wet forests in the sub-tropics are perfect for limestone dissolution. Karst in this environment develops giant dolines that pit the entire landscape, in what is effectvely the most mature, or extreme, type of karst terran. These eventually coalesce, so that the terrains evolve to those one with only isolated residual hills – including the tall conical hills and rock towers that are so well-known from paintings of China's karst. These do not develop in drier or colder climates.

Almost no rainfall means almost no karst in deserts, except that caves and dolines are commonly left as relics from wetter climates during the Pleistocene. Relict landforms are common in karst, and are often the best evidence of past climates; there are plenty in the Dales that remain from various stages of the Pleistocene.

The third climatic extreme, of cold-and-wet, created glaciokarst in latitudes where Pleistocene climates cooled into the Ice Ages. Scraped clean by ice, and with no suibsequent soil development, limestone pavements, along with dolines and caves, are the karst features that were superimposed on landscapes previously fashioned by glaciers - including those of the Yorkshire Dales.

Karst can develop on rocks other than limestone. Most common is on gypsum, which is readily soluble in water; less common is karst on salt, which is so soluble in water that it can remain at the surface only in desert climates. Both can have many sinkholes and caves. Pseudokarst is formed on very porous basaltic lavas that can also have long caves, though those are formed in the molten state and not by water erosion.

Doline of Xiaozhai Tiankeng, 600m deep, in China.

Dry valley in the Peak District of Derbyshire, UK.

Fenglin tower karst in Guangxi, China.

Limestone pavement in the Yorkshire Dales, UK.

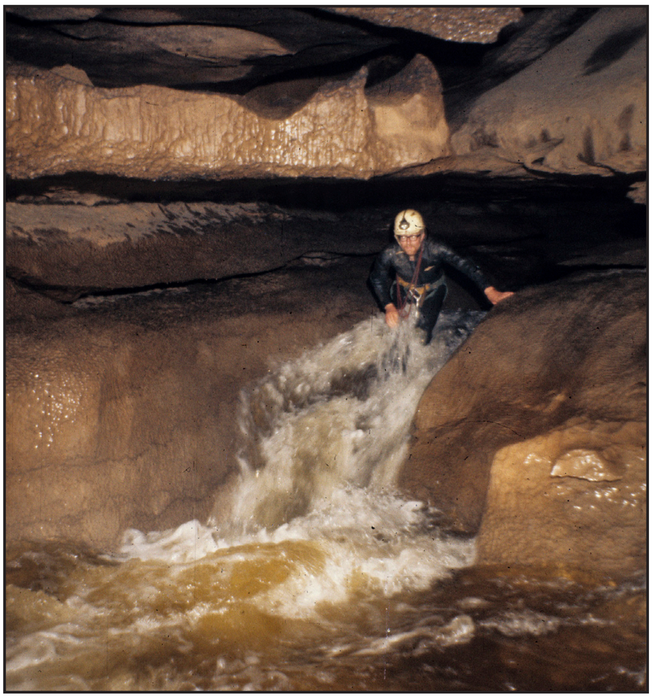
Caves in karst

Caves are an integral part of any karst landscape. Their passages are formed by through-flows of natural drainage. The inflow is either a stream sink, directly into an open cave, or percolation through networks of narrow fissures that only coalesce into a cave passage at depth. The outflow is a resurgence that may be either a freely-draining cave passage or a flooded conduit; this is normally fed by a converging system of caves and fissures; it may be called a rising if it is fed more by percolation water than by sinking streams.

Overall patterns of cave systems are strongly influenced by geological structure. Most passages are initiated along shale beds, on bedding planes, within certain beds, or along joints or faults within the limestone. It may take millions of years to establish an initial drainage route through the network of joints and bedding planes within a limestone mass, but once a through-flow is created, large cave passages can be eroded out of the rock within tens or hundreds of thousands of years. Shapes of the individual cave passages are then largely determined by how they evolved - notably whether they were formed above or below the contemporary water table, and these details are superimposed on the geological controls.

Above the water table, within what is known as the vadose zone, cave passages are free-flowing stream canyons that happen to be underground. In cross section, many are squared canyons with planar roofs along bedding planes or shale beds; others are narrow fissures aligned on vertical or inclined fractures. Long profiles of vadose passages are continually downhill, with meandering canyons between waterfall shafts that are either rounded by spray corrosion or elongated by waterfall retreat; inlets join in a dendritic pattern that may include additions through the roof. Vadose caves may be many kilometres long, and depths are only limited by the vertical range from upland catchment to valley-floor rising. A vadose cave may drain out into a valley, but most continue downstream into flooded phreatic passages.

Below the water table, within what is known as the phreatic zone (or phreas), cave passages are full of water so that dissolution of their walls, floors and roof tends to produce tubular cross sections, either circular or elongated into an ellipse along a joint or bedding. Long profiles of phreatic passages may go up or down, and may be short, flooded down-loops dictated by the geology, or may reach through a long flooded zone in limestone that reaches below their valley-floor resurgence. A phreatic system may be dendritic or braided, or can be a maze, especially if developed on two intersecting systems of joints.



Vadose canyon streamway in the Yorkshire Dales, UK.

Active phreatic tunnel in a Yorkshire Dales cave, UK.

Keyhole passage with old tube and young canyon.

A special type of phreatic cave is that formed by rising waters. These are known as hypogene caves, and their formative waters were commonly rich in sulphuric acid and geothermally warmed. Caves of this type include the complex maze caves in the northern Pennines, and caves with isolated chambers that cannot be related to descending cave streams of the past.

Scattered through many cave system, large chambers are commonly floored by breakdown blocks, where they have been modified by roof collapse. The original formation of these large caverns is often less easy to interpret, but is usually related to rapid erosion by large cave streams in zones of significant geological weakness and commonly where two or more passages join.

Only in the tropical karsts, where development has not been interrupted by glaciations, do caves mature into large sub-horizontal tunnels graded to their resurgences. In higher latitudes, interruptions to erosional maturity are normal. Notable are the rejuvenations caused by successive Pleistocene glacial deepening of valley floors. These commonly instigate drainage of previously flooded tunnels, so that vadose trenches are cut into the floor of phreatic tubes to create the distinctive cave passages with keyhole cross sections.

Calcite is deposited in the caves in the form of stalactites and stalagmites. Rainwater that has seeped through the soil is enriched in carbon dioxide and therefore dissolves a large amount of calcite from the limestone. But when it reaches an open cave, the excess soil-derived carbon dioxide diffuses into the cave air, and this causes the calcite to be re-precipitated. Old abandoned tunnels are the prime locations for the deposition of dripstone and stalactites on the cave roof and then stalagmites and flowstone on the cave floor. Together with clastic sediments of sand and mud left by declining streams, these form the suite of cave deposits that are especially valuable as datable records of past geological events.

Stalagmite depositions combine with collapse debris from varying degrees of roof failure, and also with in-washed flood deposits, eventually to block many old passages where there is no on-going stream erosion to keep them open. Alternatively, surface lowering by on-going erosion (notably by Pleistocene glaciers) can remove the rock and the caves within it – leaving truncated passages behind open entrances in limestone hillsides. Some caves are very old, but nothing lasts for ever in an upland environment of active erosion.

Drained phreatic tube in Peak Cavern, Derbyshire, UK.

Calcite deposits in a Yorkshire Dales cave, UK.

Giant passage in Deer Cave, Sarawak.

Texts are modified extracts from the author's book, *The Yorkshire Dales: Landscape and Scenery*, published by Crowood, 2007, ISBN 987 1 86126 972 0.

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