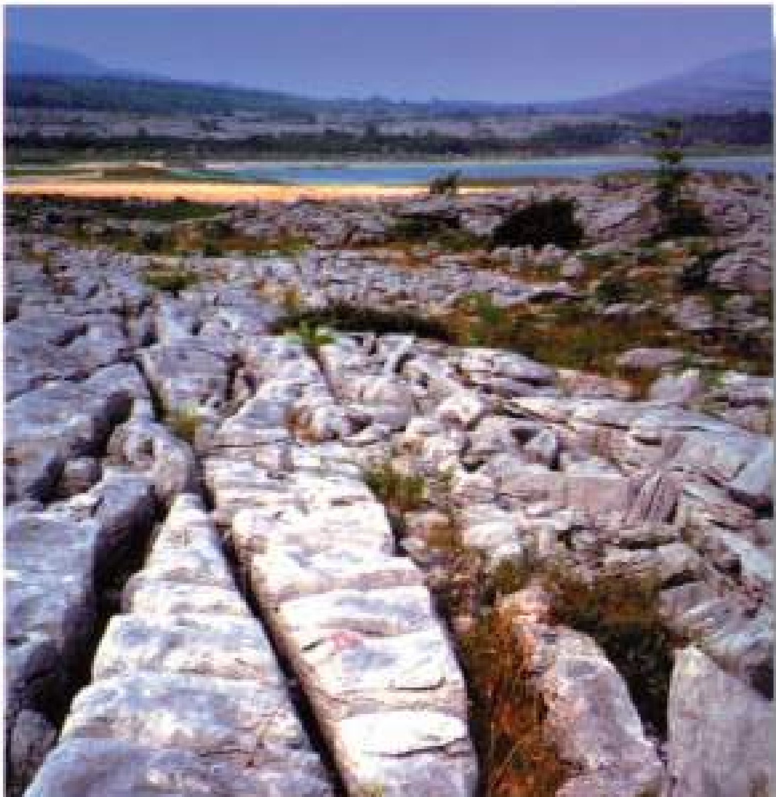
The Karst of Ireland



Limestone Landscapes, Caves and Groundwater Drainage Systems

This publication was prepared by the Karst Working Group, which includes representatives of:

- Geological Survey of Ireland
- Geotechnical Society of Ireland
- International Association of Hydrogeologists (Irish Group)
- Irish Association for Economic Geology

It was compiled and edited by Donal Daly, David Drew, Jenny Deakin, David Ball, Matthew Parkes and Geoff Wright.

Geological Survey of Ireland
The Geological Survey of Ireland (GSI) is the national geosciences agency for the Republic of Ireland whose role is to acquire, interpret and disseminate geological information. The Groundwater Section in GSI holds databases on karst features and publications, and shows karst features on hydrogeological maps produced for groundwater protection schemes.

Geotechnical Society of Ireland
The Geotechnical Society of Ireland, which was founded in December 1977, is a constituent society of the Institution of Engineers of Ireland (IEI). The aim of the Society is to promote co-operation amongst Engineers and Scientists for the advancement of knowledge in Geotechnics and allied fields such as Engineering Geology and Hydrogeology. Membership is currently about 100.

International Association of Hydrogeologists (IAH)
IAH was formally constituted at the 1956 Mexico City International Geological Congress, to promote co-operation and advance the science of hydrogeology world-wide. Many countries have national groups. IAH publishes a quarterly *Hydrogeology Journal*, a Newsletter, books and maps. The Irish Group was formed in January 1976, and has grown from an initial membership of ten to more than 80. It organises regular seminars, field trips and lectures, and encourages the participation of non-members in its activities. Our annual two day seminar, first held at Portlaoise in 1981, has become an important event for all those interested in hydrogeology and groundwater issues in Ireland.

Irish Association for Economic Geology (IAEG)
The Irish Association for Economic Geology (IAEG) was founded in 1973 to advance the science and practice of Economic Geology in Ireland, to provide relevant information on the industry to its members, to assist in education and training and to organise field excursions and regular meetings. The membership, which stands at well over 300, includes many geologists working in industry, at universities and in the state sector, within Ireland and at a large number of European and world-wide locations. Regular publications include a thrice-yearly newsletter and an Annual Review. Further information can be obtained from the IAEG Web site at www.iaeg.org.

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What is Karst?

Karst is a term used world-wide to describe the distinctive landforms that develop on rock types that are readily dissolved by water. In Ireland, limestone (composed of calcium carbonate) and to a lesser extent dolomite (calcium and magnesium carbonate) are by far the most widespread rocks that show karst features. There is also a small outcrop of a younger softer rock also made of calcium carbonate – the chalk of Co. Antrim – which shows some of the features characteristic of karstic terrains. In other parts of the world, highly soluble rocks such as gypsum (calcium sulphate) and halite (common salt or sodium chloride) are abundant and they also exhibit karstic landforms.

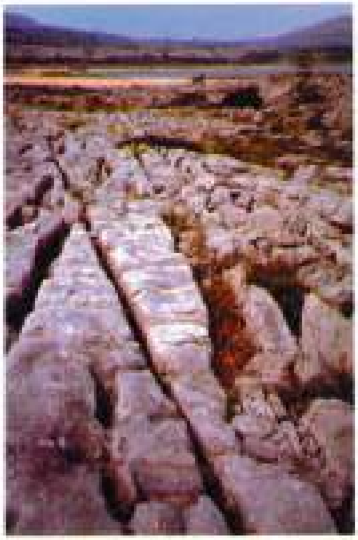
Conical karst hills in the Philippines (Ken Gardner)

> The word **karst** is derived from the Serbo-Croat word **krs** and the Slovenian word **kras** meaning stony bare ground. The Kras is a limestone region, now a part of Slovenia and Croatia, in which the distinctive karst landforms are exceptionally well developed.

Martel Stalactite, Marble Arch Caves (Robert Thompson)

Karstified limestones cover approximately one tenth of the land surface of the Earth, but some 25% of the world's population lives in these regions – for example southern China, large areas of central and southern Europe and much of central America. As the map on page 7 shows, half of the Republic of Ireland is underlain by limestones, many of which are karstified.

Typically, karst regions lack rivers and other surface waters because the rain is swallowed up by fissures and conduits in the rock and then flows as underground streams in caves. Eventually the waters return to the land surface, often as large springs. Karst areas are indicated by a general absence of permanent surface streams and the presence of **swallow holes** and enclosed depressions. The water is usually all underground in solutionally enlarged channels, some of which are big enough to be termed caves.



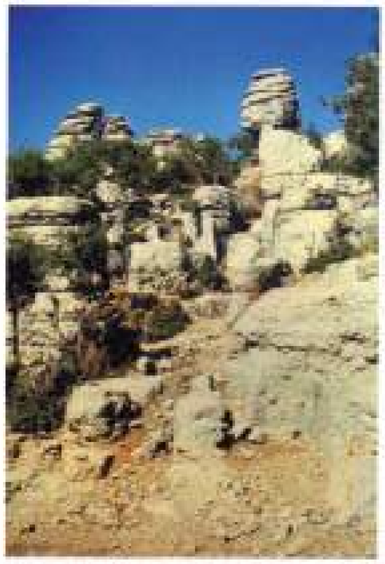
Limestone pavement in the Burren with a turlough in the backround (Donal Daly)

Karst regions have always been important to human societies. In prehistoric times they were used as refuges and are thus very important for archaeological remains – the cave paintings of Lascaux in France and of Altimira in Spain being famous examples. Karst rocks also often contain large quantities of water which are widely used for water supply.

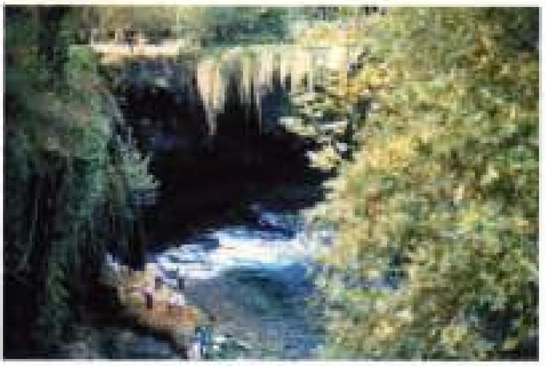
Tourism is one of the most rapidly growing industries world-wide and karst regions, in many cases with spectacular scenery and natural curiosities such as caves, attract large numbers of visitors.

Some well known karst areas and features:

- Pinnacle karst of the Guilin area, southern China
- Mammoth Caves, Kentucky, USA
- The Greek islands
- Dordogne, Vercors and Tarn areas of France
- Postojna Caves in Slovenia



Pinnacles and towers of limestone remaining when the surrounding rocks have been dissolved away, southern Turkey (David Drew)



A river emerging from a large cave near the Mediterranean coast of Turkey (David Drew)

Small solutional hollows (types of karren) pit the limestone surface on the Atlantic coast of Co. Clare (David Drew)

The Development of Karst

How karst features are formed

The development of karst (karstification) takes place best in Ireland on limestone rocks that are hard and almost impermeable to water. The rock must have cracks and fissures into which rain water can seep, and there must be a plentiful supply of rain.

Rain water is slightly acidic and this acid (carbonic acid) readily dissolves the rock, carrying it away as an invisible solution. Rain water which first passes through soil before reaching the limestone becomes much more acidic and is capable of dissolving a greater quantity of rock.

As the acidified rain water trickles down the cracks in the limestone, it progressively enlarges them which then allows a greater quantity of water to enter and hence enlarge the cracks even more. In time, the fissures are sufficiently enlarged to engulf all rainwater within moments of its falling. In some areas, rivers which rise on non-limestone rocks, flow on to the limestone and sink underground in swallow holes – again formed by the corrosive action of the river water on the soluble rock.

Underground, the waters from fissures unite to form small streams and in turn these join and excavate correspondingly large conduits. Conduits accessible to humans are called caves. At some point the underground waters return to the surface as springs, except where local geological conditions may cause the waters to emerge from the sea bed some distance off-shore, as on the Burren coast of Co. Clare. Thus caves and cave streams are the equivalent of valleys and rivers in a non-karstic area. Caves and karst fissures are common at shallow depths beneath the ground surface but they are also known to exist at great depths. The mechanism by which deep karst features are formed is not wholly understood.

In Ireland, some hundreds of caves are known, some containing rivers (Marble Arch Caves in Co. Fermanagh, for example), some long abandoned by the streams that formed them (e.g. the Mitchelstown Caves in Co. Tipperary). Unlike the mountains of the world, all of which are known, new caves are continually being discovered or new passages discovered in known caves – even in Ireland. Thus no one knows where the longest and deepest caves in the world really are.

Ireland's longest cave is Pollnagollum in the Burren, Co. Clare where over 15 km of passageways have been explored thus far. The deepest cave in Ireland is the Reyfad system near Boho, Co. Fermanagh. This cave has been explored to a depth of over 180 m below the entrance and its exploration involves descending deep vertical shafts. Recent water well drilling near Kinvara in Co. Galway discovered caves at 48 m below the present day sea level.

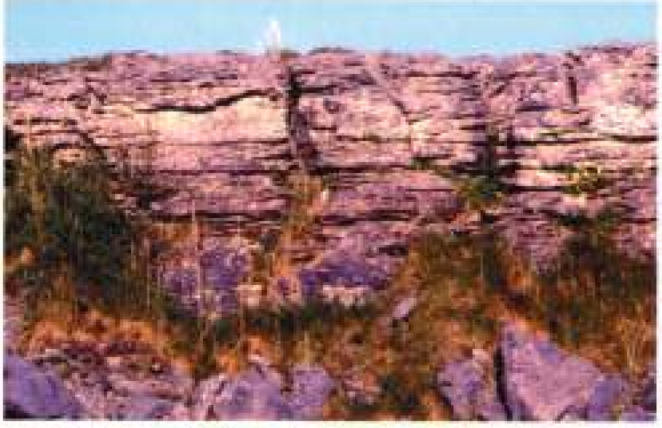
The longest explored cave in the world (by far) is the Mammoth Cave in Kentucky, with some 530 km of passages mapped. The longest cave developed in gypsum rock is Optimisticheskaja in Ukraine. The 165 km of passages in this system form a maze contained in an area of less than one square kilometre in extent. The world's deepest caves are the Lamprechstofen in Austria (-1632m) and the Gouffre Mirolda in Haut Savoie, France (-1610m). The largest underground caverns yet discovered include a chamber in Lubang Nasib Bagus in Sarawak 700 m long, 300 m wide and 120 m high, whilst the main chamber of Majlis Al Jinn cave *(now renamed)* in Oman has a volume of 4 million cubic metres.

When cave passages are abandoned or partly abandoned by the streams that formed them, drips of water entering the cave from above may deposit crystals of pure calcium carbonate (calcite) which gradually form calcite deposits, e.g **stalactites** or, as in the photograph of Dunmore Cave (page 19), **stalagmites**. The white calcite may be coloured by impurities such as iron dissolved from the rocks above the cave.

Thus a mature karst landscape is devoid of surface water. The surface may be pitted with deep hollows, conical or saucer shaped, and sometimes hundreds of metres deep and several kilometres in diameter. These **dolines** (small to medium sized enclosed depressions) act as funnels, collecting rainwater and leading it underground into cave systems.

Unless deposits of loose material blanket the limestone, e.g. glacially derived materials in the case of much of the Irish midlands, the soils which develop are typically very thin and patchy and are liable to erosion. Thick soils suitable for cultivation are confined to the hollows or dolines.

The solution of limestone rock takes place at the surface as well as underground. Many limestone surfaces are pitted with small hollows or runnels, collectively termed **karren**, which range from a few centimetres to a few metres in depth and length. The dissolution of the limestone is again due to acidified water standing in pools or running over the surface and sculpting the rock.



In the uppermost layers of limestone, solutional enlargements of joints and bedding planes is greatest. This layer is called the Epikarst (David Drew)

A desolate karst plateau in Mallorca. There is almost no level ground, doline depressions are abundant and soils are thin or non-existent (David Drew)

Ancient karst or palaeokarst in Ireland

In addition to active karst which is still functioning and developing today, there is evidence of much older karst also preserved in various parts of the country.

Relict karst is karst which formed under different conditions from those now active, but which is still exposed and being modified by present processes. Examples include remnant towers, which might once have looked like the classic towers of modern south-east Asian karst. They are difficult to recognise as they have been modified by glaciation which may have knocked off the tops and smoothed the sides. This may be the origin of some of the small hills around Lough Gill, Co. Sligo, the small hillocks in the Cork valleys and the Stradbally hills south-east of Portlaoise (e.g. the Rock of Dunamase).

Burren terraces (David Drew)

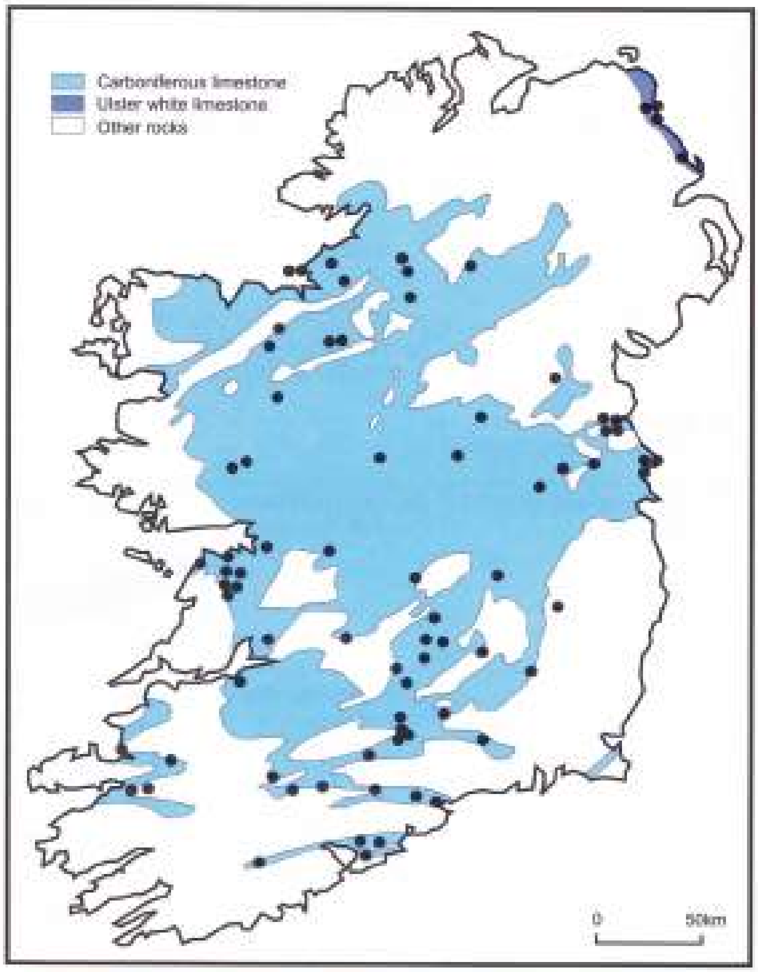
Palaeokarst is buried, inert and fossilised karst which is often difficult to find. There are buried **poljes** (enclosed depressions, 1 km or more wide) across the country, often only detectable by geophysical surveying, such as that at Dunshaughlin, Co. Meath. These are often infilled by sediments associated with the breakdown of rocks in a tropical climate; a clue to the remarkable appearance of the landscape of Ireland some 60 million years ago, when hot and humid conditions prevailed.

On a smaller scale there are buried dolines, several of which are known to contain identifiable plant remains which were deposited during the **Tertiary**. Some are connected to buried cave systems but others are isolated. These infilled palaeokarst dolines, pipes, fragments of cave passages and channels have been found across the country from Headford, Co. Mayo; to Hollymount, Co. Carlow; to a group at Tynagh, Co. Galway. Infilled karst features have also been encountered in boreholes near Tipperary and Rathdowney, and at Ballymacadam, Co. Tipperary.

A doline 10m deep in the Ulster Chalk. At Garron point, Co. Antrim the doline is infilled with a mixture of flints from the chalk, clays and volcanic ashes and lavas from the overlying basalt rock. Thus the doline was formed before the lavas (basalts) of the Antrim plateau outflowed (John Kelly)

Further south, the infilled deposits are older still, e.g. deposits of **Cretaceous** limestone at Ballydeenlea, Co. Kerry, and **Jurassic** clays at Cloyne, Co. Cork. Ancient palaeokarst is also known at Portrane, Co. Dublin, where a 15 m wide, 10 m deep, sediment-filled doline in very ancient (**Ordovician**; 440 million years ago) limestones has been recognised. In the Lower **Carboniferous** (the same age as the limestones), palaeokarst formed at Feltrim, Co. Dublin and Ballykane, Co. Kildare, when sea levels fell.

However, best known to Irish geologists are the 'clay wayboards' recorded all over the country, but classically from the Burren, Co. Clare and the Aran Islands, Co. Galway. These thin clay layers, usually rich in volcanic ash, represent periods when the seafloor was elevated above sea level for relatively short times, allowing karstification of the surface and the accumulation of a thin soil. They give rise to the distinctive terraced hillsides of the Burren: an excellent example occurs at Aillwee, where the show cave was initiated along and above a wayboard.



Location of presumed ancient karst features, caves isolated limestone hills and enclosed depressions (usually sediment filled), in Ireland (David Drew and Gareth Ll. Jones)

Du Noyer water-colour of Ross Quarry, south of Lough Sheelin, Co. Meath.

GEOLOGICAL TIME	**CONDITIONS**		
Period *(age)*	**Physical**	**Biological**	**Geological**
Quaternary *1.6 million years ago (mya)*	Ice age: mostly cold and dry with permafrost and tundra vegetation and at least two cold wet periods in which ice covered Ireland	People arrived in Ireland towards the end of the period	Peat bogs forming Ice erosion and deposition ***Solution/karstification infilling of existing cavities with glacial deposits***
Tertiary *65 mya*	Deep erosion and removal of older rocks	Birds and mammals become dominant on land	Volcanic activity in north-east Ireland ***Karst development widespread***
Cretaceous *135 mya*	Incursion of 'chalk' sea		***Ulster Chalk deposited***
Jurassic *205 mya*	Ireland largely above sea level	First flowering plants Age of dinosaurs	North Atlantic Ocean begins to form
Triassic *250 mya*	Arid conditions with deposition in shallow seas		
Permian *290 mya*			Mountain building in south
Carboniferous *355 mya*	Large river deltas capped by sub-tropical forests of tree ferns Shallow sub-tropical sea over most of Ireland		***Limestones deposited*** ***Early solution?*** Ireland's main metallic minerals formed
Devonian *410 mya*	Arid, mountainous landscape	Amphibians colonise land	Faulting and folding with injection of hot magma represented by granites
Silurian *438 mya*	Closure of ancient ocean basin	First land plants	
Ordovician *510 mya*	Sediments deposited on ocean floor		
Cambrian *544 mya*	Ancient ocean forms	First organisms with hard shells	
Precambrian *4600 mya*	Oldest Irish rocks formed c. 1780 mya		Origin of the earth

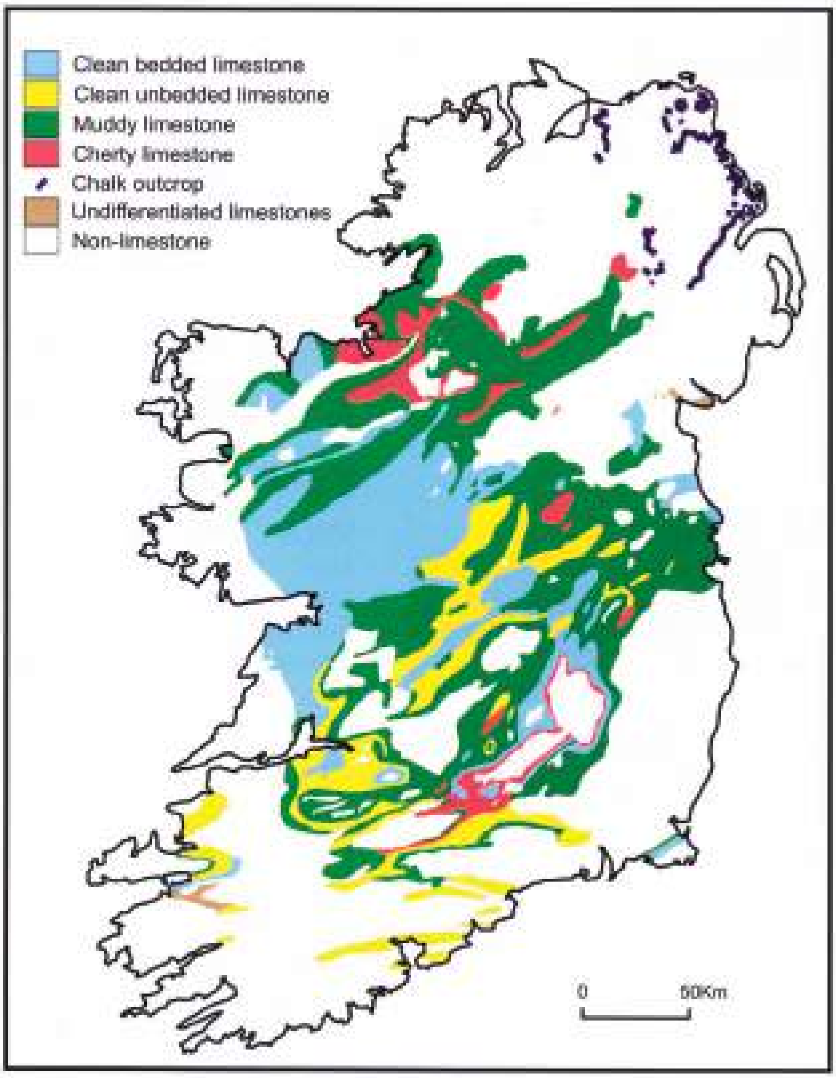
A GEOLOGICAL TIME CHART
Summarising Ireland's geological history in relation to limestones and karstification in Ireland

The Importance of Limestone and Karst in Ireland

Irish limestones

Approximately 40% of the island of Ireland, and 50% of the Republic, is underlain by limestone.

With very minor exceptions, Irish limestones belong to two periods of geological history, one known as the Carboniferous (around 300–340 million years ago) and the other known as the Cretaceous (70–120 million years ago). The Carboniferous limestones are normally hard and grey to black in colour, and are found in almost every part of Ireland (every county except Antrim and Wicklow); the Cretaceous limestone (chalk) is somewhat softer and normally white in colour, and is found only in Ulster (Counties Antrim, Armagh, Down, Derry and Tyrone).



Geological map showing extent of limestones and chalk (Morgan Burke)

Limestones are rocks, which are composed predominantly or entirely of calcite (calcium carbonate or dolomite (calcium/magnesium carbonate). Some limestones are almost pure carbonate, others contain substantial proportions of other material – most commonly sand, clay (mud or shale) and chert (very fine grained silica). The non-carbonate material may be distributed throughout the rock, may occur as small nodules (especially of chert) or may be concentrated in distinct beds (most commonly, beds of shale) inter-bedded with the limestone. The limestone may also contain small amounts of metallic minerals such as pyrite, marcasite, or galena, and in some places these may be concentrated in distinct veins or masses; where these mineral deposits are sufficiently large and concentrated to be exploited economically, they are termed orebodies, as found at Tara Mines (Navan), Galmoy (Co. Kilkenny) and Lisheen (Co. Tipperary).

Limestones can be formed in several different ways and in different geological situations, usually in the sea. They may be deposited in deep water far from land, in shallow water near the shore, or somewhere in between. Many limestones are predominantly composed of the calcareous shells or skeletons of marine organisms, but others are formed chemically by precipitation of carbonate from shallow waters. Some form in extensive horizontal layers (beds) which may be as thin as a few millimetres or as thick as several metres. Others form as massive unbedded banks or mounds of fine-grained calcareous debris (mud mounds), which can be many metres thick in the centre, thinning out towards the edges.

Dolomitic limestones (or dolomites) are rocks which have undergone chemical changes resulting in the replacement of some of the calcium by magnesium. Magnesium carbonate (the mineral dolomite) has a different crystal structure to calcium carbonate and this creates additional void space in the rock which can enhance the development of permeability and, in some cases, karstification.

The nature of the limestone strongly influences its susceptibility to karstification. Purer limestones are more susceptible than impure limestones. Another strong influence is the geological structure: folding of the limestone causes fracturing and the formation of a network of fissures along which water can penetrate and begin to dissolve the rock. In general, pure limestones tend to be brittle, allowing extensive open fractures, while impure limestones tend to deform more readily, sealing up the fractures and impeding water movement. The degree of karstification is significantly reduced where there are inter-bedded shale layers which restrict water movement and where very strong deformation causes re-sealing of fractures with crystalline calcite.

Public supply well in a karst area at Turlough, Co. Clare (Donal Daly)

Why are karst limestones important?

Karst limestones are important sources of water

Most of the largest springs in Ireland emerge from karst. Karst springs, both large and small, are ready sources of drinking water in areas where there are often no other alternatives due to the absence of adequate surface water courses. Numerous springs are venerated as holy wells, testifying to their significance for many hundreds of years.

In recent years, many new water sources have been constructed by drilling deep boreholes for both public and industrial water supplies. Some examples include the public supply wells at Cloyne and Mitchelstown in Co. Cork; the wells supplying Dungarvan and Ardmore in Co. Waterford; and those in Athenry and Kinvara in Co. Galway.

Karst limestone is often encountered in civil engineering projects

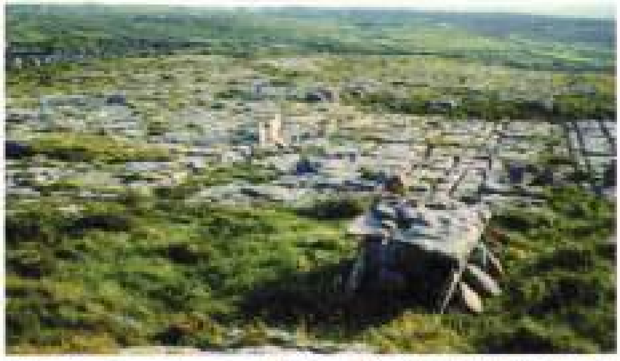
Due to its particular characteristics, including an irregular bedrock surface, the presence of large voids and rapid underground drainage, karst limestone presents special problems for engineering projects such as roads, bridges, tunnels, sewerage pipelines and mining. Careful preparatory investigations are therefore required with special design measures and provision for unforeseen problems.

Karst regions are very important for heritage/tourism

The distinctive scenery of karst regions, especially the upland karsts, is a major attraction for tourists in all parts of the world. Much of the attraction of the Mediterranean tourist regions, for instance, depends on the contrasts between the white limestone cliffs and mountain slopes, and the deep blue sea. In Ireland, the upland karst regions such as the Burren, the Aran Islands, Ben Bulben, and the Cuilcagh mountains, have particularly attractive scenery. Elsewhere, lowland karst areas also have a distinctive and beautiful landscape, including for example such dramatic features as the Rock of Cashel, the shore of Lough Leane, Killarney or the turloughs in the Gort-Kinvara area.

The caves that are open to the public, such as Aillwee Cave (Clare), Crag Cave (Kerry), Marble Arch (Fermanagh), Dunmore Cave (Kilkenny) and Mitchelstown Cave (Tipperary), attract many to the magical underground scenery.

Many people take an active interest in exploring cave systems (caving or potholing). **Speleology** (the study of caves) is an important leisure pursuit, often combined with other interests such as botany, zoology, geology and photography.



Limestone pavement and a Bronze Age wedge shaped tomb at Eanty Mor in the central Burren (David Drew)

Karst regions contain sites of archaeological importance

Caves have always been used for shelter by animals and many cave systems house a distinctive and specially-adapted fauna. Humans have used caves for habitation from the earliest times and many important archaeological collections have been discovered in caves. Excavations in cave sediments have provided vital evidence of Ireland's pre-history.

In many areas, prominent hills of karst limestone have been used as sites for some of Ireland's best-known castles, such as Dun Aengus on Inishmore, Dunamase Castle near Portlaoise, and for churches such as the Rock of Cashel for example.

Kesh caves – ancient caves abandoned by the water that formed them. They are now rich archaeological sites (Donal Daly)

Karst environments have a distinctive ecology

Karst areas often possess a distinctive ecology such as in the turloughs of Co. Galway and other limestone wetlands, and the distinctive flora of the Burren. These unique ecological environments are under threat from modern developments such as drainage, tourism, leisure activities, farming, industrial and urban development.

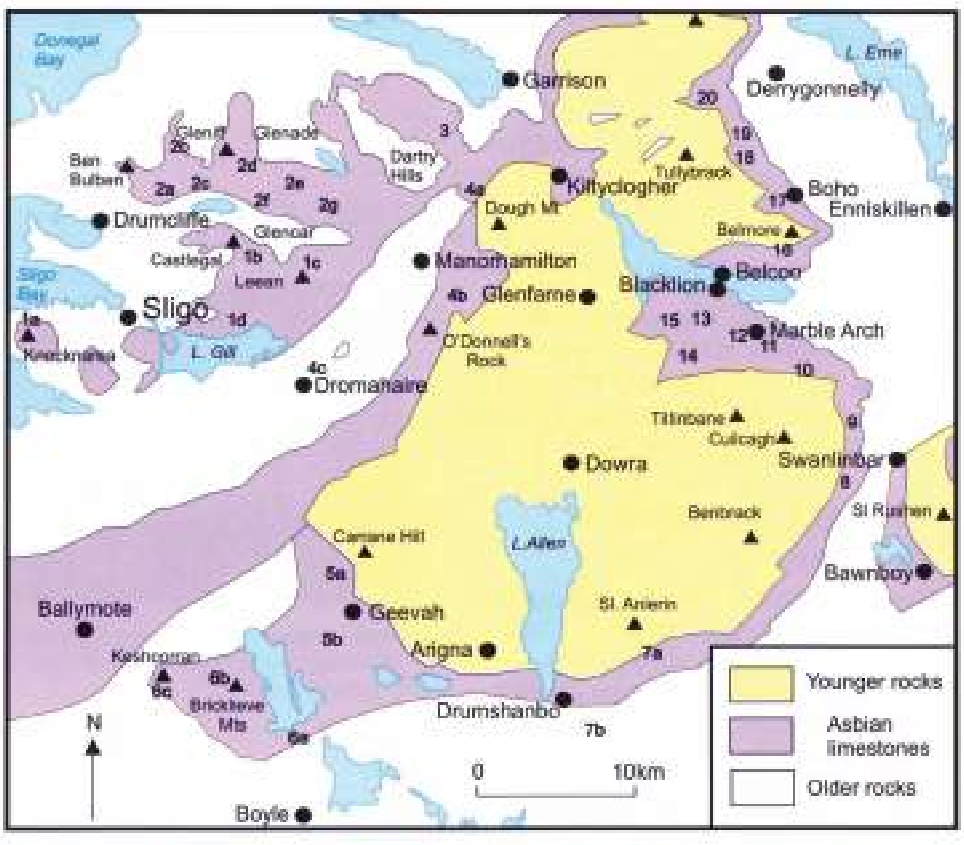
The Main Karst Regions of Ireland

This section takes each of the six karst regions in Ireland and outlines the main characteristics and types of karst features found there.

The north-western plateau karsts

Upland karsts and associated cave systems are well developed in Counties Sligo, Leitrim, Cavan and Fermanagh. The area is largely a dissected plateau with caps of shale and sandstone on some of the mountains including Truskmore summit, Dartry Hills, Dough Mountain, Tullybrack, Belmore Mountain, Cuilcagh, Slieve Anierin, Carrane Hill and Knocknarea. The uplands are often separated by cliff-edged, glacially-deepened valleys. Most of the karst and caves are developed around the edges of these mountains and on the sides of the associated valleys. A good example is Reyfad Pot on the north-east side of Tullybrack. Streams originating on the impervious shales and sandstones sink into swallow holes when they reach the limestone and fall into impressive vertical **potholes**. They then pass through the caves of the deepest pothole in Ireland, before re-emerging at Carrickbeg spring at the foot of the mountain.

Mountains which have lost their capping of impermeable rocks include much of the Truskmore upland, the Castlegal-Leean Mountains, O'Donnell's Rock, Keshcorran and the Bricklieve Mountains. In the absence of a shale cap to concentrate the drainage, the karst has developed a different character: there are no swallow holes and only rare access to cave systems. Rainwater sinks underground, either through a diffuse system of enlarged joints such as on Leean Mountain, or by being drawn into fossil potholes formed on major joints and faults such as in the Largy Rifts at the east end of the Truskmore. Here the surface is characterised by enclosed depressions, dry valleys and **limestone pavements**.

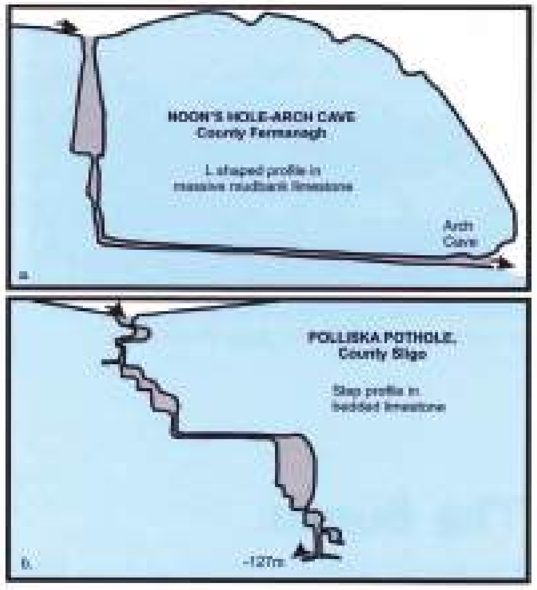


Karst of the Northwest region: 1a, Knocknarea; 1b, Castlegal; 1c, Leean; 1d, Lough Gill; 2, Truskmore Massif; 2a, King's Mountain; 2b, Gleniff; 2c, Barytes Mine; 2d, Truskmore summit; 2e, Largy; 2f, Teampol Sheitric; 2g, Barracashlaun; 2h, Outliers; 3, Dartry Hills; 4a, Saddle Hill-Dough Mountain; 4b, O'Donnell's Rock; 4c, Dromahaire; 5a, Geevah; 5b, Kilmactranny-Corran Hill; 6a, Lecarrow; 6b, Bricklieve Mountains; 6c, Keshcorran; 7a, Slieve Anierin; 7b, Skeemore Hill; 8, Aghaboy; 9, East Cuilcagh; 10, Tullyhona; 11, Prod's Pot-Cascades; 12, Marble Arch; 13, Hanging Rock-Ture; 14, Shannon Cave; 15, Pollnagossan; 16, Belmore; 17, Boho; 18, Reyfad; 19, Noon's Hole; 20, Knockmore.

The variations in limestone types affect the development of the karst landforms and cave passages. In much of the area, caves are formed in cherty, bedded limestones on major joints or faults. The initial sections of the caves are often narrow pothole rifts whose walls are characterised by brittle chert ledges. If the floors of the potholes are not choked with debris, it can be seen that vertical step profiles to the cave systems develop until a level close to that of the outlet springs are reached, as in Polliska, Co. Sligo (see Figure below). The collapse of one of these ledges, which was being used as a handhold by Ida Tighe of Sligo in Teampal Shetric, Sligo, caused her to fall 27 m down a pothole to her death in 1935, the first recorded sporting caving fatality in Ireland.

In some areas, and especially in Fermanagh, the pure Dartry limestone has allowed the development of caves such as the Marble Arch and Reyfad Systems. If the entrance leads to a pothole, this frequently descends in a single or complex shaft to the lowest level, producing an L-shaped profile to the cave system such as is seen in the Noons-Arch System. The passages reach impressive sizes in this stronger, more competent rock. High on the mountains at Gleniff, Diarmaid and Grainne's cave is located in this same limestone type.

At Boho in Co. Fermanagh, the limestones host an unusual joint-controlled maze cave and at Knockmore (Fermanagh), Pollraftara cave is formed along a major inclined fault which can be seen through much of its 3.1 km length.



Influence of limestone type on cave profiles (Gareth Ll. Jones)

The cliff at Ben Bulben marks the edge of the plateau karst (Dan Tietzsch-Tyler)

Looking out from the vast entrance to Diarmaid and Grainne's cave, Gleniff, Co. Sligo (Pam Fogg)

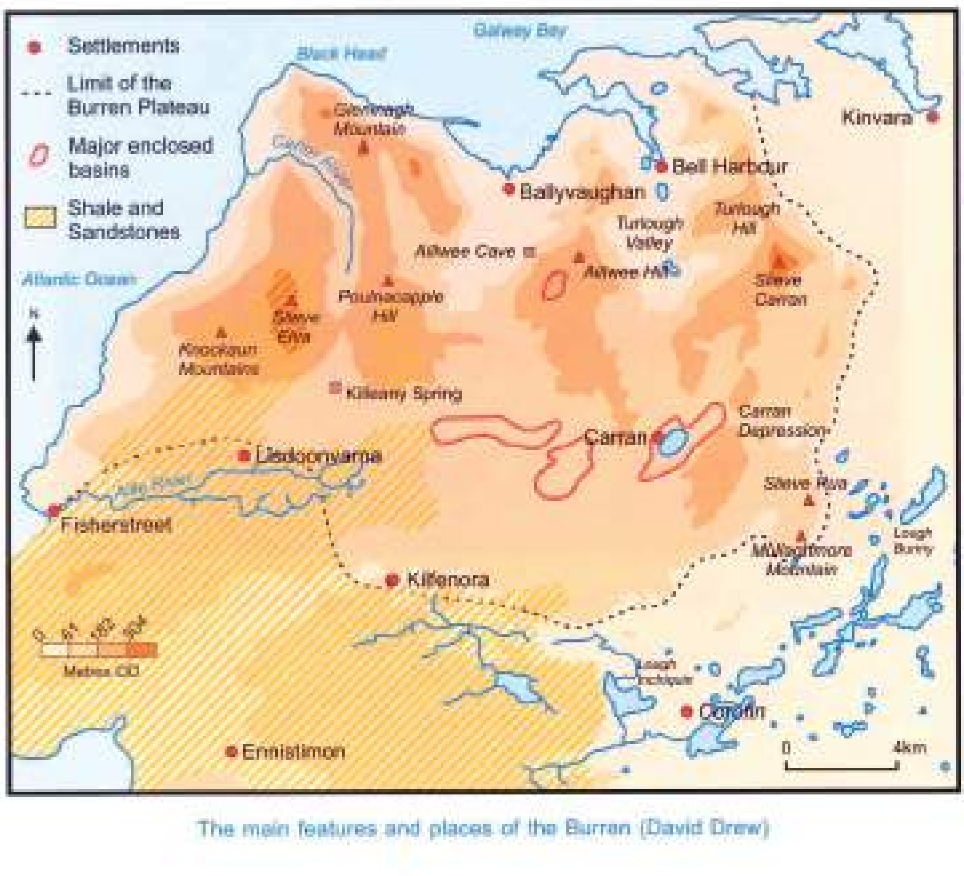
Many of the older larger cave systems were initiated before and during the glacial period. This is evident where glacial debris has been deposited within the cave system. A significant feature of the area is the glacial modification of karstic landforms, seen most dramatically in the glacial truncation of the old system of Diarmaid and Grainne's Cave in Gleniff. The topography has changed so much in this valley, that it is difficult to envisage the nature of the original cave system. The enlargement of the impressive frost-shattered entrance to the cave, suspended high in the cliffs, was caused by the cold climate at the end of the Ice Age.

The Burren

The Burren plateau of north-west Co. Clare is the finest example of a karstic terrain in Ireland, with a full assemblage of the curious landforms and subterranean drainage systems that characterise such limestone terrains. The Burren is famous internationally, not just because of its beautiful limestone landscapes but also because of the remarkable flora of the region and its rich archaeological heritage. The term 'Burren' is derived from the Gaelic for 'stony place'.

The Burren is bounded to the west and north by the Atlantic Ocean and the southern shores of Galway Bay, respectively. The southern boundary, an east to west line from Corofin, to Kilfenora, to Lisdoonvarna, to the coast at Doolin, is where the limestone passes beneath younger rocks composed of shale and sandstone. To the east of the plateau lie the Gort-Kinvara lowlands, described later in this booklet.

The Burren is 360 km^2 in extent and forms a plateau gently tilted to the south, at 200–300 m above sea level in the north and 100 m in the south, bounded by steep scarps on all but the southern flank. The highest point is the shale-capped Slieve Elva at 345 m above sea level.



The main features and places of the Burren (David Drew)

To the west of the Burren, the Aran islands are an extension of the main plateau in many respects, and for long periods during the recent geological past were almost certainly linked to the Burren by dry land.

To a greater degree than in any other karst region (and perhaps any region) of Ireland, the rocks that form the skeleton of the landscape are visible: more than 60% of the area is bare rock or rocky pasture. Accordingly, differences in the character or structure of the limestone are often manifested in particular landforms or other features of the landscape. For example, the northern hills of the Burren overlooking Galway Bay rise in tiers of cliffs and terraces where horizontal lines of weakness in the rock have been exploited by erosive waters and the loosened rock subsequently scraped away by glaciers. Below these terraces, massive, unfractured limestones form smooth slopes whilst above the terraced zones the limestones have crumbled more readily and allowed a thin soil cover to develop. These are the upland pastures of the Burren, long used to graze cattle during the winter months. Thin bands of clay or other non-soluble rocks force water, seeping down through the fissured limestone, to emerge at the surface to form many small springs – the main source of water for stock on the otherwise waterless upland. In the south-eastern Burren, the rocks have been folded and fractured by earth movements and each distortion of the strata is faithfully reflected in the landscape, for example in eccentrically shaped hills such as Mullaghmore and Slieve Rua.

A large enclosed basin (doline) on the summit of Aillwee Hill near Ballyvaghan (David Drew)

Bare rock is widespread on the hills of the north flank of the Burren overlooking Galway Bay. Glacial ice moving across the Burren from the north has smoothed the seaward facing slopes (David Drew)

Springs and Wells

Springs and wells supply almost all the water used on the Burren. Killeany spring near Lisdoonvarna is used to supply water over a wide area. The tourist centre of Ballyvaghan utilises water from springs on the mountains nearby and from a bored well just outside the town. Corofin, another important tourist centre, uses water from Lough Inchiquin, which is fed largely by spring waters from the Burren plateau.

All of these supplies are vulnerable to contamination from any pollutants that are allowed to enter the underground waters of the Burren.

The landscape of the Burren, especially the central and eastern parts, seems a stony chaos to the casual observer. Only at the junction of the limestone and the impermeable shale rocks, around Slieve Elva for example, are there valleys containing streams. Where these streams cross from the shale to the limestone they disappear underground at swallow holes, the waters flowing through cave systems before emerging from springs such as those at Killeany and St Brendan's Well near Lisdoonvarna. Away from the non-limestone rocks, the landscape is pitted with fragments of gorges and with innumerable hollows or enclosed basins termed dolines. Some of these basins are a few metres in depth and width, but others, for example the enclosed depression at Carron, are several square kilometres in extent and tens of metres deep.

Another remarkable feature of the Burren is the large expanses of bare limestone called limestone pavements. The vertical fissures (joints) in the rock have been opened by acidic rain water (**grikes**), thus compartmentalising the rock surface into blocks or **clints**, each a few square metres in extent. Limestone pavements are a legacy of the ice age that ended some 15,000 years ago in this part of Ireland. The ice scraped away the surface debris of soil, stones and the topmost layer of solutionally weakened rock, to leave a massive, uneroded rock surface when the ice melted. Extensive limestone pavements are common in high Alpine limestone areas of Europe and elsewhere where ice persisted until very recently.

Human impact on the Burren

The barren appearance of the Burren may be due, in part at least, to past human actions. Evidence from soils lodged in cracks in the rocks and from ancient preserved pollen suggest that in prehistoric times the Burren may have been wooded, with more fertile and more widespread soils than now. The cutting down of the forests by early settlers may have allowed the soils to be eroded away – an occurrence known to have taken place in many of the world's karst regions.

The Burren contains the greatest number of explored caves of any karst region of Ireland, most of them narrow, twisting canyon-like passages carrying a stream and located in the west of the area close to Lisdoonvarna.

Caves

Aillwee Cave near Ballyvaghan, containing vast, dry caverns, is one of Ireland's oldest caves and must have formed when the landscape of the Burren was very different from that of the present day.

Exploring the cave of Pol an Ionain at Ballynalackan, involves a low, stony crawl in water. However, at the end of the crawl, the explorer enters a large chamber where, hanging from the roof is a huge stalactite, 6.7 m long and reputedly the longest known in the world.

Bare rock is widespread on the hills of the north flank of the Burren overlooking Galway Bay. Glacial ice moving across the Burren from the north has smoothed the seaward facing slopes (David Drew)

Although other karst areas in Ireland have impressive archaeological remains, the passage graves on the Bricklieve Mountains for example, the evidence for human occupancy of the Burren for the past six millennia or more is striking. Stone has of necessity been the building material and hence structures have been preserved long after they were built.

In addition to the famous wedge-tombs and ring forts, the surface of the plateau is covered by networks of field walls, hut circles and other more obscure features all of which testify to the attraction humans have had to what seems a bare and inhospitable region, largely devoid of soil and water.

The western lowlands

The area extending from the River Fergus (Co. Clare) in the south, north into south Mayo, east to the River Suck and west to the large Loughs of Corrib and Mask is mainly less than 70 m above sea level, with few hills to interrupt the typical extensive plains. Unlike those parts of the central lowland further east, this area does not have a thick covering of glacial deposits and the limestone bedrock is often exposed at the surface. Many karst features are therefore apparent, although most of them are not obvious to the casual visitor.

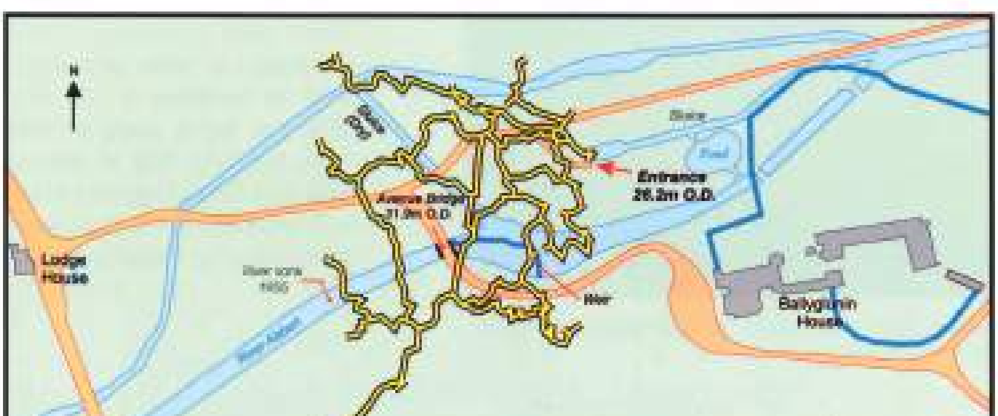
A large cavern (Pollaloughabo) on the lowlands between Gort and Kinvara. A deep pool in the cave has been explored by cave divers who have mapped an enormous water-filled passage extending for more than 1 km both upstream and downstream (David Drew)

Underground Drainage

There are several major rivers draining the area (the Rivers Clare, Robe, Abbert and Dunkellin, for example) but for most of their courses these rivers flow in artificial channels constructed in the nineteenth century to help drain the land. Before that, nearly all drainage was subterranean. In the south of the area, and especially between Gort and Kinvara, drainage was never undertaken, and here the rivers disappear underground, emerge at the surface from springs, and sink underground once more in a very complex pattern. Most of the cave passages are completely water filled and explorable only by cave divers. It is known that a vast flooded cave passage up to 25 m in diameter carries the drainage from much of this area to large springs near Dun Guaire castle on the shores of Galway Bay at Kinvara. Inland from Kinvara, many collapsed hollows give access to short sections of this underground river.

In south Mayo, 10 km east south-east of Westport, the large Aille River descends from the Partry Mountains and vanishes underground at a spectacular sink. Speleologists have mapped an extensive network of passages, often containing deep water, between the sink and the reappearance of the river at Bellaburke, 3 km distant.

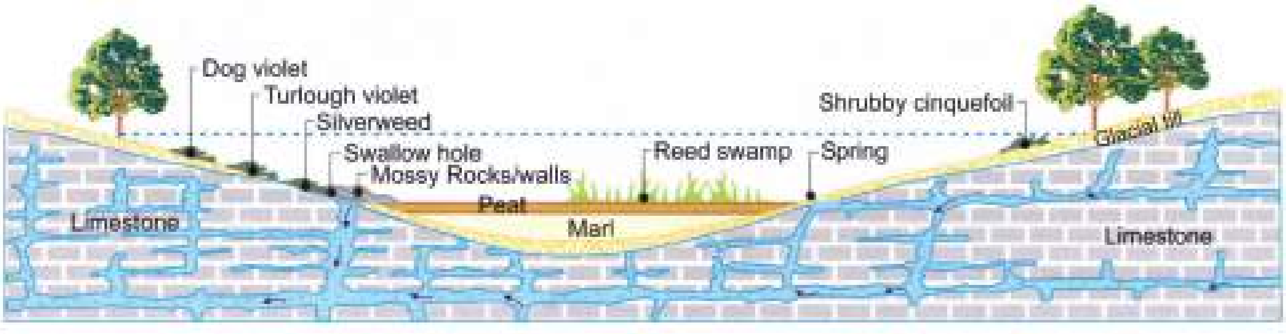
The cave of Polduagh, south of Gort, through which the Gort River flows from the Punchbowl sink (David Drew)



Map of the passages of Ballyglunin Cave in Co. Galway. The passages extend at very shallow depths beneath the River Abbert with little leakage occurring into the cave (David Drew)

Ballyglunin Cave

The River Abbert, a tributary to the River Clare, looks like a typical, sluggish lowland river. However, when the river channel was being enlarged by blasting in 1955, the river suddenly disappeared down a hole in its bed. Flow was only restored when the newly opened swallow holes were blocked. Later, an extensive cave system was discovered at a depth of only a few metres below the surface and extending beneath the bed of the Abbert River. River water leaks into the cave at only a few points; the bed of the channel presumably being clogged with glacial clays.



Cross section through a turlough showing the links between underground conduits and the turlough, and also the distinctive turlough vegetation. In the summer months the turlough is dry but in winter months water may fill the turlough to the height of the dashed blue line (adapted from Catherine Coxon)

Turloughs

Seasonal lakes, called turloughs, are a partly karstic feature. More than 100 of them have been recorded, of which the great majority are in the western lowlands. Turloughs fill and empty, often unpredictably from openings on their margins. Commonly an opening can function both as a swallow hole and as a spring (**estavelle**), depending on the season. Turloughs have a very distinctive ecology (see diagram) due to the periodic flooding with lime-rich waters. Many turloughs have been drained in order to lessen flooding, including the largest in Ireland, the 250 ha Rahasane Turlough near Kilcolgan, Co. Galway. Only in south Co. Galway and around Ballinrobe in Mayo are there significant numbers of 'natural' turloughs.

Caherglassaun Lake, 5 km inland from the coast at Kinvara (David Drew)

Caherglassaun Lake

Caherglassaun is a small turlough, located 5 km from the sea, between Gort and Kinvara. Unlike other turloughs it never properly dries out and in summer it fills and almost empties twice daily in response to high and low tide at the coast. The rise and fall is lagged between 3 and 4 hours behind the high and low tides at Kinvara on Galway Bay.

The Lough Mask-Lough Corrib isthmus

One of the most remarkable karst landscapes in Ireland is found on the narrow neck of land which separates Lough Mask from Lough Corrib. The waters from Lough Mask sink underground at numerous points on the southern shore and flow at shallow depth via many fissures and caves to emerge from the various springs in Cong village, some 5 km to the south. The ground between the lakes resembles

Gruyere cheese, being riddled with large rifts, caves and chambers hollowed out by the underground waters. The greatest concentration of swallow holes is to the east of the entrance to the Cong Canal: here the rocks form a chaotic landscape of hollows and tilted blocks where collapses have taken place into the caves beneath.

The Cong Canal and underground flow routes for water between Loughs Mask and Corrib (David Drew)

The Cong Canal

A canal linking Lough Mask with Lough Corrib was excavated in the 1840's as a Famine relief project. The canal was intended to lower winter water levels in the higher lake, Lough Mask, and to provide a navigation channel linking the lakes. The second objective was not realised as the canal encountered highly fissured karstic limestones which swallow up the canal waters during the summer months, leaving it completely dry.

Cong Canal (Matthew Parkes)

The east midlands

The limestones of the east midlands, stretching from the River Shannon and its lakes to the Irish Sea, and from Monaghan to Kilkenny, would not generally be associated with karstification. These limestones are mantled by a variable thickness of glacial and recent sediments – sands and gravels, tills (boulder clays), peat and alluvium (river silts and clays). The small-scale relief is provided by eskers, drumlins, raised bogs and river flood plains, which leaves the area resembling a plain of glacial deposition rather than a karst landscape. Isolated hills that rise up to 60 m above the surrounding lowlands consist of limestones peeping through the glacial deposits. Sandstones and shales provide the higher topographic features, such as Slieve Bloom, the Devil's Bit mountains and the Castlecomer Plateau. The surface water features – rivers, streams and lakes – are typical fluvial systems. So, unlike the Burren, the Fermanagh area or the western lowlands, there is no readily appreciable influence of karstification. However, closer examination shows many typical karst features are present, at least in some areas, which gives rise to the questions: what is the evidence of karstification? what has influenced karstification? and how karstified is the area relative to other areas?

Evidence of karstification

The main evidence of karstification comes from the presence of caves in many of the isolated hills, swallow holes in areas such as Monaghan and around the Castlecomer Plateau, infilled solution pipes and cavities in wells.

The steep, rocky, isolated limestone hills in Counties Westmeath, Offaly, Laois and Kilkenny may be residual karst hillocks (called tower karst), similar to those found in many lowland karsts in, for instance, the Mediterranean, south China and many tropical areas. The presence of what are obviously fossil remnants of formerly active caves such as Poll na gCat in Westmeath, and Mount Briscoe Cave in Offaly, support this view.

In the Carrickmacross area in Co. Monaghan, sinking streams, resurging rivers, caves and collapse features are present. Among the best known features are Finn McCool's Cave and Tiragarvan Cave. Further south, in the Drogheda area, cavities in boreholes and quarries provide the evidence for ancient karst.

In Counties Offaly, north Tipperary and Laois, some wells contain cavities; swallow holes are present but are not common; and solution pipes infilled with Tertiary clays occur at Ballymacadam, Hollymount and Ballygaddy.

In Kilkenny, there are numerous karst features such as large springs (in the Nuenna valley); swallow holes (south-west of Kilkenny in the Clonmoran/Shellumsrath area); underground drainage (in the Ballintaggart area, west of Callan); caves (Dunmore Cave), dry valleys and karst depressions (Nuenna valley).

Fore springs, Co. Westmeath (David Drew)

Lough Lene

The lakes of Co. Westmeath straddle the watershed between the River Inny (River Shannon) and River Deel (River Boyne) catchments. It was remarked by Piers in 1682 that Lough Lene drains via a surface channel eastwards to the River Deel and subterraneously via sinkholes to springs in the settlement at Fore to the north, and hence flows both to the Atlantic and to the Irish Sea. A recent hydrological study demonstrated that water from the swallow holes on the shores of the lake does indeed flow underground to the southerly spring at Fore with a flow rate of 80 m per hour.

Dunmore Cave

There are few explorable caves in the east midlands but Dunmore cave, north of Kilkenny city, is one of the exceptions. It appears to be one of the oldest caves in Ireland and is a remnant of a much larger cave system, thereby providing evidence of a mature palaeokarstic landscape in the area. It consists of a number of large caverns linked by a fossil stream cave. These caverns contain many fine examples of **stalagmites** and stalactites. The cave is important archeologically and historically and there have been numerous finds of human and animal skeletal remains, along with other interesting artefacts. The discovery of coins and other artefacts of Viking age supports the account in the Annals of the Four Masters that the Vikings massacred many people in the cave in 929 AD.

Dunmore Cave, Co. Kilkenny (Terence P. Dunne)

What factors influence karstification?

Three factors in particular seem to have influenced the degree of karstification in the east midlands:

- the lithology (type and content) of the limestones;
- the presence of low permeability sandstones and shales nearby;
- the geological history.

While karst features are present in all limestone types, they are far more common in the purer limestones than in muddy limestones. Muddy limestones underlie a high proportion of the east midlands (perhaps 70%), in particular in east Co. Offaly, Co. Dublin and Co. Meath. Karstification does not seem to be significant in areas underlain by these rocks. Where pure limestones are located close to areas underlain by sandstones and shales (for instance, at Carrickmacross and around the Castlecomer Plateau), water with a high dissolving capacity flowing on to the limestones has increased the degree of karstification.

The geological history of the area during Tertiary (from 65 to 1.6 million years ago) and **Quaternary** times (1.6 million years ago to today), while poorly understood, helps explain the present day situation. It is probable that most of the solution of the limestones occurred during the Tertiary, forming a mature karst landscape in the process. During the later part of the Tertiary, much of this landscape was dissolved and eroded, leaving residual features such as the isolated hills, caves and swallow holes.

How karstified is the area relative to other areas?

'Less karstified' is the best answer at present. A definitive answer is not possible as few studies have been conducted and the mantling of the limestone by the glacial deposits may be hiding more karstification than we are aware of. However all the evidence, particularly from boreholes, suggests that groundwater flow in fissures is more important than flow in large conduits. The predominance of muddy limestones in many areas has reduced the degree of solution. Well yields are more predictable than, for instance, in the western lowlands.

The southern valley karst in Counties Cork, Kerry, Tipperary and Waterford

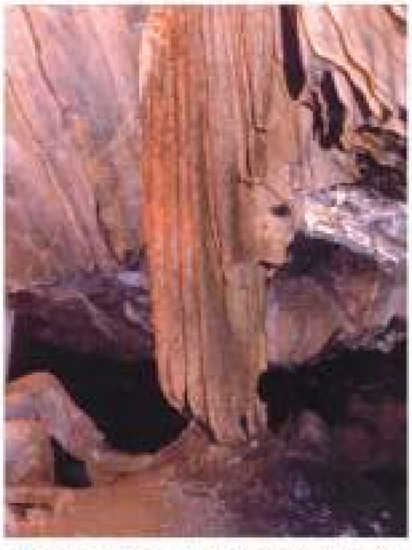
The karst in the southern counties of Ireland differs in a number of ways from that further north. The limestones in the south have been quite intensely folded: the further south, the more intense is the folding. This resulted from a mountain-building episode (the Variscan Orogeny), some 280 million years ago at the end of Carboniferous times, which created an extensive system of faults and fractures in the rocks. These were later opened up by solution to form a karst network. The work of erosion on the folded rocks has resulted in a distinctive landscape of sandstone ridges (including the mountain ranges of the Galtees and the Knockmealdowns) separated by limestone valleys drained by large rivers such as the Suir, Lee, and Munster Blackwater.

The limestone valleys themselves show a distinctive topography: the centre of the valley, underlain by the main limestone formations, tends to be elevated a little above the land on either side. The lower lying areas occur where streams or rivers have more deeply eroded the softer shales and shaly limestones immediately overling the older **Devonian** sandstones. The limestones are often largely covered and obscured by Quaternary boulder clays and gravels but can often be seen as small hills bounded by steep limestone crags. These areas expose the main karst features – caves, swallow holes and springs. Although large areas of bare limestone are uncommon, there are many small outcrops and the subsoil cover is often very thin.

Within the limestones, several different units have been mapped. The most widespread is the **Waulsortian Limestone**, comprising the coalescence of massive calcareous mud-mounds. Other limestone formations are more recognisably bedded. Investigations so far have not allowed detailed distinctions between the hydrogeological properties of the various clean limestone units to be made. In general, the **Waulsortian Limestone** is a better **aquifer** than the more shaly, bedded limestones, and is therefore considered to be more karstified.

An important factor in the development of karst in the southern counties was the relative lowering of sea level, by over 60 m, which is believed to have occurred during the Tertiary and Quaternary eras of geological time. When the sea level was so much lower, the rivers were able to cut deeply into their beds, and karst solution could penetrate well below the present-day water table creating a high porosity and permeability. When the sea level rose to its current level, the karst voids filled with water, giving rise to highly permeable limestone aquifers which are important water resources today.

Examination of limestone exposures in many places, especially at the coast (e.g. at Fenit, Co. Kerry) or on lake shores (e.g. Killarney) shows numerous open joints and surface karstification. Evidence of deeper karstification along these joints can be found in cave surveys, which often show main passages or galleries about 1–6 m apart. Cloyne Cave in Co. Cork, is one of the best examples of a grid network of passages.



Eagle's Wing, Mitchelstown Cave (Terence P. Dunne)

The southern counties include numerous important karst features: swallow holes which take in surface runoff from the adjacent hills (e.g. Thonoge sink, near Ardfinnan, Co. Tipperary and Water Rock sink, near Middleton, Co. Cork); large karstic springs (e.g. Dower spring, near Castlemartyr, Co. Cork and Tobermaing, Castleisland, Co. Kerry); and large caves, including show caves such as Crag Cave, near Castleisland and Mitchelstown Cave. Another well-known cave is Castlepook Cave, near Doneraile, which contained abundant and important archaeological remains and is consequently sometimes referred to as 'Mammoth Cave'.

The large karst springs, many of which are important regional or local water supply sources, and the relatively low lying aspect of the limestone valleys, ensure that the rivers of these areas maintain a reasonably constant flow through the summer.

The Ulster Chalk

The Cretaceous chalk (135–65 million years old) is a thickly bedded, almost pure carbonate rock and is the youngest rock unit in Ireland to exhibit karst characteristics. It is exposed as a narrow strip-like outcrop which totals approximately 80 km^2 around the periphery of the overlying Tertiary basalt (volcanic lava). The chalk dips gently beneath the overlying basalt. Before the eruption of the basalts, uplift and erosion of the chalk allowed the development of a karst landscape, and palaeokarst features are still evident at the basalt-chalk contact. The chalk, generally less than 50 m thick and with a wide joint spacing, differs from the chalk of England and other areas of north-west Europe, in that groundwater flow relies on the presence of fractures. Few open boreholes penetrate the chalk beneath the basalt, so aquifer investigations have been largely restricted to the areas neighbouring the outcrops.

Loughareema sink, the largest single sink recharging the chalk aquifer, supplied by three permanent streams. A lake forms above the sink which fills after heavy rainfall. No streams flow out of the lake. The water level rises and falls depending on rainfall and the chalk's ability to take in the water (Donal Daly)

Numerous springs emerge from the base of the chalk at its junction with the underlying, relatively impermeable, mudstones. Chemical analyses of their waters show that the springs are mainly fed by surface water which runs off catchment areas on the basalt plateau and sinks at the basalt-chalk boundary. The year-round flow into the numerous stream sinks has resulted in active dissolution of the chalk matrix in the outcrop areas. These occurrences are more common in the east, as overlying glacial deposits in the west have reduced outcrop exposure and streams tend to be perched above the aquifer. Small dolines and numerous fissures showing solution features are also dispersed over the outcrop areas.

The narrow outcrop of the Ulster Chalk along the Antrim coast. The overlying rock is basalt (Stephen Barnes)

Flow from the chalk springs is closely related to rainfall; sustained flow is very limited during prolonged dry periods. This confirms that the contribution of 'old' sub-basaltic water to the chalk springs is only a minor component of the overall water budget in the chalk. Beneath the basalt, large scale dissolution is not thought to have occurred in the chalk as recharge water is restricted and is often close to saturation with calcite before reaching the chalk.

Water tracing experiments using artificial dyes have demonstrated links between individual sinks and springs, with groundwater flow velocities between 0.3 and 2.8 km/day.

Engineering and Environmental Aspects of Karst

Engineering and construction

Karst regions may provide particular problems for all kinds of engineering projects, from house construction to major roads and bridges and also civil engineering works such as mining, canals and reservoirs. These problems mainly arise from:

- the unpredictable occurrence, extent and depth of underground cavities which may lead to inadequate foundation support;
- the great variability in the depth of subsoil, leading to unpredictability in the type and depth of excavation required and the likely extent of drilling or blasting.

Risk assessment

The implications of karst for engineering problems may be studied using a risk assessment approach with the level of acceptable risk increasing with decreasing sensitivity of the structure. For example, the level of risk due to karst in the construction of a hay-barn is much less than that for the development of a housing estate, and the subsequent investigation and site works should be designed accordingly.

The first step in the investigation of every site where karst is a potential problem should be a desk study. This will prove to be an economic and a profitable exercise. The desk study should include:

- a site walkover;
- a study of the geological maps of the area;
- reference to the Karst Database at the Geological Survey of Ireland;
- a study of present and historical Ordnance Survey maps;
- examination of any nearby site investigation records or references to past events or works;
- examination of aerial photographs;
- local knowledge;
- a study of local drainage patterns with particular emphasis on seasonal and historical variations.

The information obtained from the desk study will allow the design of a site specific ground investigation. The ground investigation could include geophysics, trial pitting, rotary percussive boreholes, rotary cored boreholes, down the hole logging and in-situ testing.

This collapse only became apparent when the topsoil was removed (Donal Daly)

Engineering problems - foundations

The presence of karst on a site can result in additional requirements in the design and construction of foundations. Foundations can be designed to span over a potential karst feature as an alternative to grouting. This might consist of a reinforced concrete strip footing, or raft, or a high strength plastic geogrid.

Engineering problems - drainage

The understanding and control of drainage is of critical importance in karst areas. Inadequately controlled drainage can trigger previously dormant karst activity. Good drainage design in karst areas should include redirection of natural drainage away from the structure, sealing of all drains and surface areas, and avoidance of soakpits and distribution systems.

Engineering problems - mining

Problems have been encountered in mining due to the presence of deep karst. One recent mining development in the Irish midlands encountered peat filled karst solution features at a depth of about 60 m.

Engineering problems - reservoirs and canals

Obviously, it is very difficult to construct water-retaining reservoirs in karst areas, and there are several examples (from abroad) of such reservoirs which failed to hold any water. Ireland has one particular example of a canal, the Cong Canal in Co. Mayo, which failed because the water disappeared through the fissures in the limestone along its course.

Flooding at Gort (Donal Daly)

Engineering problems - radon

The accumulation of radon gas in basements and beneath ground floors of buildings can be harmful to humans. Radon is a potential health hazard in karst areas, particularly those adjacent to rock types which are relatively rich in radon and where open fissures exist. An example is the Galway area where the limestone is closely associated with a granite body. However, radon problems can be ameliorated by ventilation.

Water supply

One important feature of karst areas is the absence of surface water which often leads to groundwater being the main source of supply. Drilled wells can be difficult to construct in these areas and karst springs remain critical as a method of harnessing the supply. Most of Ireland's largest springs are in karst regions, including the Kedrah springs near Cahir, Co. Tipperary; Dower Spring near Castlemartyr, Co. Cork; Two Gneeves Spring near Kanturk, Co. Cork; Cong Springs in Co. Galway; and Killeglan Spring, Co. Roscommon.

The large karst spring at Aughclogeen north of Galway city. The spring is the source of water for a considerable surrounding area (David Drew)

Karst springs have been used for water supply from the earliest times of human existence. They can range from small seasonal seepages to very large, reliable springs which may be the source of a substantial river. Many springs, both large and small, have been named, often in honour of saints, and in some cases have given their names to towns and villages, such as Patrickswell or Ballintubber. Many springs probably had religious significance in pre-Christian times.

The area around the mouth of a spring is often very boggy, especially in winter, and this can lead to pollution of the spring. Engineers use a variety of methods to combat this: for example where the spring mouth is essentially a cave, a wall is built around the spring mouth and the intake pipes are installed deep into the cave. Where the water wells up through broken rock or gravels the spring flow is often confined within a square or circular wall containing the intake and the spring is allowed to overflow in a controlled manner.

Bored wells in karst limestones can present several problems to the hydrogeologist and engineer. Firstly, it is difficult to identify the best place to drill as a successful borehole depends on meeting sufficient water-bearing fissures. If these fissures are a few metres apart and nearly vertical it can be easy to miss them. In well developed karst areas, a dry well can be drilled a few metres away from a successful one. Traditionally, this difficulty was resolved by using the services of a water diviner. Today, there are scientific methods using geophysical instruments which are often successful in identifying the presence of fissure zones. The second difficulty is that if large fissures are encountered, the limestone rock can be unstable and may collapse into the borehole. Competent drillers can overcome this, but they need to be ready for such conditions. An associated problem is that the fissures can contain large amounts of loose sediment which can enter the well, damage the pump and render the water undrinkable. Again, this can usually be solved by proper construction of the well, including the installation of well screen, casing and cement, and by careful development of the well, involving controlled pumping over a lengthy period.

As with a spring, it is important to emphasise the need for extreme watchfulness with regard to protecting the well from pollution, and this begins with drilling the well in a location where pollution is least likely.

In spite of all the problems (actual and potential) there are many thousands of successful boreholes in karst limestones throughout Ireland, delivering reliable quantities of good quality water to tens of thousands of people.

Quarrying and mining

The pure limestones in which karst develops have many uses:

- Building stone: easy to cut but strong and durable, limestone has been a traditional building material for many hundreds of years. The most decorative types which can take a high polish, are often described as 'marble': well-known examples are the 'black marble' of Kilkenny and the 'red marble' of Cork.
- Aggregate: crushed limestone is used for road construction, as an aggregate in concrete and cement rendering, and as loose chippings for driveways and paths.
- Agricultural lime: finely crushed and ground limestone is used to improve lime-deficient soils in many parts of Ireland. 1.1 million tonnes are spread on our fields annually.
- Cement: pure limestone is the major raw material in the manufacture of cement.
- Chemicals: many chemical processes require ground limestone or burned lime as an essential raw material, including steel manufacture.


Limestone quarry (Minerals Section, GSI)

The high demand for pure limestone has led to a thriving quarrying industry in Ireland. Currently, 21 million tonnes of limestone are quarried every year.

Quarrying has sometimes revealed very interesting karst features and has led to the discovery of some caves. However, caves and solution cavities, often filled with clay, can present quarry managers with both production and environmental problems.

Active quarrying can lead to pollution, for example from spillages of motor fuels. It is important that quarry operators take special precautions to ensure that spillages, leakages, or effluent from sanitary facilities provided for quarry workers, cannot enter the local groundwater. Unfortunately, abandoned quarries have often been used for the disposal of all kinds of waste which can also lead to pollution of groundwater as the effluents seep downwards along open fissures.

Some limestones in Ireland contain important deposits of metallic minerals (orebodies), especially lead, zinc and silver. In recent years, two large orebodies have been identified at Galmoy, Co. Kilkenny, and Lisheen, Co. Tipperary. In both cases, the orebodies lie at considerable depths below the regional water table in limestones which are at least partially karstified. In order to successfully develop these minerals it is necessary to pump out large volumes of water from the limestones. Detailed investigations of the water-bearing properties of the limestones were essential to the design of the mine and to the environmental impact assessment.

Agriculture

The practice of agriculture is closely intertwined with Irish karst landscapes. Farming communities are dependent on the area's characteristic soil and water resources, and agricultural practices may themselves alter the nature of these resources.

In their most extreme forms, karst landscapes can be extremely difficult to farm, as any visitor to the Burren or the Aran Islands can readily appreciate; the bare rocky surfaces have virtually no soil or water. Where there is a little more soil cover developed on a more crumbly limestone layer, as in the upland pastures of the Burren, there may be good winter grazing but in summer, grass growth may be inhibited by a lack of water. Even karst areas with a deeper soil cover may have water supply problems: the water table may be very deep, so streams and springs may dry up in summer and the grass may die back.

The famed Burren flora, found on a patchy mosaic of soil and rock, is not entirely a natural phenomenon. In the absence of traditional grazing activities, the famous flower meadows become colonised by hazel scrub. Indeed, the patchy soil cover is itself at least partly a consequence of agriculture, as previously described: clearance of the forest cover for agriculture in prehistoric times resulted in soil erosion.

A reclaimed area in the Burren (David Drew)

In the Aran Islands, there is a long tradition of creating soil on the bare limestone by collecting seaweed and sand and spreading them on the fields or in lazy-bed ridges. In the Burren, the creation of smooth, soil covered fields from rocky scrubland has become a widespread practice to facilitate agricultural modernisation. Grant-aided reclamation has involved scrub clearance, bulldozing of loose boulders and stone walls, and spreading of topsoil to make the land suitable for silage production. A balance needs to be achieved between agricultural needs and environmental and heritage considerations.

Silage clamp on bare karstic limestone (David Drew)

While upland karst areas such as the Burren plateau may suffer from a shortage of water for summer grass growth and for human and animal consumption, low-lying karst areas such as the western lowlands may suffer from periodic excesses of water. The seasonal flooding of turloughs brings the advantage of annual liming of the pasture on the turlough floor, but nevertheless many turloughs have been artificially drained to provide grazing over a longer period of the year. Occasionally, extensive flooding takes place in karst areas beyond the normal turlough winter flooding limits. In the

Gort-Kinvara area, this has given rise to problems for agricultural land use, as well as flooding roads and houses for many weeks. As with the upland dry karst pastures, a balance needs to be achieved in the turlough areas between agricultural and conservation needs.

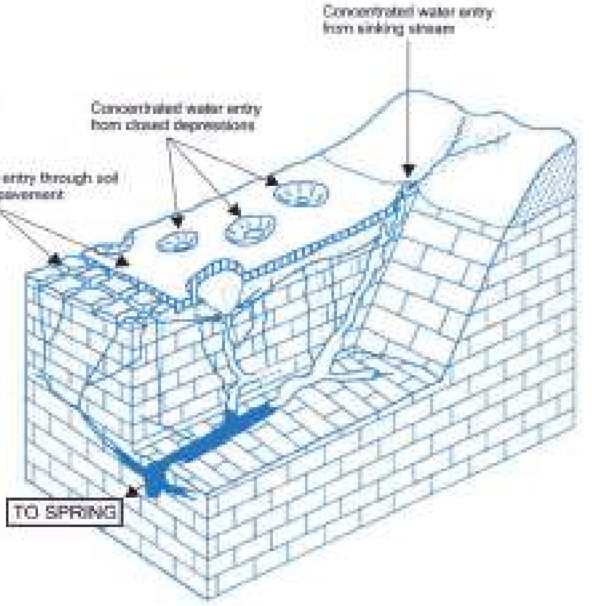
Agriculture can also have an influence on water quality in karst areas. If agricultural wastes are badly handled, they may give rise to pollution of springs and wells. Silage effluent can easily pass through open fissures into drinking water supplies if it is not properly contained. The recent move to silage bales rather than silage clamps in the Burren is minimising this risk. Particular care must also be taken with slurry storage to avoid leakages, and landspreading of slurry should avoid areas where the soil cover is thin. Farmyard runoff needs to be collected and landspread only in suitable areas.

To summarise, agricultural activity is an integral feature of Irish karst landscapes and the challenge for the future is to achieve an economically and environmentally sustainable livelihood in these areas.

Water pollution: the need to protect water resources in karst areas

Why are karst areas naturally highly vulnerable to pollution?

- Water can move rapidly through fissures widened by solution.
- Sinking streams provide direct water entry points to groundwater, with little or no filtration or attenuation of contaminants.
- Solution hollows or dolines may also provide direct entry routes through vertical shafts.
- The characteristic soil cover over karst limestone is very thin, maybe only a few centimetres deep, and so provides little protection.



Possible entry routes for contaminants to enter karst groundwater (John Gunn)

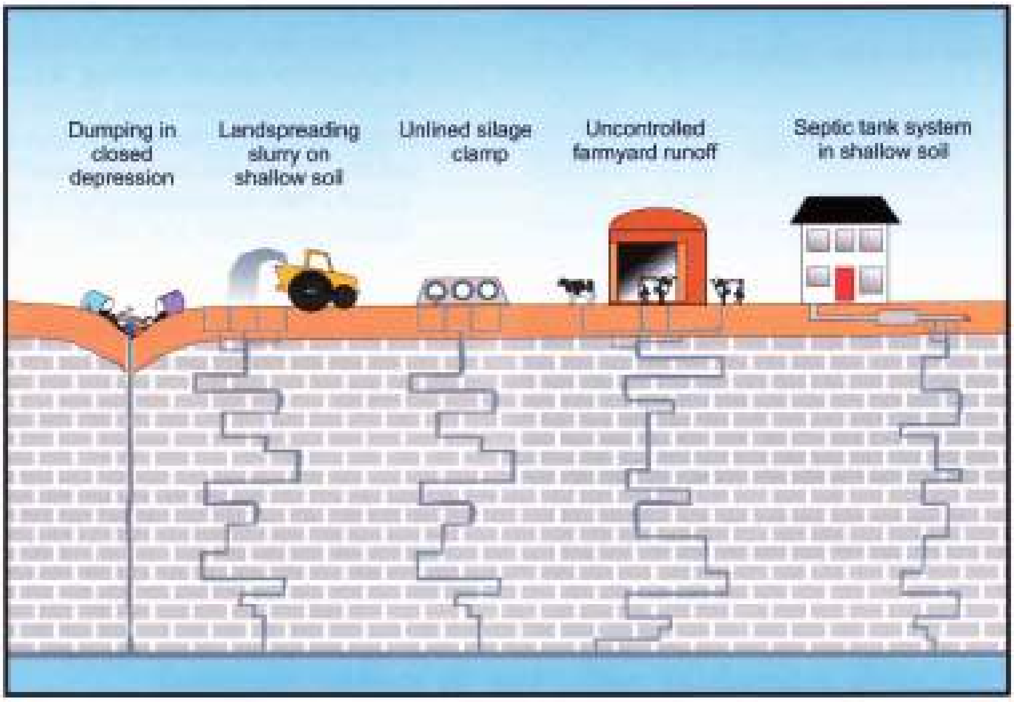
What sources of contamination are there?

Agricultural sources of pollution include badly stored farm wastes (e.g. unlined manure pits and slurry lagoons, silage clamps with cracked bases or no effluent collection system), unmanaged farmyard runoff, and sheep dip disposed of in soakholes or swallow holes. All farm effluents and dirty water should be collected and spread on land, and the rate of application should be discussed with an agricultural advisor. Excessive manure spreading, or spreading on thin soils, may cause pollution of groundwater with a range of substances.

Septic tanks may pose a risk, especially if soakholes are used for effluent disposal. Where the subsoil is very shallow, artificial percolation areas or 'package' domestic sewage treatment systems may be necessary.

Natural depressions, caves and quarries in karst limestones have often been used for disposal of wastes. Dumping of household rubbish, dead animals, farm wastes and rotten vegetables into such places is a common problem. At a larger scale, landfills in karst areas, particularly in old quarries, will cause pollution if the leachate is not properly contained. Environmental Protection Agency guidelines now prohibit landfill sites on regionally important karst aquifers.

Leaking fuel storage tanks may also cause serious water pollution, whether above ground (e.g. domestic heating oil tanks) or underground (e.g. at petrol stations).



Potential pollution hazards in rural karst areas. Pollutants move rapidly from the land surface through fractures and conduits in the limestone down to the water table. In the process groundwater gets polluted and wells may be affected (Catherine Coxon)

Types of pollutant

The pollutants found in water supplies in karst areas vary depending on the local sources of contamination. The most common problem is contamination by micro-organisms from human or animal wastes.

Farm wastes and sewage can also give rise to chemical pollutants including nitrate and ammonia. In some cases, an unusually high level of a chemical constituent (e.g. chloride, potassium), though not in itself harmful, may indicate a pollution problem. Excessive iron and manganese causing taste or staining problems, may occur naturally, but may also be released from the soil or rock into water supplies by pollution, particularly by silage effluent pollution. Sheep dip which is incorrectly disposed of may pollute water supplies with phenols and a range of potentially harmful pesticides. Leaking fuel tanks can contaminate groundwater with a range of hydrocarbons which will cause taste and odour problems and may pose a health risk, even at very low concentrations.

Removing the risk of microbial pollution in vulnerable karstic areas requires two complementary approaches. It is usually impossible to exclude all faecal micro-organisms, so the water supply must be treated to remove them, e.g. by filtration and treatment with chlorine, ozone or ultra-violet radiation. However, these treatment systems may fail occasionally (e.g. inadequate dosage of chlorine, suspended sediment interfering with ultra-violet treatment), so it is important to keep the raw water supply as uncontaminated as possible by controlling sources of faecal pollution. Prevention is better than cure!

Sinkhole infilled with rubbish (Catherine Coxon)

Construction of a bungalow and septic tank in a area where karstic limestones are at ground surface (Catherine Coxon)

Microbial pollution

Karst groundwater is particularly prone to pollution by faecal micro-organisms (bacteria, viruses or protozoans from human or animal waste) because the solutionally widened fissures and cave passages provide ready access routes. Contaminants can travel widely in very short times, with no purification.

Faecal coliform bacteria, including *E. coli*, are used as indicator organisms when testing water supplies because they occur in large numbers in human and animal waste. They are not necessarily harmful themselves (although some strains of *E. coli* are dangerous) but indicate that pathogenic (disease-causing) micro-organisms, which are more difficult to detect, might be present in the water.

Dealing with microbial pollution in water supplies

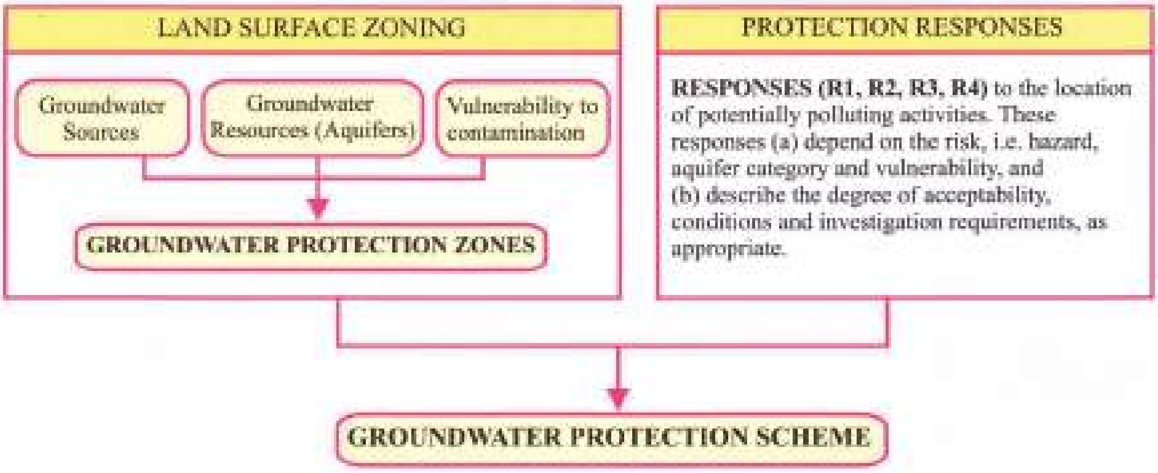
- Protect the water resource by controlling pollution sources (e.g. septic tank systems, farm wastes)
- Treat the water supply to ensure absence of faecal micro-organisms

Groundwater protection schemes in karst areas

The Geological Survey of Ireland, the Department of Environment and Local Government and the Environmental Protection Agency have jointly developed a methodology for the preparation of groundwater protection schemes. Schemes based on this methodology are gradually being drawn up and implemented by local authorities. Each scheme involves a county-wide map of groundwater protection zones, based on an aquifer map and a map of the natural vulnerability of the groundwater to pollution. This is accompanied by guidelines for controlling various sources of pollution (e.g. septic tank systems).

Karst is included in the protection scheme in two ways: firstly as part of the aquifer categorisation; and secondly, as a factor in vulnerability mapping.

Karst limestones are shown as a separate, distinct aquifer category on aquifer maps, as a means of drawing attention to the variability in the hydrogeological characteristics, the difficulties in locating successful wells, the focused nature and high velocities of groundwater flow, and the low level of pollutant purification in karst areas.



Summary of Components of Groundwater Protection Scheme

The vulnerability map mainly depends on the nature and thickness of subsoils (unconsolidated material overlying bedrock, dating from the Ice Age and the last 15,000 years since the end of the Ice Age). Two factors relating to the subsoil cover are worth noting in karst areas:

- The irregular bedrock surface arising from limestone solution (with buried solution hollows) means that the subsoil thickness is often very variable over short distances, so the degree of protection provided is hard to predict.
- Where subsoil deposits are absent, limestone weathering gives rise to a thin or patchy soil, which provides little or no protection to the underlying groundwater.

The greatest vulnerability arises where water can move underground directly at particular points, bypassing the protective soil or subsoil cover, e.g. where stream water sinks underground (swallow holes) or along streams where water is lost over a longer reach (often where an artificial channel has been created by arterial drainage).

One element in a groundwater protection scheme is the drawing up of source protection zones around major public water supply sources. Each source's catchment area (or Zone of Contribution) must be identified. In karst areas this is particularly difficult, since the underground pathways are highly unpredictable. Where a sinking stream is thought likely to re-emerge at a spring, it is sometimes possible to trace the water from sink to spring by using special dyes or other tracers. The speeds at which water travels underground in karst systems, as revealed by dye tracing, can be several km per day, as compared with perhaps one or two metres per day in non-karstified aquifers. This emphasises the importance of avoiding pollution as rapid flow means a pollutant can quickly reach a water source without any chance for the harmful matter to be filtered out, absorbed or degraded.

Extremely vulnerable areas defined in the national protection scheme methodology include:

- Areas where bedrock is exposed at the surface or where the subsoil cover is less than 3 m thick.
- Areas within 30 m of karst features (including along the area of loss of losing or sinking streams) and within 10 m on either side of losing or sinking streams upflow of the area of loss.

Conserving Our Karst Landscape

Our karst heritage

Think of Ireland's natural heritage and what comes to mind? Perhaps an image of the Lakes of Killarney, the purple-brown boglands or the Giant's Causeway, but whatever it might be it will undoubtedly include surreal limestone landscape areas like the Burren in Co. Clare and the Cuilcagh mountains in Co. Fermanagh. Some of the best karst landscapes and features in Europe are found in Ireland.

Why should the best examples of these features be conserved?

- They are an integral part of our natural heritage.
- We have a duty to future generations to preserve our heritage so that it may become theirs.
- Karst has a distinctive character. To the usual three-dimensional relief, karst landforms add a 'fourth dimension', namely the subterranean relief, a sort of negative replica of the surface drainage patterns, to which it is closely connected.
- Conservation has direct and immediate benefits for humanity.

What benefits?

- Karst areas have a distinctive beauty for both local people and visitors.
- The tourism potential of areas like the Burren and Marble Arch Caves needs no elaboration.
- They are a valuable scientific and educational resource.
- They are fundamental in understanding and appreciating our historical, ecological and archaeological heritage.
- They are often the only source of drinking water, particularly in rural areas.

Threats to our karst heritage

Karst limestone areas are a valuable part of our natural heritage, but they are also under threat from several sources: water pollution, dumping, insensitive tourism or other development, vandalism, bad caving practice, quarrying and drainage.

Farming, particularly land reclamation and drainage, can lead to infilling of features such as dolines and swallow holes, the levelling of landforms, and damaging turloughs and caves. Arterial drainage can change not only the landscape, but more significantly the water regime – the main distinctive characteristic of karst areas. Over-development and intrusive tourism can reduce the visual amenity value and pose a risk to the ecology of karst areas. Development where there has been inadequate attention to waste disposal can contaminate karst groundwater, and in the process affect the ecology. Irresponsible attitudes towards caves can lead to damage, the loss of the amenity and the educational, scientific and archaeological value of the caves.

A relatively recent threat has arisen from the demand for natural stone for gardens. Water-worn stone from limestone pavements is very attractive and in many places has been removed by heavy mechanical plant leaving a scarred surface which will take centuries of weathering before it is restored to its former condition. Stone should not be removed from any limestone pavement for garden use. Satisfactory substitutes should always be available from quarry waste or reconstituted stone. The Heritage Council and the Countryside Agency in Britain have noted the extent of trade in limestone pavement. Effective protective measures in Britain have put pressure on Irish pavement to meet the U.K. demand.

What needs conserving?

Our objective must be to conserve the best examples of the main karst features. 'Best' can be considered at international, national and county levels. The main features include caves, limestone pavement, turloughs, sinking streams, karst springs and karst landscapes.

Achieving successful conservation

Achieving successful conservation involves: selecting sites worthy of conservation; identifying practical site management techniques; having a good legislative framework backed up by site monitoring; and increasing public awareness and support. The official recognition and designation of sites is only one step. Conservation has to be supported by the landowners who are custodians of these special areas for everybody, and the public must in turn support them and their efforts.

The Geological Survey of Ireland has now undertaken this first step, as part of the Irish Geological Heritage Programme, which has the objective of conserving and promoting the best of Irish geology. Karst was chosen as the first geological theme because of its vulnerability and the ever-mounting threats. A new site selection process (building on a first listing of conservation sites from 1981) has been completed. The designation of sites will be completed by Dúchas, The Heritage Service, and those selected will become part of the national suite of Natural Heritage Areas. Local authorities and local groups could support the conservation of key national sites by selecting local or county karst heritage and educational sites and including them in their County Development Plans.

An example of the distinctive Burren flora (Bloody Cranesbill) which thrives on the limestone pavement (David Drew)

Choosing the sites is only the first and, arguably, the easiest step. Some sites may be so vulnerable that purchase of the site by the State may be necessary. However, most sites can be conserved by appropriate site management. For example, in the case of caves this could be in conjunction with the Speleological Union of Ireland, as the cavers' representative body. Cave conservation measures could include: access agreements, provision of durable walkways at popular caves, and in new caves for example, cavers could reduce their impact by taping a single route through fragile sections.

Mullaghmore Hill in the southeast of the Burren (David Drew)

The more the public wants and supports nature conservation, the easier it will be to achieve it. The concept of conservation can only be viable when it takes firm root in public opinion. Therefore, it is essential to see local people as partners/ stakeholders in karst conservation. The implication of this is that priority must be given to publicity and education. This booklet is part of that process.

Glossary of Technical Terms

Aquifer — A rock that stores and transmits water in significant quantities.

Carboniferous — The geological time period from 355 to 290 million years ago when most of our limestones were laid down (refer to table on page 6).

Clint — A block of limestone on a limestone pavement bounded by open grikes.

Cretaceous — The geological time period from 135 to 65 million years ago (refer to table on page 6 for major events).

Devonian — The geological time period from 410 to 355 million years ago (refer to table on page 6 for major events).

Doline — A small to medium sized closed depression, a few metres to a few hundred metres in diameter and depth. Dolines are formed by slow, concentrated solutional removal of rock in an area, from the surface downwards, or by the collapse of overlying rock into a cave or chamber beneath (collapse doline). Dolines function as funnels, allowing point recharge of the karstic aquifer. In the USA, dolines are termed **sinkholes**.

Dolomite — Carbonate rocks which have undergone chemical changes resulting in the replacement of some of the calcium by magnesium. Can be highly karstified in places.

Estavelle — A karst feature that can function as a spring or as a swallow hole depending on underground water levels.

Grike — A fissure (crack or joint) in the limestone bedrock that has been widened, sometimes to tens of centimetres, by the dissolving action of rainwater.

Jurassic — The geological time period from 205 to 135 million years ago (refer to table on page 6 for major events).

Karren, Karrenfield — Small (millimetres to a few metres) solutional channels, hollows or enlarged fissures on the surface of the rock. Extensive exposures of bedrock with such features are called karrenfields.

Karst — An area of limestone or other highly soluble rock, in which the landforms are of dominantly solutional origin, and in which the drainage is usually underground in solutionally enlarged fissures and conduits.

Limestone Pavement — Bare limestone surface from which soil and loose rocks have been stripped – usually by relatively recent ice erosion during a glacial period.

Ordovician — The geological time period from 510 to 438 million years ago (refer to table on page 6 for major events).

Polje — A large, relatively flat floored enclosed depression bounded by steep sides, with a floor area of one to several hundred square kilometres. Commonly, sediments blanket some or all of the floor.

Quaternary — The geological time period from 1.6 million years ago to the present day which includes the Ice Age (refer to table on page 6 for major events).

Speleology — The scientific study of caves.

Stalactite — The mineral calcite (calcium carbonate) deposited in crystalline form from lime-rich dripping waters on to the roof of a cave. Stalactites grow downwards to form tapering pendants.

Stalagmite — Calcite deposits as per stalactites but with the deposition taking place where trickles of water splash on to the cave floor. The resulting deposits grow upwards to form a column.

Swallow hole, Pothole — The point at which a surface stream sinks underground.

Tertiary — The geological time period from 65 to 1.6 million years ago (refer to table on page 6 for major events).

Turlough — Seasonal lakes found in the lowland karsts of western Ireland. They often fill and empty via estavelles.

Waulsortian Limestones — A group of limestones of Carboniferous age which were laid down as massive calcareous mud mounds. Found in many parts of the country.

Irish Place Names and Karst

(extracts from 'The Origin and History of Irish Names of Places' by P.W. Joyce. Published by Appletree Press.)

Poll: a hole of any kind. Topographically it is applied to holes, pits or caverns in the earth, deep small pools of water, very deep spots in rivers or lakes, etc. In the beginning of anglicised names it is always made *Poll*, *Poul*, or *Pull*, and as a termination it is commonly changed to *Foyle*, *phuill*, *phull* by aspiration of the 'P', and by the genitive inflexion. Diminutives: *Pullen*, *Polaun*, *Polleens*, *Pollagh*, *Pullagh*.

There are several words for a cave: *poll*, *poll-talmhan (poultaloon)*, *dearc (derrig)* or *derc* (a cave or grotto), *cuas* (anglicisations: *Coos*, *Coose*, *Cose*, *Cous*, *Couse*). Sometimes the 'C', is changed to 'H', e.g. *Hoosh*. Diminutives: *Coosan*, *Coosane*, *Coosaun*, *Coosheen*. In addition: *Uagh*, *Uaimh* (genitive: *Uamha*, *Uamhain*) and *Uath* are very common, the latter denoting an occurrence in a cave. Anglicisations: *Nahoe*, *Nahoo*, *Nahoova*, *Nahone*, *Nahoon*, *Oovan*, *Owen* (occasionally).

Indications of water are numerous: *Uisce*, anglicised to *Iska*, *Isky*, and *Isk*. *Turlough*: dried lake. *Tobar*, *Tiobrad*: well (*Tober*, *Tipper*, *Tubber*, *Tubbrid*). *Uaran*, *Fuaran*: fresh or cold water springing from the earth (*Oran*).

Where to Find Out More

Caving as a sport

If you want to see more than you can see in a show cave, join a Caving Club where you can learn to explore caves safely in company with experienced cavers. Never go caving alone or without the proper equipment and good knowledge of current local water level conditions.

Caving clubs

The Speleological Union of Ireland c/o AFAS, House of Sport, Longmile Road, Walkinstown,Dublin12, can provide contact details for clubs and cavers in all areas. Most of its members are also part of the Irish Cave Rescue Organisation.

Journals/magazines

Irish Speleology (The Journal of the Speleological Union of Ireland); published irregularly. c/o AFAS, House of Sport, Longmile Road, Walkinstown, Dublin 12.

Cave and Karst Science (The Transactions of the British Cave Research Association); published three times a year, subscription (1996) £16 per year, post paid. Contact British Cave Research Association, London WC1N 3XX.

Caves and Caving; British Cave Research Association, published 4 times a year. Free to members.

Descent magazine has an Irish column (six published per year) and is available by subscription from Wild Places Publishing, 51 Timbers Square, Roath, Cardiff, CF24 3SH, UK.

Reference books/textbooks

Caves of Co. Clare, edited by C. Self, University of Bristol Speleological Society, 1981.

Caves of Ireland, by J.C. Coleman, Anvil Books Tralee 1965 (out of print).

Caves of NW Clare, by E.K. Tratman, David and Charles, 1969.

Groundwater and Karstification in mid-Galway, South Mayo and North Clare, by D.P. Drew and D. Daly, Geological Survey of Ireland Report Series RS/93/3, 1993.

Karst Geomorphology and Hydrology, by Derek Ford and Paul Williams, published by Chapman and Hall, 1989. ISBN 0 412 44590 5.

Karst Geomorphology, by J.N. Jennings, published by Basil Blackwell, Oxford, 1985.

Limestone Geomorphology, by S. Trudgill, published by Longman, London, 1985.

The Caves of Fermanagh and Cavan, by G. Ll Jones, G. Burns, T. Fogg and J. Kelly, 1997, Florencecourt, Co. Fermanagh.

On Stony Ground: an investigation into trade in water-worn limestones between the United Kingdom and the Republic of Ireland, by Pendry,S. and Allan,C.(Eds). Countryside Agency, the Heritage Council and TRAFFIC International, 1999

Show caves

Aillwee Cave, Ballyvaghan, Co. Clare.
Tel. 065-7077036/7077067. Open mid-March to early November.

Crag Cave, Castleisland, Co. Kerry.
Contact: the Manager, Crag Cave, Castleisland, Co. Kerry. Tel. 066-41244.

Dunmore Cave, Ballyfoyle, Dunmore, Co. Kilkenny.
Tel. 056-67726. Open daily mid March to mid October, and at weekends in winter. Phone Office of Public Works, Dublin to confirm.

Marble Arch Caves, Florencecourt, Co. Fermanagh.
Contact: the Warden, Marble Arch Caves, Marlbank, Florencecourt, Enniskillen, Co. Fermanagh, BT92 1EW. Tel. 02866-348855 within Northern Ireland and 04866 348855 from the Republic of Ireland. Open March to October.

Mitchelstown Cave, Burncourt, Co. Tipperary.
Tel. 052-67246. Open daily

Geological Surveys

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Dublin 4

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Fax: +353 1 6681782
http: //www.gsi.ie

Geological Survey of Northern Ireland
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Belfast BT 9 6BS

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048 90666595 from Republic of Ireland
Fax: 028 90662835 within Northern Ireland
048 90662835 from Republic of Ireland

Sponsors

Public Bodies

The Heritage Council
Rothe House
Kilkenny
Telephone: +353-56-70777; E-mail: heritage@heritage.iol.ie

ENFO - The Environmental Information Service,
17 St. Andrew Street, Dublin 2, Ireland.
Telephone: 1890 200191; Fax: -353-1-8883946; E-mail: info@enfo.ie;Website: www.enfo.ie
ENFO is a free public service of the Department of the Environment

Environmental Protection Agency
P.O. Box 3000, Johnstown Castle Estate, Co. Wexford.
Telephone: +353-53-60600; Fax: +353-53-60699; Website: http://www.epa.ie/

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Peter Bennett
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Telephone: (028) 92629424; Fax: (028) 92606719 (within Northern Ireland)

Bord na Mona Environmental Limited
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Telephone: +353-45 431201; Fax: +353-45 431647

K. T. Cullen & Co. Ltd.,
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Geotechnical & Environmental Services Ltd., The Innovation Centre, Carlow RTC, Green Road, Carlow
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Dames & Moore Inc.
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Telephone: +353-1-4754422; Fax:+353-1-4754878

Minerex Environmental Ltd
Taney Hall, Eglinton Terrace, Dundrum, Dublin 14
Telephone: +353-1-2964435; Fax: +353-1-2964436

O' Callaghan Moran & Associates
Granary House, Rutland Street, Cork
Telephone: +353-21-4321521; Fax: +353-21-4321522

O' Neill Ground Water Engineering
7 South Main Street, Naas, Co. Kildare
Telephone: +353-45-895668; Fax: +353-45-881705

M.C. O'Sullivan & Co. Ltd.
Consulting Engineers, Carnegie House, Library Road, Dun Laoghaire, Co. Dublin.
Telephone: +353-1-2020870; Fax: +353-1-2020707

TES Consulting Engineers
Unit 4, Blanchardstown, Cooperate Park, Dublin 15.
Telephone: +353-1-8030401; Fax:+353-1-6601702

Patrick Briody & Sons Limited
Aquadrill Services, Water Drilling & Site Investigations Services, The Grove, Rathangan, Co. Kildare
Telephone: +353-45-524360; Fax: +353-45-524785.

Show Cave Owners

Marble Arch Caves
Cuilcagh Mountain Park, Marlbank Scenic Loop, Florencecourt, Co. Fermanagh

Mitchelstown Cave
Burncourt, Cahir, Co. Tipperary

Aillwee Cave,
Ballyvaughan, Co. Clare

Societies

IAH (Irish Group)
c/o Geological Survey of Ireland, Beggars Bush, Haddington Road, Dublin 4
Telephone: +353-1-6707444; Fax: +353-1-6681782

I.A.E.G.
c/o Geological Survey of Ireland, Beggars Bush, Haddington Road, Dublin 4
Telephone: +353-1-6707444; Fax: +353-1-6681782

Aerial photograph of Mullaghmore area, Burren, Co. Clare
by Dr. Con O'Rourke, Teagasc.

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