NORTHERN ENVIRONMENTAL EDUCATION DEVELOPMENT

A NON-TECHNICAL GUIDE TO THE GEOLOGY OF THE BURREN REGION, CO. CLARE, IRELAND

part of the Northern Environmental Education Project

by

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Introduction

This illustrated guide forms part of Burren Connect's work with the Northern Environmental Education Development (NEED) project, and is divided into two parts. The first part of the guide, "The story of the rocks", explains how the rocks of the Burren region were formed and the events that have shaped them during their history. The second part of this guide, "Common landscape features", describes briefly some of the most common features that characterise the landscape. For more information on the structure, aims, and results of the NEED project, please see www.joensuu.fi/need and www.burrenconnect.ie/geopark/education.

The Burren region in North County Clare encompasses the landscapes of the Burren, the Cliffs of Moher, and the western part of the Gort-Kinvarra lowlands (Fig. 1). The landscapes of this region are underlain by different rock types. Limestone occurs in the north and east, i.e. the Gort-Kinvarra lowlands and most of the Burren. Sandstones, siltstones and shales occur in the south and west, i.e. the Cliffs of Moher, and high ground in the west and centre of the Burren e.g. Slieve Elva (Fig. 2, overleaf). Variations in the landscape across the region reflect not only rock type, but also the more recent geological history, such as the effects of the most recent glaciation (ice age) and the length of exposure of the rocks at the Earth's surface.

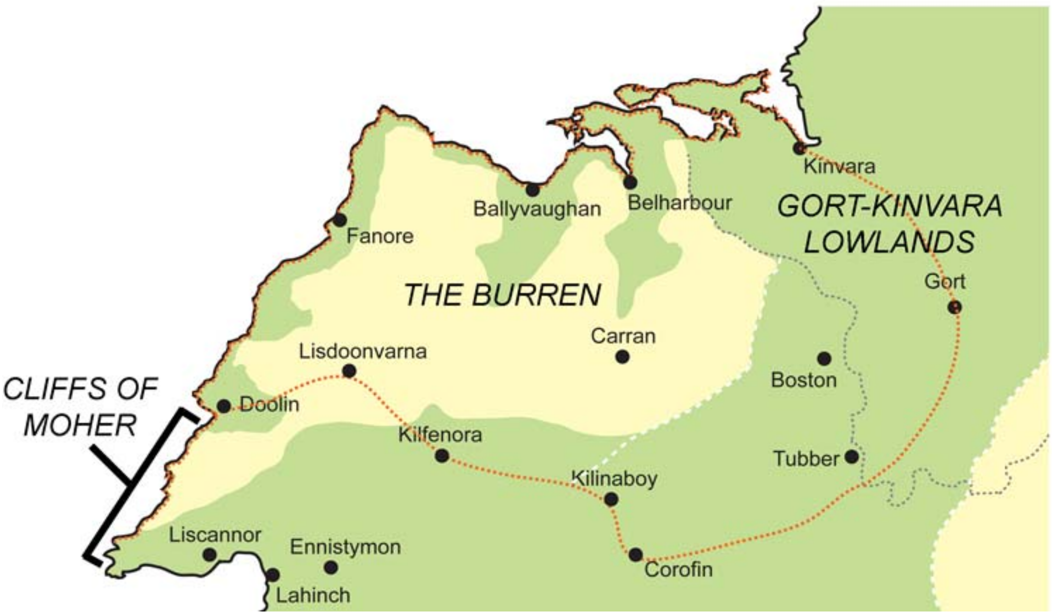

Figure 1. Map of the Burren region (orange dashed line), showing the Cliffs of Moher, the Burren, and the Gort-Kinvara Lowlands (white dashed line). Areas below 60 m OD are shaded in green.

PART 1: The story of the rocks (geological history)

The rocks in the Burren region were deposited when Ireland was located ~ 10°S of the Equator, during the Carboniferous period in Earth history, which spans 359-299 Ma (megaannum: millions of years ago). The limestones were deposited during the Viséan stage (345-326 Ma) of the Carboniferous, and the sandstones, siltstones and shales, during the Namurian stage (326-315 Ma).

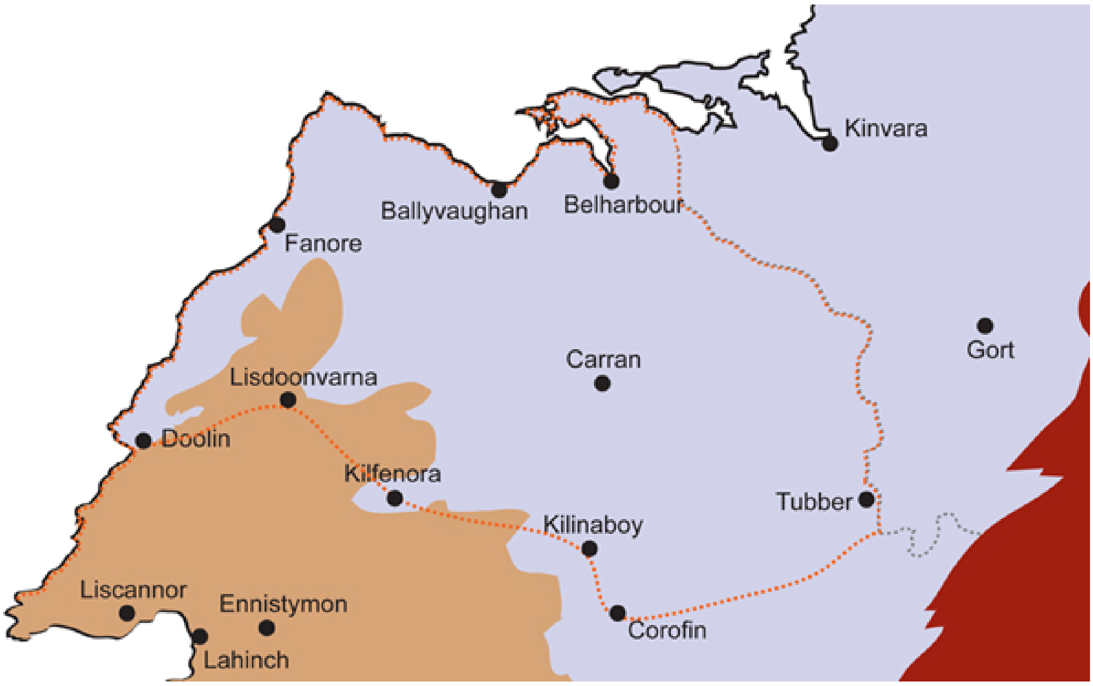

Figure 2. Simplified geological map of the Burren region and surrounding area, showing limestone (pale blue), younger siliciclastic rocks (pale brown), and older siliciclastic rocks (dark brown).

A shallow tropical sea teeming with life

The limestones of the Burren region are about 800 m thick. Only about 500 m, however, is exposed at the Earth's surface; the rest is below ground. The limestones formed in a warm, shallow, tropical sea that once extended across most of Ireland, the UK, and large parts of northeast Europe. The limestones contain the fossilised hard skeletons of a variety of marine organisms; the soft tissues of these organisms decayed and are not preserved. The most common fossils are crinoids (relatives of starfish), corals (very similar to those alive today), brachiopods (a filter-feeding animal with two shells that is found today on the ocean floor in the deep sea), and gastropods (snails) (Fig. 3). Most of the fossils are broken to some degree, and very few are found in their life position. These features indicate that the fossils were transported or moved around in a high-energy environment and show that the floor of the shallow tropical sea was agitated by waves. Fossils make up only a small proportion of the limestones, however. Most of the grey mass of the limestones is composed of microscopic particles of calcium carbonate. These particles have a variety of origins: some precipitated directly out of the water column, others are the faecal pellets of zooplankton and other invertebrates, and others still represent microscopic ground-up fragments of the hard skeletons of marine animals such as corals and brachiopods. There are very few particles of clay and sand in the limestones. This shows that there were no major rivers flowing into the tropical sea in the Burren region, possibly because the climate was too dry.

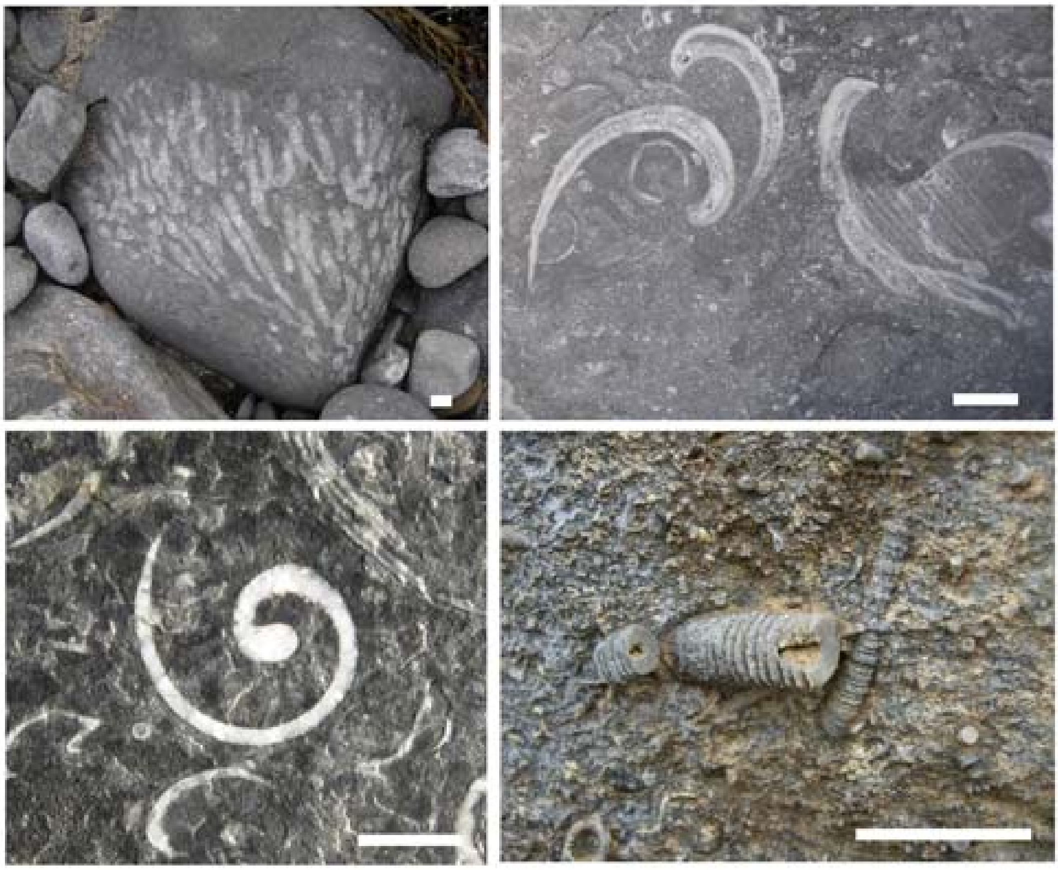

Figure 3. Common fossils in the limestones of the Burren. Clockwise from top left: corals, brachiopods, crinoids, and gastropods.

Changes in sea level and an ancient ice age

Although the limestones appear relatively uniform, different layers do show subtle changes in composition. These changes reflect variations in environmental conditions.

During deposition of the limestones, the Earth was in the grip of an ice age, with alternating advances and retreats of polar ice caps. As a result, global sea level fluctuated constantly, and occasionally was low enough to expose the limestones of the Burren at the Earth's surface. When this happened, the limestones were weathered and dissolved by rainwater, forming ancient karst landscapes (Fig. 4). Sometimes these exposed limestones were covered by soil. These ancient soil layers are visible today as thin bands of mudstone ("clay wayboards"; < 1 m thick) that occur at several horizons in the limestone sequence (Fig. 4). The mudstones contain particles of volcanic ash that were probably transported by wind from volcanoes in Co. Limerick that were actively erupting at the time.

Figure 4. An undulating ancient karst surface (white arrow) covered by a thin layer of mudstone, i.e. an ancient soil layer (black arrow).

The limestones also contain occasional thin (50-200 mm thick) bands of dark grey to black chert (Fig. 5, overleaf). Chert is a hard rock composed of silica (which makes up most sand) and so it often stands proud of the limestones by a few centimetres. Unlike the clay wayboards, the bands of chert were not deposited along with the limestones. In fact, the chert formed much later, from the remains of the silica-rich shells of microscopic algae that lived in the tropical sea and were deposited in the lime sediments. The pressure of the overlying layers of sediment caused the silica in the shells of these algae to dissolve and to form a gel that flowed through the limestone along bedding planes, where it eventually precipitated out as hard, silica-rich layers of chert.

Figure 5. Thin dark-coloured chert bands in limestone; each is ~ 5 cm thick.

The sea deepens and all is quiet

Over time, the shallow tropical sea in which the limestones were forming began to deepen as the sea floor slowly subsided (lowered due to stretching of the Earth's crust). Eventually, despite ongoing fluctuations in sea level due to the glaciation, the limestones that were forming ceased being exposed at the Earth's surface; as the sea deepened, the limestones were no longer affected by waves, except during storms (which can agitate sediments in deeper waters). Suddenly, ~ 326 Ma, there was a major rise in sea level as the basin deepened very rapidly, and formation of limestone ceased abruptly. For several million years, almost no sediment was deposited on top of the limestones in this deep sea, except for the teeth and bones of fish (and other marine vertebrates) that settled out of the water column above. These hard tissues are rich in phosphate, and because of the very low inputs of other types of sediment, the phosphate from these tissue remains was concentrated into a thin band of black, phosphate-rich sediment on top of the limestones. These phosphate deposits are up to 2 m thick near Doolin and were once mined as an ingredient for fertiliser. Later on, small amounts of very fine clay particles began to settle to the sea floor, forming black shales. The clay particles probably came from very fine river sediments carried far away from the coast by currents, and were the only sediment deposited in the region for about five million years. At this time, the deep sea floor was extremely inhospitable to life: there was no light, very low oxygen levels, abundant dissolved sulphides, and no organic matter in the sediment. The only fossils found in the shales are therefore the remains of animals that lived higher up in the water column, close to the water surface, e.g. cephalopods. Pyrite (fool's gold) also occurs in the shales, and often replaces the shells of the cephalopod fossils (Fig. 6)

Figure 6. Pyritised goniatite fossils in black shales. Specimen top left is ~ 2.5 cm wide.

A delta approaches

About 318 Ma this quiet, deep-water environment was overwhelmed by the influx of extremely large volumes of silt and fine sand. These coarse-grained sediments built up a slope in front of a massive, complex delta system that was prograding from a land mass to the west. The sediments on this slope were deposited so quickly that they became gravitationally unstable, and slid and slumped down the slope before they were fully lithified. The results of this can be seen in the spectacular slump folds in the rocks on the south side of Fisherstreet Bay (Fig. 7, overleaf).

Figure 7. Slumped, folded sandstones and siltstones of the Fisherstreet Slide. Cliff is ~ 10 m high.

In the delta

As the delta approached, sediment was being deposited faster than the basin was deepening, and so the environment became progressively shallower. As a result, the slope sediments are overlain by sandstones and siltstones that were deposited on the delta itself, both on the shallow-water delta shelf and at the delta front (where the shelf slopes down to the basin floor). The rate of deposition was extremely fast: hundreds of metres of sediment were laid down in less than 2 million years – compare this to the black shales, where it took ~ 8 million years to deposit only 12 metres! The deltaic sediments are exposed spectacularly at the Cliffs of Moher, where repeating cycles of sandstone, siltstone and mudstone are visible. These cycles reflect changes in sea level that were caused by the same glaciation that affected deposition of the limestones. Each time sea level rose, the delta shelf was flooded by the sea, and marine mudstones were deposited on top of the deltaic sands and silts. After the rise in sea level, however, the delta would have continued carrying sand and silt out into the ocean, resulting in sandy sediments being deposited on top of the mudstones. The siltstones and sandstones were laid down during flood events; in between the flood events, the sea floor was relatively calm, allowing current ripples to form on the sediment surface, and organisms to make trails in the sediment (Fig. 8, overleaf). The siltstones and fine-grained sandstones of Liscannor show extremely abundant trails (trace fossils) made by an extinct arthropod (a woodlouse-like animal) and / or a gastropod (snail).

Figure 8. Ripples (left) and horizontal trace fossils (right) in siltstones at the Cliffs of Moher.

There are no rocks younger than these deltaic sediments in the Burren region. However, it is thought that an additional 2.5 km of sediments were deposited on top of the deltaic sediments, but were later eroded away (see below).

Burial, gentle squashing and uplift

After deposition, the rock sequence of the Burren region was gradually buried up to depths of ~ 2.5 km below the surface. About 300 Ma, there was a mountain-building episode in southern Europe that caused compressive (squashing) stresses to travel through the Earth's crust. By the time these stresses reached the Burren region, they did not have enough energy to bend the rocks into tight folds, but only to tilt them slightly and fold them gently. The rocks are usually tilted at between 2 and 5° to the south, and gentle folds can be seen at Slieve Roe and Mulloughmore (Fig. 9, overleaf).

The tectonic forces that caused this tilting and folding also resulted in the formation of many joints, or fractures, in the limestone. These fractures were initially microscopic but were widened by hot mineral-rich fluids that forced their way through the rocks during burial. Evidence of these fluids is seen today in the mineral-bearing veins that run roughly N-S through the entire limestone sequence. In most cases, the minerals have been weathered away and the spaces widened by dissolution of the limestone to form N-S fissures. Some of the veins, however, still contain minerals such as calcite, fluorite, galena and pyrite.

Figure 9. Folded limestones at Mulloughmore.

Figure 10. Veins in the limestones of the Burren. Left: A cluster of calcite veins (yellow-white). Top right: Close-up of a calcite vein. Lower right: A calcite vein (dark line running from centre left to centre right) weathering away to leave a thin fissure (centre to centre).

The rock sequence is thought to have been uplifted in several phases over approximately 250 million years. Each phase of uplift would have eroded rocks exposed at the surface, relieving the pressure on the rocks underneath. This “depressurisation” would have allowed the underlying rocks to relax and expand, forming microscopic fractures in the rocks. Such fractures are extremely abundant in the limestones of the Burren region and are visible today as fissures; unlike the fissures formed by the N-S veins, however, these younger fissures have no regular orientation. In fact, these younger fissures often run in different directions in successive limestone beds. This reflects slight differences in the way different limestone layers relaxed according to their precise composition.

Exposure at the surface

The Burren region has probably been above sea level for the past 50-60 million years, and so more sediments did not accumulate. Instead, the exposed rocks experienced prolonged weathering and erosion at the Earth’s surface. These processes removed the siltstones and sandstones from over much of the region, and eventually the underlying shales. The shales in particular are easily weathered to friable (crumbly) masses of rock fragments and would easily have been eroded, thus exposing the limestone at the surface. The limestones of the Gort Lowlands were exposed about 20-30 Ma, and their surface has been lowered to only a few tens of metres above sea level by slow but continuous dissolution of the limestone. It is thought that shales still covered the Burren until the start of the most recent ice age (the Pleistocene glaciation). The ice sheets would easily have eroded most of the weathered shale, exposing limestone at the surface in places. The Pleistocene ice age ended in Ireland ~ 13,000 years ago, at which point parts of the Burren may have had a soil cover of some description. Evidence from pollen suggests that much of this soil cover was removed during the Bronze age ~ 1600 BC.

Faults (surfaces in which the rocks on either side have moved past each other) are extremely rare in the Burren region.

PART 2: Common features of the rocks and landscape

The Burren region is relatively unusual as many of its landscape features have been formed not by erosion or deposition, but by *dissolution* of the underlying limestones. Such regions are termed “karst”, after the Kras region in Slovenia where this type of dissolution-dominated landscape was first described. Today, many people think of the Burren as a typical karst landscape when, in fact, it is not typical at all! The karst features of the Burren have been developing for only a few thousand to a few million years. In geological terms, these are very young features and so the landscape of the Burren is an “immature” karst. A good example of a “mature” karst landscape is the Gort-Kinvarra lowlands, in which karst features have been developing for much longer, i.e. several tens of millions of years.

The Burren is most correctly termed a “glaciokarst” region. This is an area where the development of karst features (karstification) has been influenced by the effects of glaciation. The most common glaciokarst features visible in the Burren region include limestone pavements, grikes and clints, kamenitzas, karren, dolines, erratics, drumlins, dry valleys, turloughs, swallow holes, and springs. Each of these features is described briefly below.

Limestone pavements

Figure 11. Limestone pavement with clints (blocks of limestone) separated by grikes (fissures).

Limestone pavements are the “classic” glaciokarst landform. They are horizontal or gently sloping surfaces of bare limestone that are dissected by surface features such as grikes and karren (see below). Limestone pavements are formed by the erosion of overlying soil, weathered rock, and weak bedrock by the action of ice sheets or glaciers, thereby exposing fresh surfaces of limestone. Approximately 20% of the Burren is limestone pavement, with an additional 30% consisting of a combination of pavement and rendzina (an organic-rich, calcareous soil). Limestone pavements occur only in areas that have been glaciated recently. In the Burren, the most pristine pavements occur near the boundary between the limestones and overlying shales.

Grikes and clints

Grikes are vertical or near-vertical fissures in limestone pavement that develop by the widening of pre-existing fractures in the rock by dissolution. The blocks of limestone separated by grikes are termed clints. Grikes and clints occur throughout the limestone of the Burren region; grikes are commonly up to 800 mm wide and up to 2 m deep.

Kamenitzas

Kamenitzas (solution pans) are shallow, rounded, flat-bottomed basins on the surface of exposed limestone; they are usually a few centimetres to 30 centimetres wide. They develop by dissolution of the limestone by standing water. Kamenitzas occur throughout the limestone pavements of the Burren region and are particularly well-developed in the north of the region and along the western coastline.

Figure 12. Kamenitza on limestone pavement surface. Approx. 15 cm diameter.

Karren

Karren are small-scale, mm- to m-sized features formed on the limestone surface. They are classified according to their shape and size: the most common forms are rillenkarren (small runnels or channels about 20 mm wide), rinnenkarren (larger runnels about 200 mm wide), and trittkarren (shallow horizontal steps). Despite their apparent similarity to channels formed by erosion, karren are formed by the dissolution of limestone by water flowing off the pavement surface.

Figure 13. Rinnenkarren.

Figure 14. Trittkarren.

Dolines

Dolines are bowl-shaped depressions in the land surface that can be several metres to several hundreds of metres wide (see Fig. 15, overleaf). They can form via dissolution of rock from the surface downwards, by the collapse of overlying rock into a cave, or by a combination of these processes. Complex or compound dolines used to be described using the term uvala, but this term has now largely fallen out of use. There are at least 1500 dolines in the Burren with an area greater than 100 m^2. Most of these large dolines occur in the east of the area; this reflects the fact that they are a feature of a more mature karst landscape. The Carran Depression is ~ 9 km^2 in area and is the best example of a doline in Ireland. It began to form several tens of millions of years ago, as a river flowing over the surface of the shales eventually eroded through to the limestone underneath and disappeared underground.

Figure 15. Doline on Knockaunsmountain.

Erratics

Erratics are pieces of rock that have been transported from their original location by moving ice. They can be up to several metres wide, as in the examples around Poulsallagh and Murroughtoohy, but many smaller, pebble- or cobble-sized erratics also occur in the Burren. Most erratics in the Burren region are of limestone, but erratics of more “exotic” lithologies, e.g. granite and schist (each transported from Co. Galway) are common, particularly on the north coast of the region. Erratics occur at up to 200 m above sea level in the Burren region, indicating that the ice sheet that covered the area was at least a couple of hundred metres thick.

Figure 16. Limestone erratic near Poulnabrone.

Drumlins

Drumlins are long, low, rounded hills up to 1 km long and 30-50 m high. They consist of unsorted glacial drift deposited and moulded by ice. They typically have a steeply inclined side that originally faced "up-current", and a more gently inclined side that faced "down-current". Drumlins form during the latter stages of a glacial period, when ice begins to melt, and often occur in clusters or swarms, such as those that occur throughout the Gort-Kinvarra Lowlands.

Figure 17. Drumlin near Kilshanny.

Dry valleys

Dry valleys are valleys that were eroded at some time in the past by surface rivers or streams but that now lack a permanent surface water flow as the stream now flows underground. The origins of many of the dry valleys and gorges in the Burren region are enigmatic. Some may have formed during glacial advances, when underground drainage channels were blocked by ice and surface water was forced to flow overground. Other dry valleys formed simply because dissolution of limestone at the surface formed fissures large enough to capture surface streams, e.g. the Coolagh River dry valley (Fig. 18, overleaf). Yet other dry valleys may represent collapsed cave passages. A combination of two, or all three, processes could have occurred in some cases! The Ballyvaughan and Turlough valleys are among the oldest landscape features preserved in the Burren. They probably reflect the original position of ancient rivers that flowed over the land surface when it was still covered by shales, several tens of millions of years ago. These valleys, and many other dry valleys in the Burren, are now floored by thick deposits of glacial till.

Figure 18. Coolagh River dry valley.

Turloughs

Turloughs are seasonal lakes where both the inlet and outlet are underground. In true turloughs, fluctuations in water level reflect variations in the level of the water table due to changes in rainfall. In some turloughs, water level changes occur because the lake is connected by underground passageways to the sea, and therefore is affected by the tide. Other lakes with a varying water level can appear similar to turloughs, but in this case, the changes in water level reflect a buildup of water in the lake following high rainfall as the outlet is too small, or too blocked, to allow the water to escape fast enough. Turloughs are common in Ireland but many have been drained artificially to reduce flooding. Examples in the Burren region include Lough Aleenaun and Knockaunroe.

Swallow holes and springs

Swallow holes and springs are the points at which surface streams or rivers pass underground, and re-emerge at the surface, respectively. In the Burren, swallow holes are common along the limestone-shale contact, where surface streams passing over the relatively impermeable shales sink upon reaching the more permeable limestones. Springs occur throughout the Burren region and also within a few tens of metres offshore. Most springs here have a flow rate of less than 20 litres per second but some flow at more than 500 litres per second, e.g. at springs of the Fergus River. There are numerous smaller springs that rise at the land surface where a bedding plane in the limestone is underlain by an impermeable layer such as clay or chert. There are nine major underground drainage systems in the Burren region, the largest being that of the Fergus River and Kinvara-Corranroo.

Figure 19. The Coolagh River swallow hole.

Caves

Caves typically develop where water flow through a rock mass is prevented by an impermeable (water-tight) layer. In the Burren region, most cave passages that have been explored have formed on a layer of impermeable chert or clay, and follow this bed downslope for considerable distances. Many of the cave passages also show evidence for the stream exploiting joints in the limestone, e.g. sharp bends and vertical drops. Most of the caves in the Burren developed above the water table and are termed “vadose” caves. Phreatic cave passages, which form below the water table, are relatively rare in the Burren; the best example is the Aillwee cave, which is at least 350,000 years old. An extensive phreatic cave system underlies the Gort-Kinvarra Lowlands, but many parts of it are extensively flooded, blocked by glacial deposits or collapsed.

Figure 20. Entrance passageway at Aillwee Cave. The rounded roof profile represents the original geometry of phreatic tube.