Local Cave Leader/Cave Instructor Certificate

Caves & Karst

British Caving Association

Supporting document for the BCA Leadership Schemes: Caves & Karst

Introduction

This document, developed by Phil Baker of behalf of QMC aims to provide a resource for holders of the Local Cave Leader or Cave Instructor Certificate (CIC) and those working their way through these schemes. It is indicative of the level of knowledge regarding cave development required at the relevant award level.

QMC is indebted to John Gunn and Andrew Farrant who kindly allowed the use of their text for their BCRA booklet 'The Formation and Development of British Caves and Karst' (June 2022) including selective use of their diagrams and photos (other illustrations by Gethin Thomas). Their text is abridged in this document and appears in normal typeface.

The bullet point introductions (*in red italics*) to each section are written by Phil Baker and introduce each theme for the reader. These alone indicate the required knowledge for a LCL holder/candidate. The further normal text is the level required for a CIC holder. **Keywords** which an award holder could be expected to explain are in **bold** within the text for each award level. These are also listed at the end of the document.

The complete BCRA booklet by John and Andrew offers further recommended reading (beyond the scope of CIC requirements), as is the BCRA Glossary. BCA award holders are encouraged to seek these out to extend their knowledge once they have assimilated the concepts in this resource.

Note that this document does not cover broader geological concepts nor flora, fauna, or fossils – these will be covered in other QMC resources.

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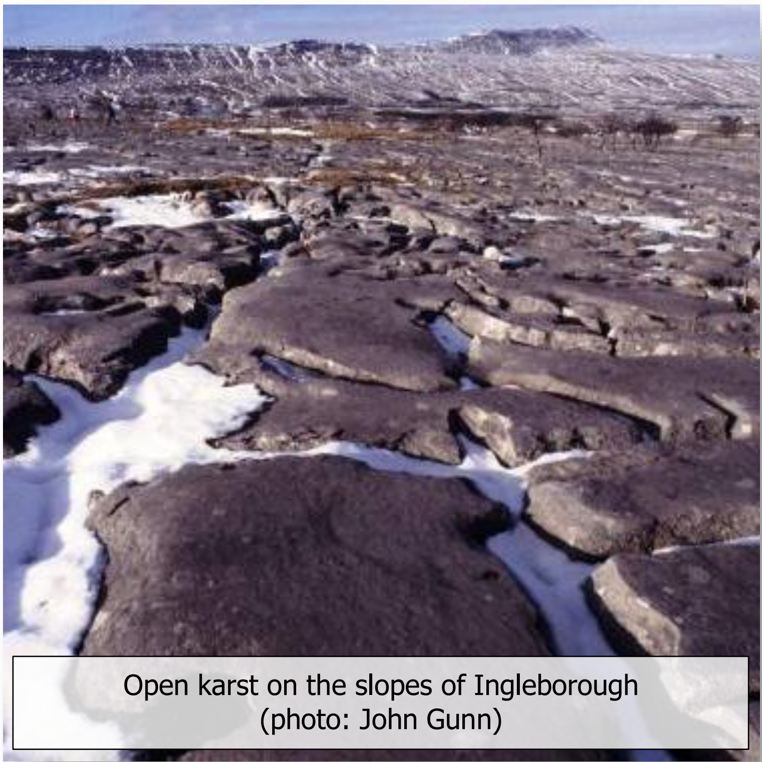
The Formation and Development of British Caves & Karst

- *The definitions of **cave** (natural cavity accessible by a human) and **karst** (limestone landscape)*
- *The concept that karst derives from rocks that dissolve easily (the process of **dissolution**) and allows water movement below the surface*
- *Karst is usually applied to **limestone (carbonate)** rock*
- *Caves may develop below areas of surface rock that is non-cave bearing, such as sandstones and **sedimentary** (clastic) rocks, if the limestone lies beneath them, such as in South Wales*

A **cave** is a naturally formed void in an earth material (rock or sediment) that is large enough for human entry. A distinction can be made between explorable cave and caves that are blocked by sediment or breakdown and thus not presently enterable. Caves are found in many different types of rock and some are formed in unconsolidated deposits but globally the majority are formed by **dissolution of carbonate rocks**. Globally there are also a substantial number of volcanic caves (also called lava caves) and in the marine realm, virtually every hard rock coast contains littoral caves (also called sea caves) that are largely formed by mechanical processes.

The term **'karst'** derives from an ancient word, karra/gara, meaning stone and was first used scientifically in a region on the present border between Slovenia and Italy. . This region has distinctive landforms and contained large areas of bare limestone. There have been numerous definitions of karst but a good starting point is to say that surface karst is characterised by distinctive landforms and **hydrology** that result from a combination of high rock solubility and underground water movement along preferential pathways that are enlarged over time by dissolution.



Open karst on the slopes of Ingleborough
(photo: John Gunn)

The most obvious karst settings occur where limestones crop out at the surface over an extensive area **(open karst)** such as in parts of the Yorkshire Dales.

Where limestones dip down beneath non-carbonate rocks water circulation will continue and caves may form. In many parts of Britain, the **Lower Carboniferous** limestones are overlain by **Upper Carboniferous** clastic rocks (**sandstones and mudstones**) and there are many kilometres of cave passage that extend beneath the non-limestone cover rocks, one of the best examples being Ogof Draenen in South Wales. Here less than 15% of the 70km of known passage are beneath areas where carbonate rocks crop out at the surface and the remaining cave passes beneath areas that would not be considered karstic based on the surface landforms.

The Geology of Carbonate Rocks

- ***Limestone*** *is composed of* ***calcium carbonate ($CaCO_3$)*** *and comes in many different forms*
- *Most form in shallow warm seas, from the shells and hard parts of marine animals or from calcium rich plankton that saturate the water and precipitate out as a* ***sedimentary*** *deposit*
- *Some are formed by growth of* ***coral reefs*** *and similar bodies*
- *The carbonate mud may be churned over by burrowing organisms and excreted out*
- *Heat and pressure by burial of more deposits compacts and cements them* ***(diagenesis)*** *and turns them into rock (lithification)*
- *Dolomitised limestone (**dolomite** or dolostones) also forms caves in a similar way and is made up of calcium magnesium carbonate, $CaMg(CO_3)_2$*

Limestones are those rocks predominantly composed of **calcium carbonate ($CaCO_3$).** Limestones can come in many different forms, depending on the type of calcium carbonate grains that make up the rock, and variations on the depositional environment, sea level, climate and its subsequent geological evolution. Most carbonates form in marine environments, usually in relatively shallow tropical waters typically less than a few hundred metres depth, although they can also form in deeper water.

Calcium carbonate, both calcite and aragonite, is primarily derived from the skeletons or shells of marine organisms such as corals, foraminifera and molluscs. These can be from organisms that live on the seabed and within the sediment, or from the rainout of planktonic organisms that live within the water column. As the number and type of marine organisms change over geological time, so the limestones will vary in their composition.

The type of rock that is formed depends on the processes of carbonate formation, transportation and sedimentation. Some limestones are constructional in origin. The obvious example is a **coral reef**, but other organisms can build up significant structures. The **reef knolls** in Derbyshire are an example of such a carbonate build up (although not a true reef, as they are not composed of coral).

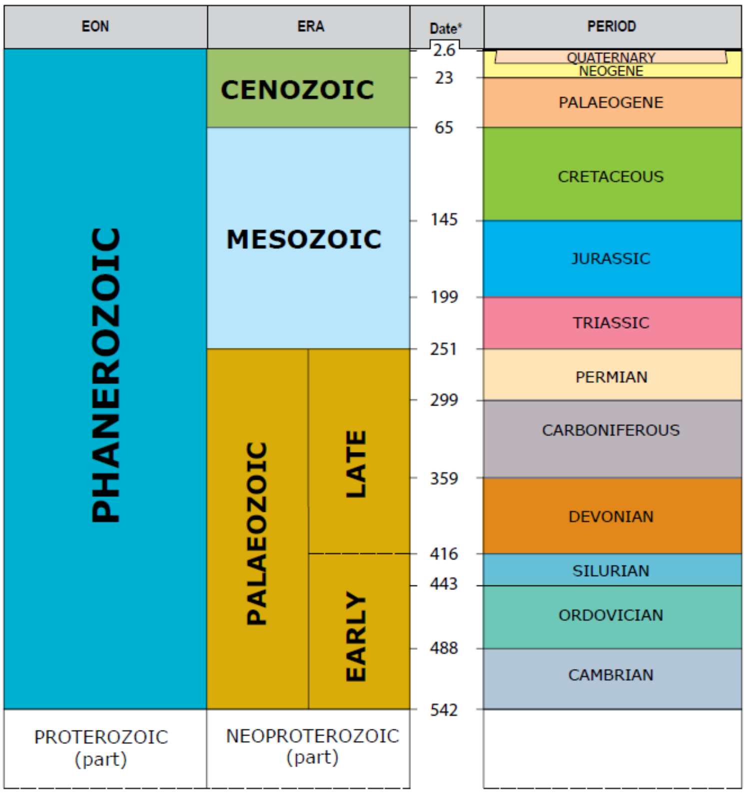
Once carbonate sediment has been deposited, it can be further modified by burrowing organisms that churn through the sediment, ingesting and excreting it. Many carbonate rocks such as the Chalk and the Carboniferous limestones are essentially large piles of excrement. Once the carbonate grains have been deposited, they turn into rock by a process known as **diagenesis.** This is the physical or chemical transformation of sediments into rock by geological processes, usually due to heat and pressure following burial, which can alter their physical and chemical composition, or precipitation of secondary minerals. This can take place very rapidly in carbonates due to the soluble nature of the material. Some carbonate sand dunes can lithify in just a few thousand years. They are usually cemented by calcite, to form a limestone.

A 'reef' limestone formed by carbonate build up over time on the warm shallow sea environment. High Tor Derbyshire. The carbonate build up is the massive limestone bulk, seen above normal bedded limestones beneath
(photo: Alan James/Rockfax)

Another rock-forming carbonate mineral is **dolomite**. This is similar to calcium carbonate, but composed of **calcium magnesium carbonate,** $CaMg(CO_3)_2$. Rocks where the carbonate material consists chiefly of dolomite are termed dolostones, although 'dolomite' is commonly used to denote both the rock and the mineral. They are typically a honey-brown colour with a sandy texture. This can be seen in parts of Ogof Draenen, and in caves in the Forest of Dean.

British Cave and Karst Areas

- *Most UK caves are in **Carboniferous limestone which is c360 – c330 million years old,** and appears in Mendip, South Wales, Ireland, Peak District and Yorkshire Dales.*
- *In Devon the limestone is older (from the Devonian geological period), and in Scotland the oldest UK carbonate rocks appear (over 500 million years old).*



Geological time periods

By far the greatest concentration of karst and caves in the UK are in limestones of **Lower Carboniferous** age. In northern England, the Lower Carboniferous is dominated by the **Great Scar Limestone Group,** with a succession of thin limestones interbedded with mudstone and sandstone above. These form the classic karst landscapes of the Yorkshire Dales. Similar limestones occur in the Peak District (Peak Limestone Group) and North Wales (**Clwyd Limestone Group).** Further south, the **Pembroke Limestone Group** extends from the Bristol-Mendips region west through the Forest of Dean, around the margins of the South Wales coalfield and across into Pembrokeshire.

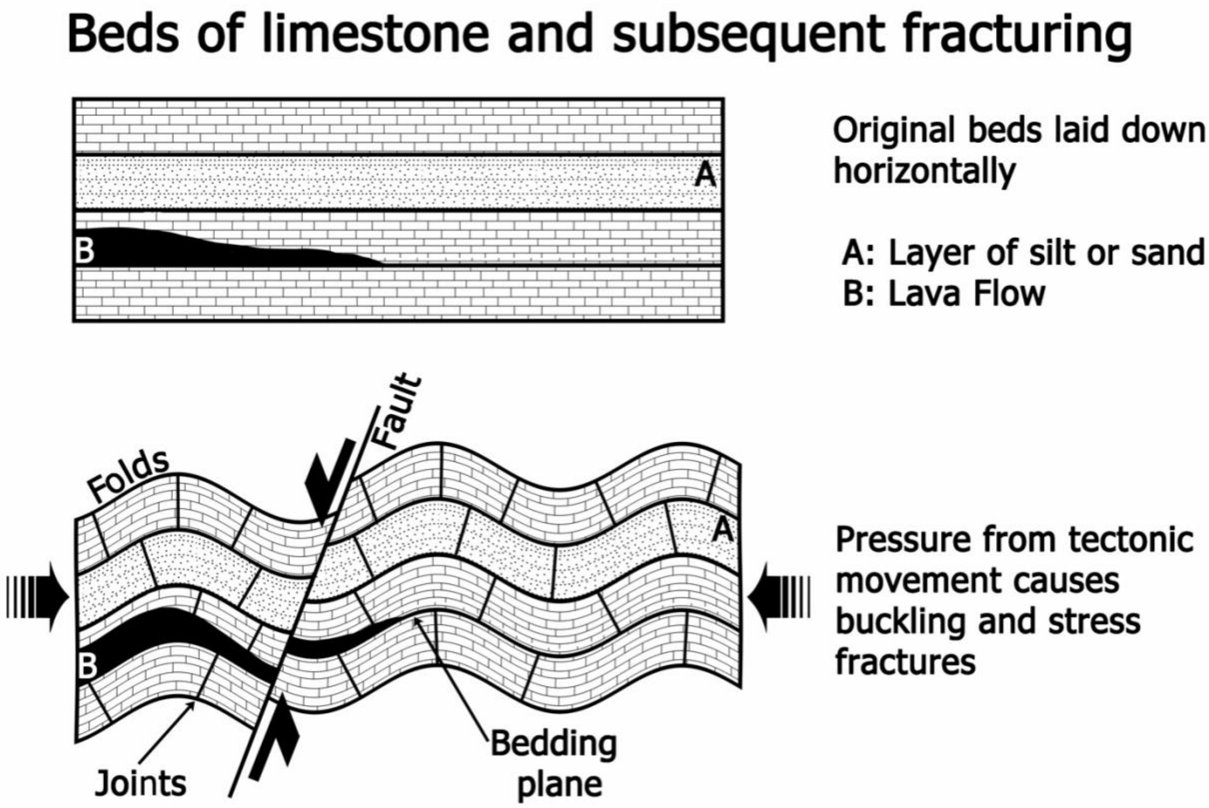
The **Devonian carbonates** of southwest England comprise massive limestones that are highly fossiliferous and weakly metamorphosed.

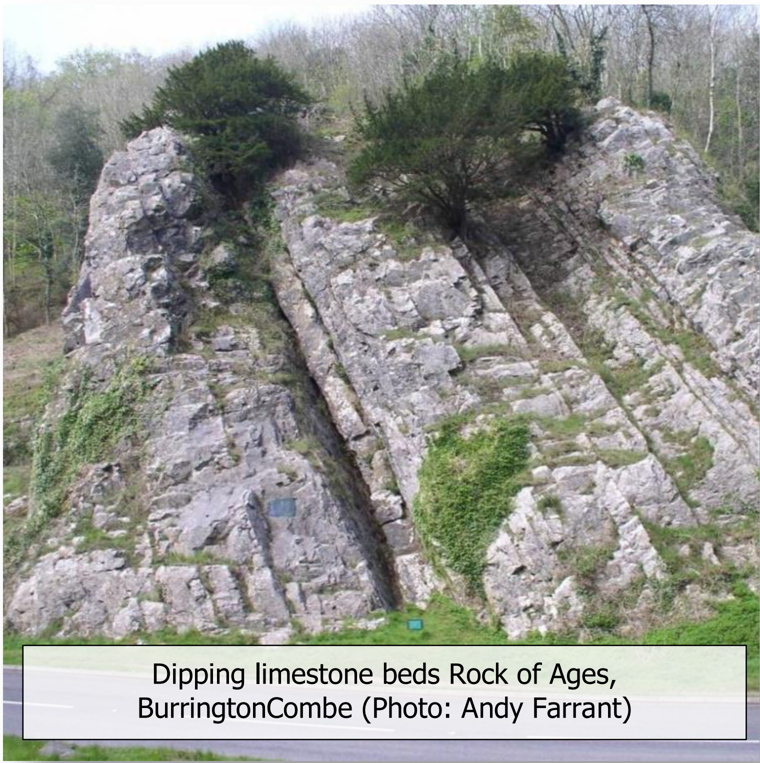
In Scotland, three distinct rock units form the main caving areas. The youngest are Jurassic limestones that crop out and contain small karst areas and caves on Skye and on the adjacent mainland. Next, the Cambro-Ordovican Durness Group forms a narrow, discontinuous belt, extending along the north western side of Scotland. **Assynt** is the main caving area and hosts the best-developed karst drainage systems in Scotland. The oldest rocks in Britain with caves and karst are the Dalradian Supergroup (late Precambrian to Cambrian age) that form a stripe karst northeast from Appin.

Geological Structure

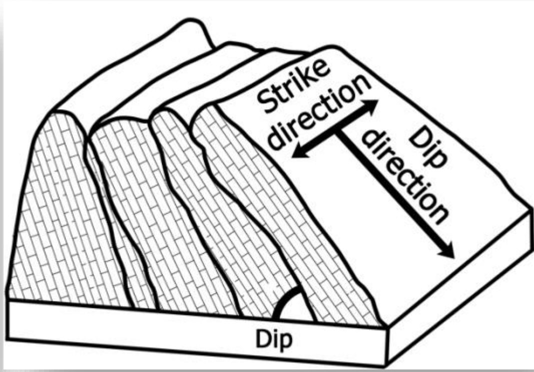
- *Originally the carbonate sediments are generally laid down horizontally in layers called **beds.** These vary in composition and thickness depending on the environmental conditions*
- *Each bed has a top and bottom surface called a **bedding plane***
- *If there is an influx of other materials such as **volcanic ash, mudstone or lava** the limestone beds might be interspersed with these other rocks*
- *The beds may then be **deformed** by earth movements (caused by the movement over geological time of the **earth's tectonic plates**) and **fold** or crack (causing joints and faults)*
- ***Joints** are often at 90^0 to the bedding planes and have no movement along them*
- ***Faults** planes are where the rock masses have moved relative to each other. They often contain sharp broken rock fragments (breccia) caused by this movement*
- *Faults may later experience **mineralization** by hydrothermal fluids rising into them and cooling, depositing lead, iron and zinc in addition to other minerals*

Once sediments have been deposited they are subject to compaction and cementation **(diagenesis)** before they become rock **(lithification).** They can then be deformed by **tectonic processes** including **folding and faulting**.

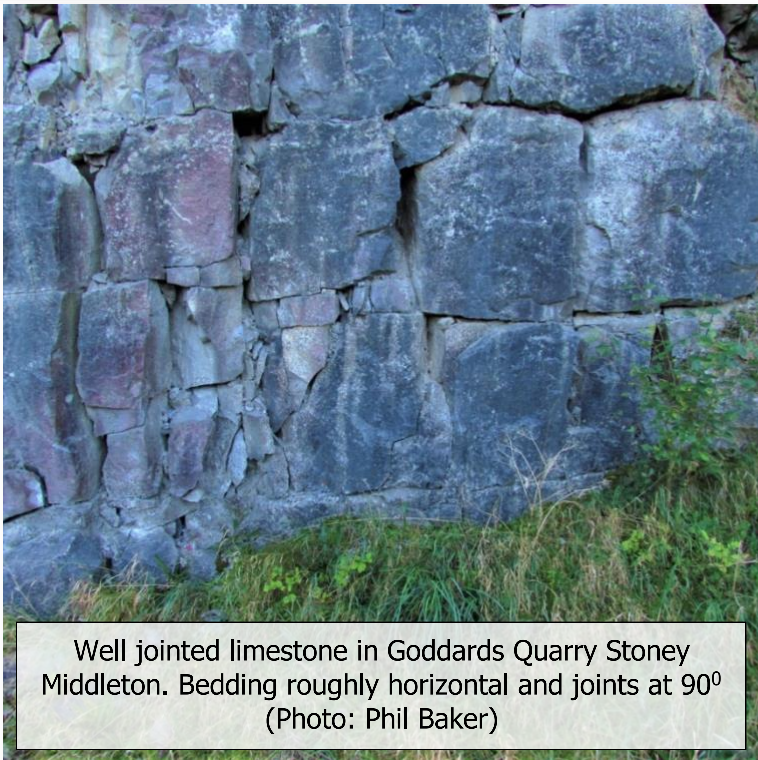




Dipping limestone beds Rock of Ages, BurringtonCombe (Photo: Andy Farrant)

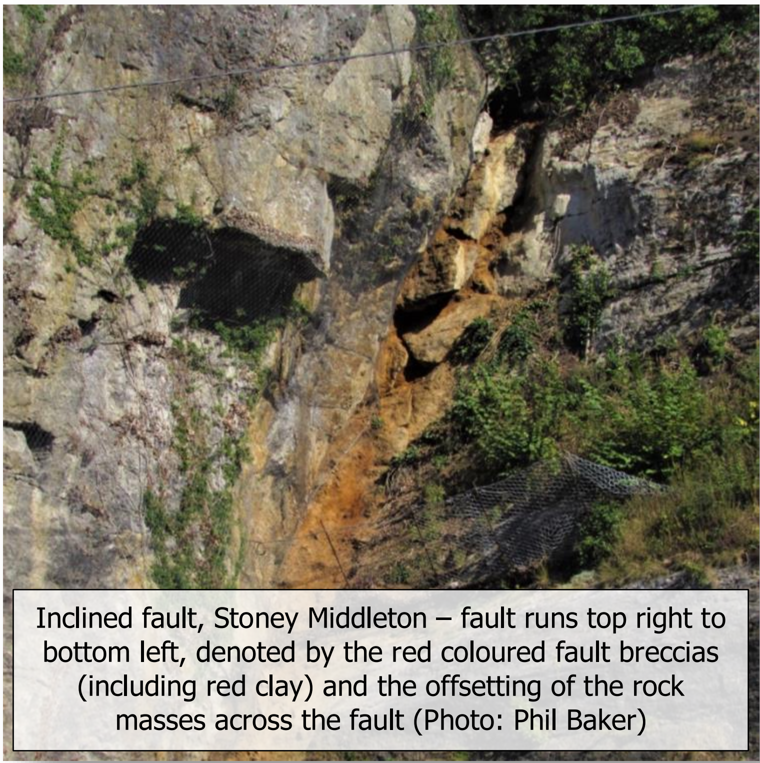


Bedding planes are discontinuities that are formed by a change or hiatus (break) in the depositional environment, for example a change in sea level. They divide the rock sequence into a series of layers or beds, which can be from just a few mm to >10 m thick. In some cases, the bedding planes may be a thin layer of mud or volcanic ash (known as a 'wayboard' in Derbyshire) or represent a period of emergence with karstic development or soil formation. Some limestones, notably reef limestone and oolites have few bedding planes due to their mode of deposition.



Well jointed limestone in Goddards Quarry Stoney Middleton. Bedding roughly horizontal and joints at 90^0 (Photo: Phil Baker)

Joints are vertical or steeply inclined fractures that do not displace the rock either side. They result from brittle fracture of a rock body or layer as the result of tensile stress, for example during folding.



Inclined fault, Stoney Middleton – fault runs top right to bottom left, denoted by the red coloured fault breccias (including red clay) and the offsetting of the rock masses across the fault (Photo: Phil Baker)

In the Carboniferous limestones they tend to be **normal** (ie at 90 degrees) to the bedding, but **conjugate fracture** sets also occur – these are inclined joints that intersect at a high angle forming a X. Joints most frequently occur as parallel, evenly spaced joint 'sets'.

Faults are distinct from joints in that they displace the rock-mass either side. **A fault plane** is typically marked by a crush zone with broken up rock fragments ('fault gouge' or **breccia**) and fibrous markings known as **slickensides**. For minor faults, this may be only a few mm-cm wide, but for major faults such as the Dent or Craven Faults in the Yorkshire Dales, the damage zone can be several metres wide. In some cases, the fault plane may be mineralised, usually with calcite but potentially other minerals.

Gentle upfold (anticline) in limestone, Wardlow (Photo: Phil Baker)

Many British caving areas are also former mining areas, with localised iron, lead and zinc **mineralisation**. These deposits are formed by the expulsion of warm mineral rich fluids from an adjacent sedimentary basin up into the surrounding permeable rocks, As the solutions moved up out of the basin, they cooled and reacted with the host rock, precipitating minerals, usually along pre-existing fractures and sedimentary discontinuities, forming **mineral veins**. The most common minerals are lead and zinc sulphides (galena and sphalerite).

Stylolites are another type of discontinuity peculiar to limestones. These appear as irregular seams or wavy lines a few mm-cm high like a heart monitor trace. They are formed by **pressure dissolution**. This involves the dissolution of carbonate minerals in areas of relatively high stress, with the stylolite marking the zone where materials have been removed. The serrations occur parallel to the direction of maximum stress


Stylolites in OgofDraenen (Photo: John Gunn)

Carbonate Dissolution and Precipitation

- *Slightly **acidic water** (from carbon dioxide in the atmosphere and soil cover) dissolves the limestone through a process called **dissolution***

Limestones are only slightly soluble in pure water, but when rain falls through the atmosphere, it dissolves carbon dioxide, forming a weak **carbonic acid**. This is able to dissolve more limestone. A common error is to say that dissolution produces calcium bicarbonate, which is soluble. This is NOT a correct representation and the process actually results in a solution that contains calcium (and magnesium if present in the rock) ions and hydrogen carbonate ions:

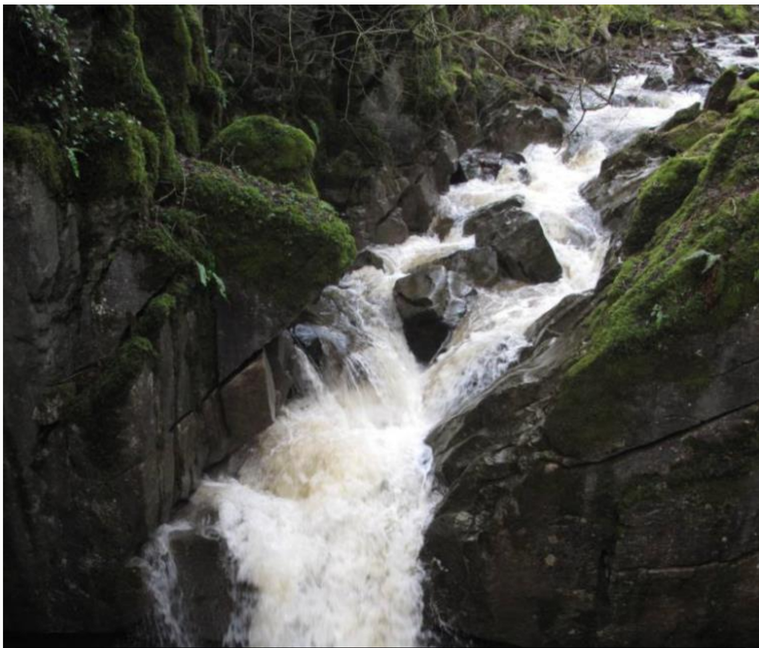
$CaCO_3 + H_2O + CO_2 = Ca + 2HCO_3$

Wherever there is a soil cover there is a marked increase in carbon dioxide, which is produced by microbial processes, soil fauna and plants roots. It is this source of carbon dioxide that drives the dissolution process in most karst areas. **Percolation water** that has dissolved carbon dioxide as it passes through the soil is commonly referred to as being **aggressive** because it is able to dissolve limestone. In most British caves, the concentration of carbon dioxide in the air is markedly less than the concentration in the overlying soil, so when water emerges into a cave, it rapidly loses carbon dioxide (back into the atmosphere), becomes supersaturated in CaCO3 and deposits the calcium carbonate as **speleothems.**

Whilst carbonic acid is by far the most common solvent in karst areas, other acids may contribute to conduit enlargement, particularly at an early stage in the evolution process. Of primary importance is the generation of **sulphuric acid** by oxidation of iron sulphide minerals such as pyrite, which are commonly present in shales.

Water in Carbonate Rocks

- *Limestone forms beds of rock, with occasional layers of other rock between them*
- *These limestone beds then crack due to earth movement events (orogenies) forming joints and faults*
- *The cracks within the limestone sequences (bedding planes, joints and faults) allow water movement through the rock mass*
- *However, it is not just the fact that cracks form in limestone that make it the main cave forming rock – it is also the unique relationship it has with acidic water that is key*
- *Water flows through the cracks (initially very slowly along the bedding planes)*
- *Once these channels grow large enough they are called conduits, which allow turbulent flow – this is more efficient at eroding the limestone to form caves*
- ***Percolation** water moves downwards through the rock from the surface*
- *Water may also enter into a cave directly as a stream into (a **swallet** cave) or exit as a stream/river (a **resurgence** cave)*



Concentrated allogenic recharge Cwm Pwll y Rhyd
(Photo: Rich Hill)

Dispersed autogenic recharge - the limestone in this part of the Peak District is overlain by 1-3m of sediments(Photo: John Gunn).

Most limestones have a low **primary permeability** but the permeability of adjacent beds may be higher permitting some water movement. In addition, most limestones are laid down in beds that are separated by bedding planes. Most limestones are fractured by joints and faults. As water flows through these initially very small openings it is able to dissolve the limestone. As the openings get larger, they are able to transmit more water, which dissolves the rock and enlarges them still further. Gradually, a network of interconnected dissolution channels develops. Water flow through channels is slow and laminar but over time the more efficient channels grow at the expense of less efficient channels and form **conduits** in which flow is **turbulent**. Conduits grow more rapidly than channels and some may grow large enough to become caves.

Percolation is the process by which water moves vertically through rock - hence the water that enters through the roof of a cave is commonly called percolation water. In karst areas, a distinction can be made between **allogenic recharge**, which is water that first has contact with other rocks and then enters limestone, and **autogenic recharge**, which enters limestone without contact with any other rock.

There is commonly a clear interface between the unsaturated (**vadose**) zone and the saturated **(phreatic**) zone, which is called the water table.

Concentrated allogenic recharge occurs where streams that form on non-carbonate rocks flow into a limestone area and sink at a point or points, commonly called swallets. Rain falling onto soil over limestone provides **dispersed autogenic recharge**

Surface Landforms

- *Common and distinctive surface features in limestone areas include water runnels, **clints** and **grikes, shakeholes** (dolines) and **dry valleys** as the water finds pathways below the surface*

Where carbonate rocks crop out at the surface the only source of carbon dioxide is the atmosphere, which limits the amount of dissolution. Despite this spectacular **solution runnels** (karren) form on inclined surfaces in virtually all climatic zones. In areas where

Intersecting joints (grikes) and tabular clints at Sheshymore in the Burren, County Clare, Ireland (Photo: John Gunn)

the gradient is sub-horizontal there may be extensive areas of bare **limestone pavement**, where tabular blocks **(clints)** are separated by dissolutionally enlarged joints **(grikes).** In Britain, these are largely confined to areas that were ice-covered in the last 50,000 years and are commonly referred to as glaciokarst.

Collapse doline - Hull Pot, Yorkshire (Photo: John Gunn)

Steep sided collapse **dolines** are important for cavers because by definition a cave-sized void must form to provide the space into which the overlying rock collapses. Unfortunately, this means that collapse dolines are associated with extensive **boulder chokes** that commonly prevent access to the cave passage that must exist in an upstream and downstream direction. Hull Pot in the Yorkshire Dales is a good example. However, some cave systems are accessed from collapse doline such as Great Douk Cave in the Yorkshire Dales and Chartists Cave in South Wales.

Long, well-developed **dry valleys** are found in many British karst areas. Some, particularly those in the Peak District, were originally formed on less permeable rocks that overlie the limestone. As these rivers cut down into the limestone flow was lost due to karstification of drainage leaving the valleys dry although many were subsequently re-occupied by surface rivers during Quaternary cold phases when permafrost rendered the ground impermeable.

Upper Lathkill Dale, Derbyshire is a classic dry valley (Photo: John Gunn)

Cave Development

- *Caves can form by **water descending and dissolving the rock** along the way or by **fluids rising upwards** from deep in the rock mass cave.*
- *The former caves go through **several stages** in their creation - the first as water seeps through small cracks as mentioned earlier. This is a slow process, and certain beds favour the development of pathways such as shales.*
- *The later stage is when the channels allow turbulent flow and the cave is actively growing at a more rapid rate, affected by glacial/interglacial periods and surface erosion causing the valley level to lower*
- *As this happens older higher passages are abandoned becoming **relict** cave*
- *Later **modification** may occur such as roof collapse (**breakdown),** development of **boulder chokes** or infill of passages with sediments*
- ***Caves from rising waters develop over long geological time periods.** Large vertical cavities such as Titan Shaft can form as the hot fluids enlarge mineral veins on their upwards journey.*

There are two primary classifications of caves: **epigenic** and **hypogenic.** Epigenic caves are formed where water descends from the surface under gravity and dissolves soluble rocks. In contrast, hypogenic caves are formed by upwards-flowing fluids. The fluids originate either from distant sources (confined by lower-permeability strata) or from deep sources (commonly **geothermal**). Both epigenic and hypogenic caves are present in Britain and their origins are considered in more detail below.

Epigenic cave development

Before the development of dissolutionally enlarged pathways most carbonate rocks are virtually **impermeable.**

However, water can move slowly through an interconnected network of small voids including joints, fractures, faults, bedding plane partings and other discontinuities. Initial flow is distributed along these interconnected fissures, which are then subject to dissolution. This is the **inception** phase, which represents the change from 'rock with no conduits' to 'rock with conduits'. Some particular discontinuities may be especially prone to early dissolution by virtue of their physical or geochemical characteristics.

These are termed **inception horizons.** These can be bedding planes, thin shale bands, such as those that occur in the Great Scar Limestone Group in Yorkshire, volcanic ash layers (termed wayboards in Derbyshire), hardgrounds and flint/chert bands.

Once water is able to flow through the rock, dissolution can commence. When chemically aggressive water enters the rock via fractures, the initial rate of dissolution is rapid. However, the rate of dissolution is not linear and slows markedly as the water approaches saturation with carbonate.

Following inception there are three phases in the life of an epigenic cave: **gestation, development and abandonment**.

Gestation is the period when small conduits grow to accessible caves. During gestation, some channels attract more and more flow and hence grow larger than those channels with less flow. Gestation ends when two conditions are met, firstly the channel penetrates through to an open void, either an existing section of cave passage or the land surface, and secondly it grows large enough to permit **turbulent flow** (around 10mm). At this point, there is a sudden transition (often termed ‘breakthrough’) with much more rapid dissolution along the entire flow path, and a increase in the enlargement rate. Breakthrough marks the point at which a channel becomes a conduit and the start of the **development** phase (see discussion below). Once a particular flow pathway has achieved breakthrough, it will rapidly enlarge, capturing flow from adjacent fractures and channels.

The time for conduit enlargement after breakthrough is rapid, and caves can reach human size within a few thousands of years.

During the **development** phase, the cave is occupied by flowing water and is actively growing. Groundwater flow and cave development are influenced by glacial-interglacial climatic variations, base level lowering and valley incision. This is followed by the **abandonment** of higher-level passages. Over time, repeated phases of cave formation and valley incision can lead to a stacked series of cave levels. For example, in the Mendips, up to six distinct cave levels can be identified, each formed in relation to a particular phase of valley incision and base level lowering.

The development phase ends, and the **abandonment** phase starts, when there is no longer any water flowing through the cave, which then becomes relict, although it can still be modified by collapse and sediment or speleothem deposition. Cavers often refer to passage that no longer has an active stream as being 'fossil' but this is not correct - these passages are simply **'relict'** as in most cases they are still evolving as a consequence of percolation water inputs.

Bedding collapse Chartist Cave (Photo: Rich Hill)

As uplift and erosion continue, cave systems will eventually collapse or become unroofed. As a passage enlarges, it may become too large for the roof to support the weight leading to collapse and the formation of a more stable arch shape.

A thinly bedded limestone with lots of shale partings is likely to collapse more quickly than a cave passage in a massive, strong limestone.

Although the four phases are sequential, they are commonly all present within a single cave system. For example, inception processes may be slowly enlarging channels that are tributary to conduits that discharge into a cave stream. The active stream passages may lie beneath abandoned upper levels which, although relict in the sense that they are now longer growing in size, continue to develop both by growth of speleothem and by breakdown.

Hypogenic cave development

Titan – a hypogenic cave
(Photo: Robbie Shone Photography)

Dissolution of limestone by carbonic acid is not the only way caves can form. They can also be created by acidic, commonly thermal, artesian waters that either rise from depth or are confined beneath less permeable strata. These are known as **hypogenic caves.** Two main types of hypogenic caves occur in Britain: isolated **phreatic vein cavities** associated with deep phreatic dissolution along mineral veins; and **maze caves** associated with rising artesian flow.

Classic hypogenic maze cave passage with inlet and outlet rifts, Hudgill Burn Mine Cave
(Photo: Andrew Farrant)

Deep **groundwater flow** within a sedimentary basin can enable water to reach significant depths (2-3 km) and temperatures. Where these thermal waters rise up along major fractures, faults and mineral veins into adjacent limestone, they can dissolve out the rock, creating caves and thermal springs. Where these are developed along vertical mineral veins, phreatic vein cavities form. As they are active over long timescales, large, vertically extensive cavities can form. Examples include Eldon Hole and the 180m deep Titan Shaft in the Peak District. Other similar cavities occur in North Wales, the Mendips and the northern Pennines. Being deep-seated features, hypogenic caves can form over longer timescales than epigenic caves.

Hypogenic maze caves are formed by the slow upward flow of acidic water through a soluble rock. Good examples occur in the interbedded Upper Carboniferous limestones and mudstones of the northern Pennines. Here caves form by the slow upward flow of acidic water from mudstones through a thin limestone bed and back into mudstones. The acidity is generated by the oxidation of sulphide minerals within the mudstones and mineral veins by oxygen-rich groundwater, generating sulphuric acid. As this water passes from the mudstones up through a thin limestone bed, the acid dissolves out cavities along the all the fractures, creating a complex maze cave.

Cave Geomorphology

- *Cave geomorphology describes the shape of cave passages and relates them to their formation*
- ***Phreatic passages** are often the earliest passages as water enlarges a bedding plane or joint during inception. They form with the pathway completely full of water and as the water is moved by pressure it can move upwards as well as along and downwards, forming characteristic oval shapes as it enlarges bedding planes, joints and faults*
- ***Vadose passages** form by free-flowing water dictated by gravity leading to stream canyons*
- *If a phreatic tube drains due to uplift or valley lowering it becomes vadose, so a classic T shape passage is formed with the origin of the phreatic tube seen as the roof, with a canyon below*
- ***Vertical pitches** form in vadose caves, down joints or other fractures. They are circular in shape as the spray affects all the walls equally (in contrast to phreatic vein cavity shafts which appear oval along the feature that was exploited)*
- *Smaller features such as **scallops** are also visible, including anastomoses tubes, testament to the initial inception of the pathways along low angle bedding planes*
- *The **size of scallops** indicates the water speed (slow = large, fast = small) and **direction of flow** is shown by the shape with the steep face facing upstream.*

- *Being able to recognise the origin and development of caves by observing these features allows the cave instructor to add insight into the underground journey for the group that they are with*

Cave passages come in a variety of different shapes and sizes. The two most common types are **vadose** and **phreatic passages**. Phreatic passages were totally water-filled at the time of formation. As dissolution is able to occur all around the passage circumference, phreatic passages will enlarge to form rounded or **elliptical passage** cross sections. Phreatic passages are often developed at the intersection of a bedding plain and a joint, with the passage .

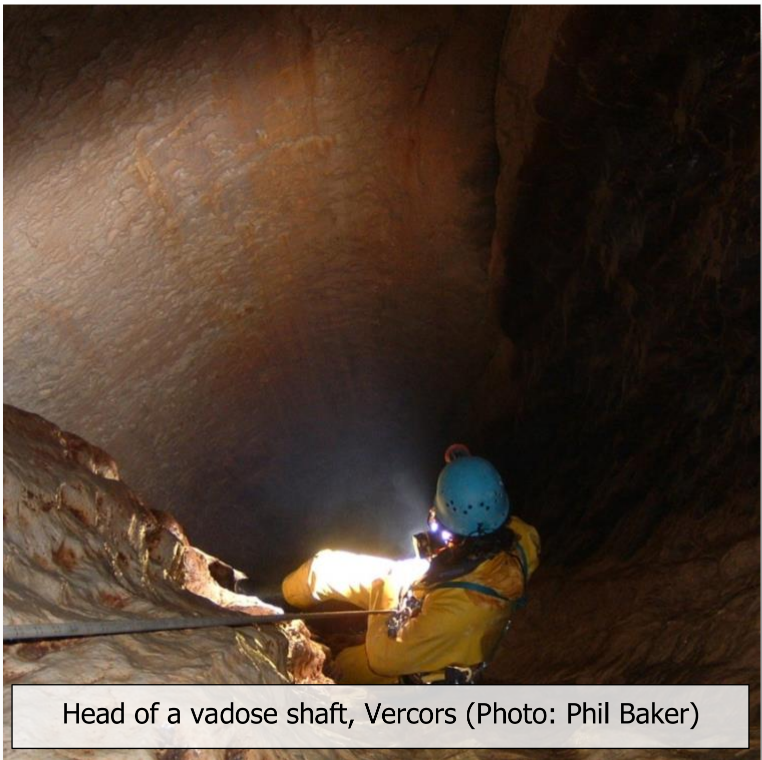
Phreatic tube in Peak Cavern, Derbyshire, carries a small, percolation-fed, stream for most of the year but in wet weather water backs up in downstream sumps and the tube fills to the roof. The tube has developed on a prominent horizontal bedding plane but runs across a series of joints enlarged in the foreground (Photo: John Gunn)

Phreatic **aven** in Bagshawe Cavern, developed upward along a small joint (still visible in the darker lava bed which is not soluble, unlike the underlying limestone). Note the bedding is horizontal and the joint at 90^0 to it. (Photo: Phil Baker)

Vadose passages are those that are formed by a stream with a free air surface. As the stream only erodes the passage floor, the passage incises downwards The result is typically a tall, narrow canyon shaped descending passage, a succession of shafts or a mix of the two, descending downwards until it reaches a zone of saturation or emerges at a spring. They are commonly developed along joints, leading to linear passage elements.

A common element of vadose passages are shafts or pitches. These are especially common in well-fractured horizontal or gently dipping limestones, such as the Yorkshire Dales. In dipping limestones, the downward flow of water is usually broken by bedding planes, creating stepped passages with many small climbs, such as seen in many Mendip caves. **Vadose shafts** form rapidly as the walls are often lashed by spray and thus covered by free-flowing sheets or films of vadose water streaming down the walls. These waters are under-saturated with respect to calcite and rapidly dissolve the walls that are within reach of the spray. In plan view, pitches tend to form a rounded or elliptical shape, depending on the lateral extent of the spray. This also explains why pitches tend to be larger than the passages leading to and exiting from them.

Vadose canyon in Speedwell Cavern, Derbyshire (Photo: John Gunn)



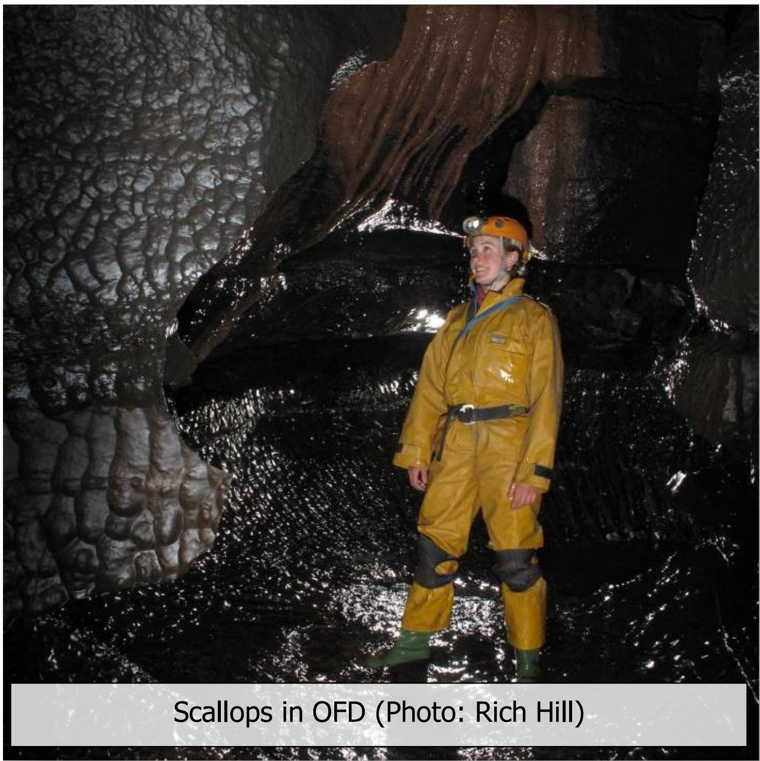
Head of a vadose shaft, Vercors (Photo: Phil Baker)

A fall in the elevation of the point where the cave stream emerges at surface due to valley down cutting, uplift of the rock-mass or sea-level fall, can drain phreatic passages which become occupied by a vadose stream. Over time, a classic **'T' shaped** passage can develop with the initial phreatic tube in the roof, and a **vadose trench** carved in the floor.

In many caves the original phreatic tube may be hidden from view high up in the roof of a deep vadose canyon. These passage forms can be very useful in deciphering how the cave evolved over time.

The Peak Cavern streamway upstream of Squaws Junction shows an elliptical phreatic passage that has developed on a prominent bedding plane beneath which there is a vadose trench (Photo: John Gunn)

As well as the gross passage shape, smaller features caused by dissolution can be recognised, sometimes termed 'speleogens'. These include **scallops,** anastomoses, half tubes, notches and pendants. The most common are the small asymmetric scoop-like depressions in the rock known as scallops. These are formed by turbulent water flow. Their size and shape indicate water flow direction and velocity, and can help determine palaeoflow directions in caves as the steeper face of the scallop points upstream. The size is proportional to the velocity of water flow , with larger scallops indicating slower flow.



Scallops in OFD (Photo: Rich Hill)

Anastomoses are complex networks of interlinked small dissolution tubes typically a few centimeters across. They can form in two distinct ways. The most common is by slow phreatic water flow along a bedding plane parting or fracture. They represent an early phase of cave development (a channel or conduit), that is abandoned when water finds a preferable route. They are generally only exposed by subsequent wall or roof collapse.

Anastomoses, OgofDraenen (Photo: Mike Simms)

The shape of a passage, and the features contained within it, including scallops and other speleogens allows the caves history to be unraveled. By studying passage shapes and speleogens throughout the cave, individual phases of development can be identified and put into sequence.

Summary for all award holders

Caving is a unique activity in that it is the environment itself that makes it so special. The whole group are immersed in a fascinating and timeless place throughout. To understand cave development offers a lifetime of learning which often presents more questions than answers..... A BCA award holder should be able to link their knowledge of cave development to their journey through a cave system and explain it in a practical, coherent and interesting way at a level relevant to their group. It is hoped that this resource is written in a way that helps that process.

Summary of keywords:

LCL and CIC	CIC
Cave	Open karst
Karst	Hydrology
Limestone	Lower/upper carboniferous
Dissolution	(360 – 330mya and 330 – 299 mya)
Carbonate rock	Sandstone/mudstone
Sedimentary	Reef knoll
Carboniferous limestone (360 –330 mya)	Calcium magnesium carbonate
Calcium carbonate ($caco_3$)	Lithification
Coral reef	Dip
Dolomite	Peak/clywd/pembroke
Diagenesis	Great scar/devonian limestones
Bed	Orogenies
Bedding plane	Normal/conjugate joints
Ash/mudstone/lava	Fault plane/breccia
Tectonic movement	Slickenside
Fold	Stylolite
Joint	Aggressive (re: acidic waters)
Fault	Speloethems
Mineralization	Sulphuric acid (re: pyrites)
Carbonic acid	Low primary permeability
Percolation water	Conduit
Swallet/resurgence cave	Turbulent flow
Phreatic/vadose	Allogenic/autogenic recharge
Water table	Doline/dry valley
Clints/grikes	Runnels/limestone pavement
Shakehole	Epigenic/hypogenic
Boulder choke	Geothermal
Breakdown	Anastomoses
Caves developed by descending or	Inception/gestation/development/
Rising water (concept of)	Abandonment/relict
Shape of phreatic/vadose/combined	Phreatic vein cavity
Passages (concept of)	Maze caves
Scallop (shape and size)	
Pitch trench/aven	