# Banner Rocks

## The Geological Heritage of County Clare

Matthew Parkes

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By Matthew Parkes

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This book is a visual exploration of the geological heritage of County Clare. Using data gathered during a 2005 audit of 44 sites of geological and landscape importance in County Clare, it presents some of the superb geology exhibited in these special places, and briefly explains the stories told by the rocks. It provides a record of sites of importance, but **is not a guidebook** to visit them, as many are not accessible, on private land.

## Acknowledgements

Congella McGuire, Heritage Officer with Clare County Council, is thanked for steering this project to a conclusion. Dr Eamon Doyle, Geologist with the Burren and Cliffs of Moher UNESCO endorsed Geopark is thanked for his valuable and varied input to the book. Dr Sarah Gatley of the Geological Heritage and Planning Programme of the Geological Survey of Ireland provided great help. Claire McAteer and Scott Engering are thanked for their work on the original 2005 audit, which inspired this book project. Brian McCarthy, Senior Executive Planner and Angela O'Sullivan, Staff Officer, Clare County Council are thanked for their support. Tony Bazley, Ronan Hennessy, Colin Bunce, Pat O'Connor, Margaret O'Brien are all thanked for their inputs to the project.

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The Heritage Officer
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Aras an Chontae Clair
New Road, Ennis, Co. Clare
Tel: (065) 6846408
Email: cmcguire@clarecoco.ie



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Cover image: limestone pavement at Sheshymore
Inside cover image: stunning cliff scenery near Loop Head
Title page image: near Bridges of Ross
Top image: Foohagh, near Kilkee
Back cover: East Clare landscape near Kilbane, Broadford

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# Foreword

Formed from volcanic eruptions, the shells of ancient sea creatures, the sands and muds of long gone deserts and deltas, the rocks of Clare have since been buried, heated, folded and shattered as they were raised into mountains and eroded to give us the landscape we see today. County Clare has been in the making for over 450 million years.

Geology sets the scene for the varied and beautiful landscapes and seascapes of County Clare. Geology forms the geomorphology and is the foundation for soils, drainage patterns, biodiversity and quality of farmland that we have inherited from our ancestors. In turn this has influenced our settlement and social history.

Clare is a county of contrasts and has three distinct geological areas, all significant and important in international terms. East Clare has the oldest rocks in Clare, they have been strongly influenced by folding, and faulting and are exposed in the uplands of Slieve Aughty and Slieve Bernagh and the good farmland and tree covered landscape surrounding Lough Derg.

In North Clare, The Burren (from the Gaelic word 'Boireann' — meaning 'place of stone') is an extensive area of karst limestone. Typical karst features such as dolines, turloughs, clints and grykes are found on expansive areas of exposed limestone pavement, that we have all learned about in school Geography, are all beautifully illustrated in this book. The geodiversity of the Burren sets the scene for the wonderful and renowned biodiversity of the Burren and the East Burren Wetlands, which are a very special group of calcareous, turloughs, fens and lakes of high water quality.

The Burren and Cliffs of Moher Geopark was awarded UNESCO-recognised Geopark status in 2011 in recognition of the important geology of the area and its contribution to the sustainable livelihoods of a significant number of people living there. The area has attracted national and international schools and university groups for decades and in more recent years an increasing number of non-specialist tourists.

Spectacular and dramatic cliffs, sea stacks and islands are along the Atlantic ocean of the west coast of Clare are much younger. The rocks themselves are about 315 million years old and were deposited in an ancient sedimentary basin similar to modern day deltas in the Gulf of Mexico, West Africa and Brazil. This offers an opportunity for geology students and major petroleum companies the world over to study and research these rock characteristics. Even though the rocks exhibit the characteristics of oil bearing rocks, there is no oil to be found in Clare as the rocks were heated and fractured and lost any oil they may have had millions of years ago.

The foundation of this book began with the first county geological survey completed by Matthew Parkes, Claire McAteer and Scott Engering in 2005. The survey was a partnership between Clare County Council, Heritage Council and the Geological Survey of Ireland and was the second such county survey to take place in Ireland.

Today many individuals and organisations promote the geology of County Clare and partners such as the Burren and Cliffs of Moher Geopark, the Burren Outdoor Education Centre, Geological Survey of Ireland and the Natural History Museum bring due recognition to the geology of the area. From their work, sites of geological interest continue to be discovered, which will require further survey and will add to future editions to this publication.

I wish to thank Matthew Parkes for his diligent attention to detail and dedication to writing this book and Eamon Doyle in particular for his continued support and enthusiasm for the project.

—Congella McGuire, Heritage Officer, Clare County Council

# Introduction

County Clare is justly famous for its scenery, with an international reputation for the treasured landscapes such as Lough Derg, Loop Head, the Burren and the Cliffs of Moher. The bedrock foundation, with hundreds of millions of years in the formation and shaping, and the more recent history of geomorphological processes such as coastal erosion and limestone solution are what have created that underlying geodiversity. Geological understanding is best achieved on the ground at sites where the rocks and landforms are displayed. County Clare has a wealth of such natural and man-made sites, which were audited in 2005, in order to provide information and for informed decision making for forward planning. Although that report was written in plain language, it was still quite a technical document. This book aims to present the same information in a far more accessible way for the people of Clare, the Banner County, and for the many visitors who also come to share in the fantastic landscape. It presents the best of the sites, with copious photographs and explanatory diagrams in a way that any reader should be able to gain an appreciation and understanding of their importance, without any previous formal study of geology.

# Access and safety

The inclusion of any site in this guide is neither an indication nor an invitation to access any site without permission from the landowner. Some sites, such as foreshore between high and low tides belong to us all, but access to the foreshore may be across private land. Some others are in the ownership of Clare County Council where public access is freely permitted. Others may be in private ownership or in commonage, but where access has traditionally been allowed. However, the majority are in private ownership, and any visitors must get landowner permission themselves. This guide confers no permission to a visitor. Whilst access information is current at the time of publication, situations can change rapidly and it is the readers' responsibility to check, if planning to visit any site in this book.

It is also the readers' responsibility to look after their own safety by taking sensible precautions if out in the countryside, observing safety instructions and exercising common sense, such as not going near cliff edges in windy conditions, or keeping children under parental control. If visiting any coastal site, the local tide times should be checked and all care taken not to get trapped by rising tides. Neither Clare County Council nor the author are in any way liable or responsible for any injury or loss to any person using this book.

Background image is a view of Mullaghmore.

# What is Geology?

In this section we provide a very few simple fundamentals of geology to assist the reader in making sense of the sites that are described. Geology is synonymous with 'Earth science' and is the application of other sciences such as chemistry, physics, biology and astronomy to the study of the Earth. Here are some basic concepts:

## Rock types

Original molten magma from below the Earth's surface sometimes erupted as volcanic rocks like basalt or andesite lavas. Magma that crystallises as a rock below ground is most commonly found as granite. All these rocks are classified as *igneous*.

*Sedimentary* rocks, usually laid down as sediment on the sea floor, are diverse. They include conglomerates, which has large rounded lumps; breccias, with large angular fragments; and – going down in particle size — sandstones, siltstones and mudstones or shale. Limestone can be formed in many different ways, but it generally contains a lot of shell debris from living animals, as well as chemically precipitated lime sediment.

Both igneous and sedimentary rocks may be altered by strong heat and/or pressure. The resulting *metamorphic* rocks include slate (from mudstone), marble (from limestone), and schist, quartzite and gneiss. Limestone, sandstone and shale are the most common types of rock found in Co. Clare.

## Rock Structures


Sedimentary rocks are built up in layers called beds. These can be very thin or several metres in thickness, depending on the type of rock and the environment it formed in. If originally horizontal, they can later be tilted, so they dip in a direction at a specific angle. They can also be folded into anticlines (upfolds) and synclines (downfolds). Faults are where the rock is fractured and displaced along the fracture, even if only by a few centimetres. A fracture without displacement is simply called a joint.

## Geological time

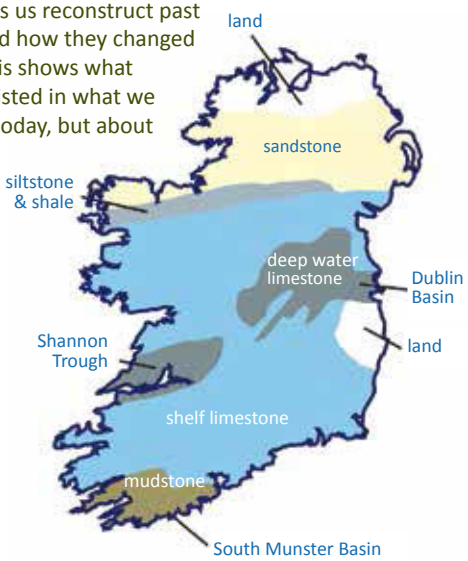
Geological time is generally measured in millions of years, not the tens of years we measure human lifespans by. The age of the Earth is 4.6 billion years, but the rocks we mostly see in Clare were only formed around 300-340 million years ago, with some older rocks in East Clare, but all much younger than Ireland's older mountain chains in Connemara, North Mayo and Donegal for example, which are mostly from around 600-700 million years ago.

Stratigraphy is the cornerstone of geology. We need to understand not only what events and environments have occurred on the Earth, but the sequence in which they happened. Stratigraphy helps us place different rocks into a framework of time, and we can then correlate sequences and events that occurred in different places. Geological time is subdivided into many different periods, some of which are familiar to people, but mostly they are not. The last section of the book provides an overview of the different events through time in the county.

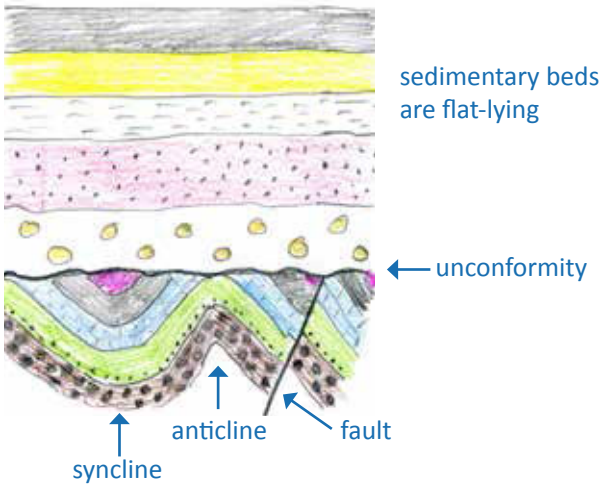
In East Clare we find rocks from three main periods. The oldest, the Ordovician (485 to 443 million years ago) is only seen in some small areas within larger upland areas of Silurian rocks (443 to 419 million years ago). The uplands are blanketed by Devonian sandstones and conglomerates from 419 to 359 million years ago. There were long breaks in deposition through Silurian to Devonian Periods so we see an unconformity here, with Silurian rocks folded and eroded down before being covered over.

One period is most relevant for almost all the remaining sites described here. The Carboniferous Period (about 359 to 299 million years ago) was when the majority of sites in North Clare and West Clare formed. In the early part of this period (the Viséan), Ireland was inundated by a warm tropical sea, with limestone deposited widely. After some time (in the Namurian), rivers draining land to the north started filling the sea with mud and sand sediments, some forming as deltas like today's Mississippi Delta.

Stratigraphy helps us reconstruct past environments and how they changed through time. This shows what environments existed in what we know as Ireland today, but about 330 million years ago in the Carboniferous Period.




## Cross-sectional view of rocks

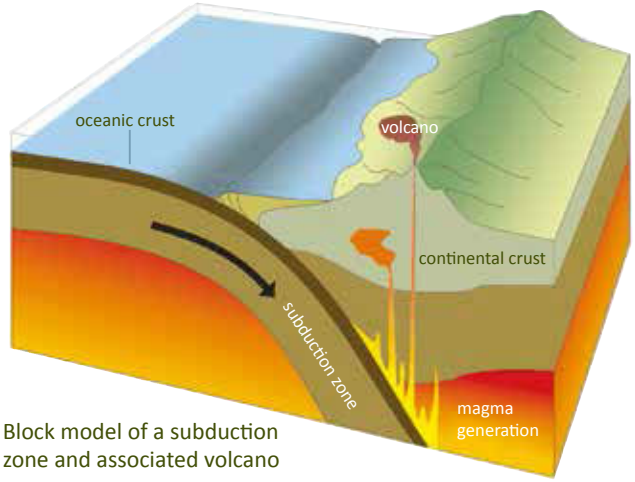



An unconformity represents a time period and the events that deformed, folded and eroded the lower rock sequence. Younger rocks lie flat on top of them.

## Plate tectonics

Around 50 years ago there was a radical leap forward in our understanding of how the Earth works. The skin or crust of the Earth is made up of mobile plates which move around. The term used to describe this movement is ***plate tectonics.*** At some margins between plates, magma rises to create new crust. At others, one layer of crust slides beneath another in a subduction zone, often creating volcanoes in the process. At other plate boundaries there is sideways displacement, such as the San Andreas Fault in California. Any of the slow movement of plates or volcanoes can cause earthquakes and even tsunamis. If two continental crust areas are pushed together then mountain building can occur – or orogeny. The Alps and the Himalayas are two such modern mountain chains.

Plate tectonics is important for understanding the development of the land mass of Ireland. Ireland was once in two very separate 'halves' that were separated by an ocean that geologists call Iapetus. The two halves joined together more than 400 million years ago when the Iapetus Ocean was closed by plate tectonic movements (see the story panel on page 15). This Caledonian orogenic episode left its mark in the uplands throughout Ireland. However a later orogeny, the Variscan mountain building episode, affected the southern part of the country, mostly in Cork and Kerry but its effect was felt in Clare in more subtle folding of the rock layers, or strata.




Block model of a subduction zone and associated volcano

## Mapping rocks

In this book, for some sites, some rocks are referred to by names such as **Formation** and **Group**. If a geologist is mapping, he or she would look at all the characteristics of rock exposures. If consistent characters are seen across an area then those units may all be defined as one formation with a local name (e.g. the Ballymalone Formation is found near Tuamgraney). A formation is a mappable unit of similar rocks. Several formations in the same succession across a wider area, or a very large area of broadly similar rocks may be classed as a Group. The Central Clare Group, for example, is mapped across most of West Clare.

To learn more about geology, the book *Understanding Earth Processes, Rocks and the Geological History of Ireland* published by the Geological Survey of Ireland is recommended as the best source. See page 63.

| PERIOD | SERIES | GROUPS | FORMATIONS | MILLIONS OF YEARS (AT THE BASE) |
|---|---|---|---|---|
| Carboniferous | Namurian | Central Clare Group | | |
| | | Shannon Group | Gull Island Formation<br>Ross Sandstone Formation<br>Clare Shale Formation | 318 |
| | Viséan | | Magowna Formation<br>Slievenaglasha Formation<br>Burren Formation<br>Tubber Formation | 347 |
| | Tournaisian | | Waulsortian Limestones | 359 |
| Devonian | | | | 419 |
| Silurian | | | | 443 |
| Ordovician | | | | 485 |

## What is a County Geological Site?

Prior to the audit of 2005, the geological interest of many sites included here was really known only to a small number of geologists. The classification of County Geological Site (CGS) was included in the National Heritage Plan of 2002, at the suggestion of the Geological Survey of Ireland. This is on a non-statutory basis and serves to recognise the scientific geological interest, the educational value or other importance of a site, without placing any new impositions or responsibilities on the landowners. However, no site can be damaged or destroyed unknowingly by a new development, once it is included within the Clare County Development Plan and in the planning system of the Local Authority, since there will have to be consultations if any development is proposed that affects the site. County Geological Sites are adopted into the County Development Plan, with an objective to protect them.

In the absence of the resources for the National Parks and Wildlife Service to designate geological Natural Heritage Areas (NHAs) in partnership with the Geological Survey of Ireland, the CGS scheme is the only effective protection for geological heritage in the short term. It has been successfully implemented since 2002, with 17 county audits completed and many other counties adopting a provisional list in their County Development Plans.

However, the audit of County Clare's geological heritage in 2005 was at the earliest stage of such audits, and was based on the best information available to the Irish Geological Heritage Programme in GSI at that time. Through completing many more counties since, the process has evolved considerably. The vision of what County Geological Sites could encompass has expanded, to extend beyond what was on the list of scientifically important sites, to include amenity sites and educational sites, with publicly accessible geology. A future supplementary audit, may lead to a bigger second edition of this book.

The full geographical extent of sites can be seen on the Public Data Viewer option on the Geological Survey of Ireland website: www.gsi.ie/Mapping.htm

# East Clare

## — Uplands of Ancient Oceanic Rocks

Caher Hill in the foreground

East Clare landscape near Broadford

Slieve Bernagh from the south

East Clare has the oldest and more complex succession of rocks in the county. The uplands of Slieve Aughty, Slieve Bernagh and the Cratloe Hills are all composed of Silurian rocks. They are mostly mudstones, siltstones and sandstones that were deposited on an ocean floor, but then swept up in the Caledonian mountain building event (or orogeny) to become some of many similar areas across the southern half of Ireland. Even older, Ordovician rocks also occur as small faulted areas of rocks at Ballyvorgal in the south west end of Slieve Bernagh and near Feakle in Slieve Aughty.

The Caledonian mountain building event left the former ocean floor sediments as hard rocks in mountain chains. Naturally, erosion and weathering set in, and during the Devonian Period, these mountains were much reduced, with coarse sediments such as sandstones and conglomerates being deposited by rivers across the land surface. These accumulated as a blanket of rocks on and around the Silurian rocks, now widely seen across the plateau areas as rough, red coloured pebbly sandstones.

The Silurian and Devonian sandstone rocks comprise most of East Clare, but the beginning of the Carboniferous Period, around 359 million years ago, saw the low lying eroded areas begin to get covered by the sea, as sea level rose. As Ireland was situated in warm tropical areas at that time, the sediments formed in the sea were limestone. Such deposits now occur in the valley from Tuamgraney towards Ennis and in the southern areas bordering Limerick and into the Shannon Estuary.

# Ballyvorgal South

Small rock exposures occur in the stream along the edge of the forestry. Limerick City and the River Shannon are seen in the distance.

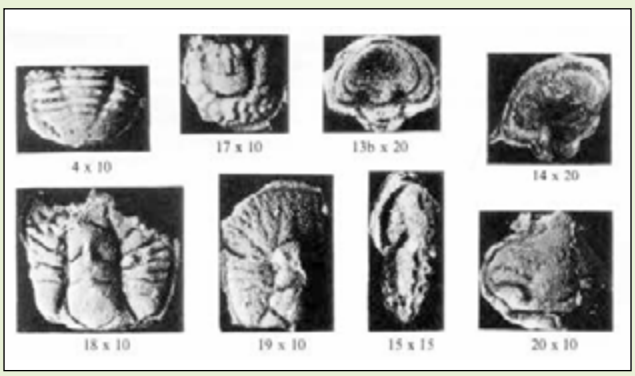
## Geological Interest

The Ballyvorgal site is where an unusual collection of fossils was made. The fauna has been well described and contains a characteristic mix of very small trilobites and tiny brachiopod shells. The type of assemblage at Ballyvorgal is from very deep water environments on the outer part of continental shelves, but from the Ordovician Period, around 450 million years ago (see study topic on page 15).

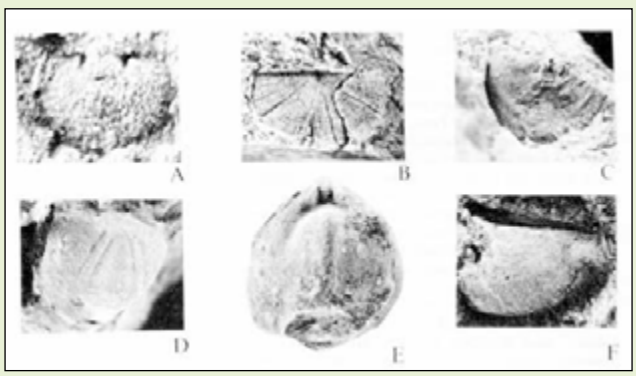
As well as providing information on ancient biogeography, Ballyvorgal is an important site for understanding and dating the rocks of Slieve Bernagh. This site is the type locality for five species of trilobite – they were originally described as species based on fossils collected at Ballyvorgal.

## Visiting Ballyvorgal South

The site is on private farmland, poorly exposed and not suitable for visiting.




Some typical trilobite fossils from Ballyvorgal. Each mould of the original shell is only 1-4mm in width




Some typical brachiopod fossils from Ballyvorgal. Each mould of the original shell is only 1-4mm in width

# Ballycar South

Although no rock is exposed, the broad grassy ridge is underlain by the debris flow rocks. Limerick City is seen in the distance.

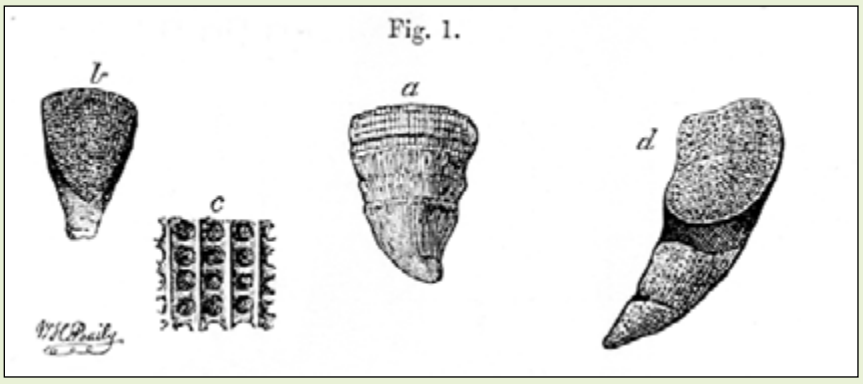
## Geological Interest

Ballycar South is an important site as the rocks here, which are presently not exposed at the surface, have yielded a very diverse assemblage of fossils of brachiopods, corals, gastropods, trilobites and bryozoans of Silurian age. These rocks were deposited by a submarine debris flow. This means that a mixture of sand and pebbles, which became unstable, moved downslope under its own weight, perhaps triggered by an earthquake. The debris was transported from a shallow sea floor into a deeper marine basin, taking with it and preserving many of the inhabitants of the environment at the time.

Although presently no rock is exposed the site has potential for further investigation as the nature of this type of deposit means that it could yield very new and different species. Such debris flows of this age are rare in Ireland but Ballycar is the best studied and has the richest fauna.

## Visiting Ballycar South

The rocks are presently unexposed, and on private farmland, so unsuitable for visiting, although the view from the public road shows a broad grassy ridge underlain by the debris flow rocks.




Reproduction of an original woodblock print from the GSI Memoir for one inch Sheet 142, of a 'new' coral species from Ballycar. It was named *Petraia dunoyeri* by the GSI Palaeontologist William Hellier Baily, after his colleague George Victor Du Noyer in 1860. Three different perspectives are shown plus a close-up of detail.

# Ballymalone

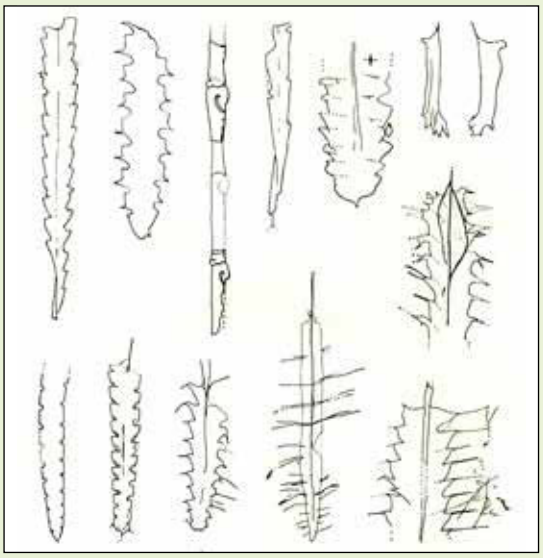
The shales in Ballymalone Quarry are iron rich and there was a chalybeate (iron impregnated) spring in this vicinity.

## Geological Interest

Ordovician rocks here have been dated by graptolite (extinct marine planktonic animals) fossils from the streambed, adjacent to the quarry in 1969. The site provides the only representative section of these rocks in the northeastern part of the Slieve Bernagh area, and therefore complements the Ballyvorgal South site. The availability of fresh, good exposures in the quarry offers great potential for more detailed research on the graptolite fauna.

## Visiting Ballymalone Quarry

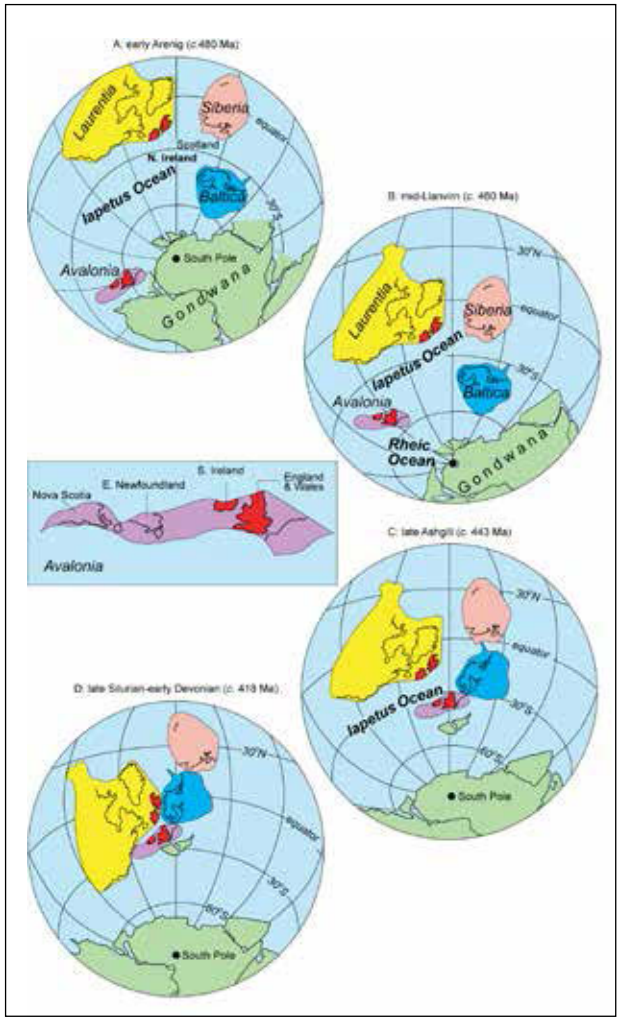
The site is largely of academic interest as a good place to see reasonably fresh exposure of the Ordovician Ballymalone Formation with potential to study graptolite fossils, but as private property, it should only be visited with the permission of the landowner.



Outline sketches of graptolite fossils from Ballymalone. They often look like little saw-toothed pencil streaks.

# The Iapetus Ocean: a tale of two halves

Ireland is made up of two 'halves', which were originally separated by an ocean that geologists call Iapetus. The axis of the Iapetus Ocean ran along a roughly southwest-northeast trending line through central Ireland from the Shannon Estuary to Clogher Head in Co. Louth. The Ordovician and Silurian rocks in the Clare area were deposited on the northwestern side of Iapetus in deep waters.




The northwestern half was on the margins of a North American continent; the southeastern half was on the margins of the European continent, on a microcontinent called Avalonia. Plate tectonic movement throughout the Ordovician Period gradually forced the land masses on either side of the Iapetus Ocean together. Ireland's two halves converged and eventually combined in Silurian times. Rocks hidden in County Clare tell only a small part of this story.

A graphic of schematic globes shows the passage of Ireland as two halves on either side of the Iapetus Ocean closed together through time, beginning with the oldest at the top, moving down from 480 to 460 to 443 to 418 million years ago (please note that the relative size of Ireland and Britain has been exaggerated for clarity).

In plate tectonic movements (see page 8) of the Earth's crustal plates, new crust is generated at ocean spreading ridges (for example in Iceland and down through the Mid-Atlantic Ridge). When this happens, it is balanced by the destruction of crust beneath a subducting plate elsewhere. Subduction involves a plate, usually of thinner oceanic crust, sliding under another plate and being melted back into the Earth's mantle. This happens at depths of 30km or more. Where continental crust occurs, it is less likely to be subducted: instead, the plates push together and buckle up into mountain ranges. The Alps and the Himalayas were formed in this way. Many of Ireland's rocks are slivers of crust that slid together along transform faults (like the famous San Andreas Fault in California), which compensate for various stresses and allow plates to move sideways.

# Caher Hill

## Geological interest

Hill exposures of Ordovician volcanic rocks, graptolitic shales and cherts on Caher Hill are classified and mapped by geologists as the Caher Hill Formation. Volcanic lavas known as trachytes overlie a succession of black shales and cherts and breccias. These rocks collectively provide a record of sedimentation and volcanic eruptions within the contracting Iapetus Ocean, during the Ordovician Period (see study topic on page 15). Graptolite fossils found within the black shales have provided evidence of the age of the rocks.

## Visiting Caher Hill

These rocks are on private land and not suitable for general visits. They are not especially well exposed, so primarily are only of specialised scientific interest.

Sparse scattered rock exposures are found on Caher Hill.

# Maghera TV road quarry

Maghera Quarry in 2004

## Geological Interest

A type of volcanic rock called olivine-pyroxene tuff is exposed in a small quarry along a private road. The quarry is within a suite of Ordovician rocks which include volcanic rocks such as spilite, pyroxene-olivine basalt, basic tuffs, volcanic breccias and amygdaloidal trachytes, as well as graptolitic black shales and cherts. This quarry is one of very few places where this part of Clare's geological history is actually exposed.

## Visiting Maghera TV Road Quarry

The quarry is not suitable for visiting.

# Kilbreckan Mine

The chimney remains are cloaked in ivy, but only fragments of the steam engine house survive.

## Geological Interest

An abandoned mine site, engine house ruins and spoil heaps at Kilbreckan Mine, are a testament to lead and silver-bearing mineral deposits in cherty Carboniferous limestone and dolomite. It was worked intermittently for silver and lead from 1834 until 1856. The mineralised bodies contain silver-bearing galena, pyrite, chalcopyrite, sphalerite and calamine in a calcite host-vein. Other minerals include Bindheimite(a silver-bearing antimonite of lead), Bournonite (a sulphide mineral of copper, antimony and lead), Hemimorphite (a minor ore mineral of zinc), Quartz and Smithsonite (another zinc ore). In addition Kilbreckan is the type locality for the mineral 'Kilbrickenite' – now confirmed as the mineral Geocronite (a white sulphosalt mineral of lead). The main body of ore minerals, trending north-south, has a pipe-like shape and is up to 1m in width.

## Visiting Kilbreckan Mine

A good sense of the compact site can be seen from the public road, but it is not suitable for visiting. Much of the site is heavily vegetated, and individual shafts and other features are fenced off for safety reasons by the Exploration and Mining Division of the Department of Communications, Energy and Natural Resources. All shafts are flooded. There are areas and tracks with spoil (mostly white calcite, which was termed 'gangue' by miners as an unwanted material) where vegetation may not gain a foothold due to metal toxicity. However, the site has considerable mining heritage interest to specialists, as well as its mineralogical importance.


1850 plan of the site

## Historic mining and modern mineral exploration

Clare people might be more familiar with the story of characters such as Paddy Hannan (1840-1925) from Quin, County Clare, who discovered gold in Kalgoorlie, precipitating the greatest gold rush in the history of Australia, than they are with the local history of mining in Clare.

County Clare would not stand out in many people's minds as a significant mining district, like Avoca, Glendalough or Allihies, yet in the 19th Century there were many small mines operating in East Clare, and records of mineral finds, not all of which were economic to invest in. They were all developed on veins of lead ore, often silver bearing, within the Carboniferous Limestone.

There was an older group of small mines in the Ballyvaughan district, but the main area was in East Clare between Ennis and Tulla. Kilbreckan (see page 17), Ballyvergin and Ballyhickey were the three main mines, where steam engine house and chimney remains can be seen today, but Milltown, Carrahin, Crowhill and Moyriesk all had mine workings.

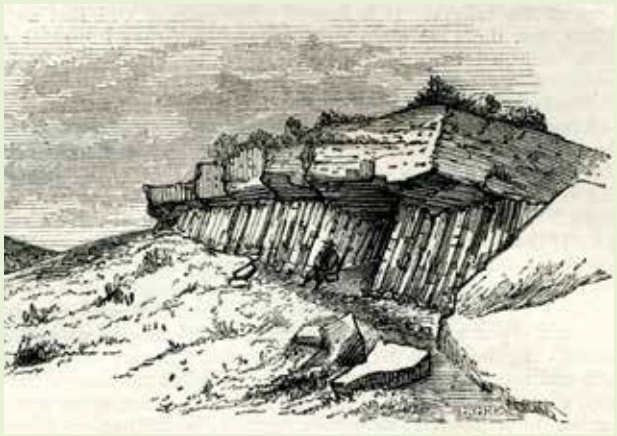
Mining history will show that the rise and decline of particular mines can be quite arbitrary, with many factors coming into play. With many, a small deposit of ore, such as a vein, can be worked out in a few years. With others the economics of supply and demand can cause a profitable mine to fail, if a new cheaper supply becomes available somewhere else in the world. Major demand for a metal, for example during wartime, can make an uneconomic deposit suddenly attractive enough to mine. Technological changes are also very important, along with advances in understanding of how particular mineral deposits formed.

All the above factors mean that old mine sites can become viable again, and there has been extensive exploration in the East Clare district in recent decades. The Government's Exploration and Mining Division issues Prospecting Licences to companies, who are required to complete an acceptable work programme and spend a certain amount of funds on exploration. The country is split into hundreds of prospecting licence areas, and for example, PL3679 which contains Kilbreckan has seen hundreds of boreholes drilled to assess the deposit, which might become a new mine in the future, if proved economic, and all appropriate environmental, planning and licencing is addressed. www.mineralsireland.ie has much information on this topic.

It is also worth noting that during the 17th century there was an iron smelting industry in the Slieve Aughty area on the western side of Lough Derg, based on bog iron ore and on some mineral deposits. Little now remains except some overgrown and ruined blast furnaces. www.furnaceproject.org is a website dedicated to these structures and their history, with Clare County Council support.

A modern drill rig, enclosed to reduce noise, operated by Lundin Mining in the mineral exploration at Kilbreckan.

# Ballycroum Hill



Sketch of the unconformity at Ballycroum Hill from the 19thC GSI Memoir

## Geological Interest

This site is a great place to appreciate the immense time involved in many geological phenomena. The site is an excellent example of an unconformity (see page 8). It has Devonian age sandstones and conglomerates overlying Silurian siltstones. Flat-lying conglomerate beds from around 380 million years ago are seen overlying the truncated ends of nearly-vertical beds of Silurian slaty rocks, originally deposited as mud and silt on the ocean floor around 430 million years ago. The time gap represented is approximately 50 million years, during which the Silurian rocks were transformed from their original oceanic sediments into hard rock, and then folded and tilted to their upright position. They were then subjected to erosion over an extended period. The land surface was worn down to a flat plain, nearly at sea level. The Devonian conglomerates lying above this eroded surface are deposits of rivers which occasionally flowed within a largely arid environment of the period.

## Visiting Ballycroum Hill

As the site is alongside the East Clare Way, it is reasonably accessible to view from the walking route.

# Sraheen Mushroom Stone

Sraheen Mushroom Stone

## Geological Interest

The stone in question is an example of a phenomenon classed as mushroom stones. These are thought to have formed when lakes existed for periods long enough for water to dissolve the limestone below the lake level. Emergent limestone above the lake level was not dissolved. In some cases an alternative explanation that the stem of the mushroom was buried by bog has been suggested. See the main discussion on these unusual stones on page 32-33.

## Visiting Sraheen Mushroom Stone

The stone can be seen over the roadside hedge. It has a long undercut on the side away from the road.

Sraheen Mushroom Stone

# Tuamgraney

The rundkarren are developed on the joint surfaces.

## Geological Interest

An isolated rock outcrop in the centre of Tuamgraney shows some Carboniferous limestone with well-developed karstic features. The green area, or Garden of Remembrance in the town centre is notable for the large tree, the memorial to Dr Edward MacLysaght (1887-1986) and the Marian Shrine. However, it is also a fine geological feature, displaying some beds of Carboniferous limestone, with a moderate dip of about 30 degrees to the north-west. They are characterized by solution runnels known as karren, running down the exposed surfaces. Such weathering features are more usually seen in the Burren.[see study topic page 26].

## Visiting Tuamgraney

It is reasonably straightforward to find in the centre of town, and is fully accessible. However Cotoneaster plants on the south side are beginning to obscure the geological interest.

The beds dip gently northward.

# Rineanna Point, Shannon Estuary

The Waulsortian limestone at Rineanna Point is heavily karstified with various types of karren (see page 26).

## Geological Interest

The base of Carboniferous Waulsortian limestone is exposed on a shore section on the southern shore of Rineanna Point. Waulsortian Limestone is a particular type of limestone that formed as mounds of carbonate mud on the sea floor. Only a thin sequence is exposed as it is very low lying ground. The limestone is heavily karstified, with karren and kamenitza (solution pits) – see the study topic on page 26.


## Visiting Rineanna Point

The natural coastal exposures, close to the Shannon Airport runways are not easily accessible without having to cross private farmland to access the foreshore. It is advised to check locally before attempting to visit the rock section.

# Tomeens

The roof collapses in Tomeens bring daylight into the wide meanders of the subterranean river.

## Geological Interest

This site has an unroofed and partially roofed active river cave. It is developed within Waulsortian limestone. The Tomeens consists of a linear river cave on part of the Tomeens River. There are 10 caves in total, each separated by surface collapses. The amount of surface collapse is not surprising owing to the fact that there is rarely more than 2-3m between the ground and the roof in areas where the cave has a width of 10-15m. Also of interest are a number of stream oxbows and dry oxbows, where the part of the river has been abandoned in favour of a more direct route. Many factors including surface collapse, tree roots forcing open joints in the limestone and humic acids (derived from rotting vegetation) dissolving the limestone will see the cave eventually becoming an open canyon with the river downcutting its limestone bed. The site was originally a significant tourist attraction and drew lavish praise in the 18th and 19th centuries.

Inside a part of Tomeens

## Visiting Tomeens

The landowner may provide tours for groups by arrangement, but it is on private land and permission must be sought from the landowner in advance.

# North Clare

## – The Burren limestones and karst landscapes

No gold at the end of this rainbow, only limestone in the Burren National Park.

Vigo Cave

Dramatic limestone cliffs at Ailladie on the coast road south of Fanore

North Clare as defined here is also known as the Burren, and is an iconic landscape in Ireland – purely because of its geology and the interaction of water with the geology, and the way humans have adapted to that landscape. The combination of a thick succession of limestone beds, ordered in nearly horizontal layers, capped on many hilltops by shales, along with the scouring erosion of the Ice Age has created a distinctive landscape, which we term a karst landscape.

The term karst generally implies a landscape of bare limestone, characterised by underground drainage, with a suite of specific landforms such as limestone pavement, dry valleys, enclosed depressions, sinkholes for streams, caves and resurgent springs. In the Burren the limestone was covered by shale rocks, providing an impermeable barrier to water, so surface streams on the shales often sink underground immediately on passing onto limestone rocks. The combination of shale caps and bare limestone has greatly influenced the development of the characteristic landforms of the Burren, but the shale cap was greater before the various advances of ice sheets over the area in the last 2 million years, so geomorphologists can have great fun working out the details of the evolution of the Burren.

Ice sheets scraped lots of rock clear allowing the sculpture by water of the limestone. In other parts ice carried and deposited till – a ground-up mix of rocks and clay, that provided soil, so we get the contrasts of green grassland on till, abutting grey rock platforms.

Of course the limestone itself has much interest and the sites described are separated into sections within the North Clare chapter. They are grouped into karstic landscapes, caves, mushroom rocks and those sites with limestone and fossils of interest.

# Karst

Karst has its own set of terms for the particular features that form when acid rainwater dissolves limestone rock. These are featured here with photographs to explain them without long descriptions, but there are many others beyond these few common types.

Kamenitza or solution pans are shallow depressions in pavement surfaces that capture water and often have algal crusts in their base. The edges are often quite fretted and sharp.

Rillenkarren are narrow, sharp-edged solution grooves formed on steep limestone faces.

Doline is the term for an enclosed depression such as this small one near Poulnabrone.

Across the Burren, both on bare limestone pavement and in grassy areas, single large boulders are found. These are erratics, left behind by the ice sheets as they melted

Limestone pavement is composed of clints (the upstanding blocks of rock between grykes (the expanded joints).

Rundkarren are larger runnels in the limestone pavement formed under soil cover.

## Other terms you should know:

**Polje** is the term for a large enclosed depression such as the Carran Enclosed Depression (see page 28)

A **Turlough** is a seasonal lake, in karstic areas, where the water fills and empties from specific sinks and risings, usually with an impermeable floor of lake marl, and a range of specially adapted flora.

## Karstic landscapes

The following sites are large areas showing a wide range of karst landforms and geological interest. It is difficult to encompass everything in a short piece in this book, but the further reading suggestions (see page 63-64) will lead you to other information if you wish to explore further.

# Aillwee Hill

Mill Sink in winter, one of hundreds of karstic features of interest in this site

### Geological Interest

This site, located on Aillwee Hill in the north-central part of the Burren, contains the densest concentration and best examples of classical karst features in Ireland. These features, including springs, sinks, fossil caves, dry valleys and various enclosed depressions or dolines may have developed since the Pliocene (since 5 million years ago) by streams flowing off a former shale cover which was impermeable and insoluble. The shale was then eroded off by later ice advances, leaving bare limestone.

A series of discontinuous dry valleys, 20-50m wide and 5-20m deep, dissect the summit and flank areas of Aillwee Hill. The most complete valley is located at Ballymihil. These dry valleys go towards the large and deep Glensleade doline (with a floor area of 1.5km$^2$) and record the disintegration of a fluvial drainage system on shale into a doline-oriented karstic drainage system.

A large complex doline (an uvala) is situated at the summit of Aillwee Hill. This is the largest and most spectacular such diagnostic karst feature in Ireland. Numerous smaller dolines occur on the summit plateau and several small springs and sinks occur in the valleys and depressions.

Other karstic features in the area include fossil cave systems. The best developed are Maze Holes, a linear network of passages that honeycomb a limestone spur in the summit uvala. These caves, formed when the watertable was some 250m higher than at present, must be of great antiquity.

### Visiting Aillwee Hill

This is a large site with many landowners, with some areas locally accessible via public roads around the site, footpaths and in public visitor sites like Aillwee Cave.

# Carran Enclosed Depression

Carran Enclosed Depression in wet winter conditions, looking northeast

## Geological Interest

The Carran depression is the largest karstic enclosed depression in Ireland and Britain. It is approximately 4.5km2 in area and 40m deep, implying a considerable length of time for development. The depression is divided into sub-enclosed basins and is ringed by moderate to steep slopes. Water enters the hollow via springs and exits via the Castletown sink in the south. The waters are traditionally thought to re-emerge at the Fergus River Cave and other Fergus valley springs. Under wet conditions much of the floor of the depression becomes flooded even though the 'watertable' is some 120m below the floor of the feature. The structure and hydrology of this depression resemble a polje (very large closed depression in a karst area).

## Visiting the Carran Enclosed Depression

A series of public roads through the site allow a good range of views and close-up familiarity. The higher ground around offers the best perspectives, especially from the viewing point with information panel beside Cassidy's Pub in Carran.


Carran Enclosed Depression

Carran Enclosed Depression in dry conditions in the autumn, looking across the Castletown River sinks

# Mullaghmore/Slieveroe/Knockanes

Mullaghmore viewed from the south

## Geological Interest

The isolated mountains of the Mullaghmore – Slieve Roe – Knockanes site hosts many interesting features including spectacular limestone terraces and pavements, which have developed on the flat and inclined limestone beds. A diverse range of sub-aerial karren features (see page 26) are found at this locality. Densely scattered limestone erratics are the best such examples in the Burren region. Other features of note include the ancient Glenquin gorge, the marl floored Lough Gealáin and the abandoned cave at Gortlecka, which has large scallop shaped depressions preserved in the walls indicating slow moving water dissolved them away. Movements deep within the earth's crust were responsible for the formation of the Glenquin Gorge, which appears to be quite a shallow feature to the north but becomes cliff-sided to the south. Lough Gaeláin, a pseudo-turlough, is a shallow lake with interesting marl deposits and some mushroom stones on the northern shore. The Mullaghmore – Slieve Roe – Knockanes site is a very important karst site, but extremely little scientific work has been done here. It has great potential for academic study.

## Visiting Mullaghmore/ Slieve Roe/ Knockanes

The site is mostly part of the Burren National Park, and is therefore accessible to all free of charge. Since it is largely a wilderness area, sensible precautions must be taken if going hillwalking to explore the landscape. However, designated walking trails are the best introduction to the area.

Illustrative woodblock print sketch from the 19th century GSI Memoir

# Poulsallagh

Poulsallagh seen from the roadside in stormy weather. As well as the karst affected by organism such as sea urchins, there is a large storm beach of blocks tossed inland by large waves.

## Geological Interest

At Poulsallagh Bay and the coastal section immediately to the north of it, a compact area of foreshore exhibits a sequence of biochemically dissolved karren landforms (mainly hollows 1-50cm deep and 5-300cm wide) that is the equal of any site in the world. Karren formation at this locality is a result of respired carbon dioxide dissolving the limestone as well as the boring and burrowing activities of marine life and algae. Direct dissolution of the limestone by seawater is of negligible significance. The karren forms become increasingly well-developed towards low water mark, reflecting the increase in life.

Eroded glacial deposits have protected some of the limestone from solutional erosion. On the south side of Poulsallagh Bay, where part of this protective layer has been eroded away, smooth, karren-free limestones are exposed and still preserve glacial striae (scratches from rocks at the bottom of the moving ice sheets). The northern part of the site includes remnants of cave passages, some with quartz rich sediments derived from across Galway Bay. These erratic rocks (normally large rocks left by glacial ice, unrelated to the local bedrock on which they rest) are evidence of an earlier glacial till removed from the Burren area by a more recent ice movement. The area provides an ideal teaching environment and fuses biological, geological and geomorphological processes.

## Visiting Poulsallagh

Traditionally permissive access has been allowed to visitors along this shore area.

# Sheshymore

Sheshymore limestone pavement

## Geological Interest

Sheshymore hosts an extensive area of undisturbed limestone pavement with well-developed karren forms. Tabular blocks of limestone or clints are elongated in an east-west direction. Curved joints and crosscutting joints are common in the southwestern area producing triangular clint blocks. The central and eastern areas of pavement are smooth and predominantly karren-free suggesting previous burial beneath a protective layer of calcareous glacial till. Grikes are deepest in this area (1.5-2.5m). Karren forms in this area include solution pans (or kamenitza; shallow pools in the limestone), rundkarren (rounded grooves) and meanderkarren. Physical and chemical weathering has resulted in the decay of the peripheral limestone pavement to clitter and vegetated rocky grassland.

In the Burren, traditional animal farming practices have prevented scrub encroachment onto limestone pavement and onto the orchid and species rich limestone grasslands. This is an ongoing issue with projects encouraging farmers to maintain these practices for conservation purposes in a changing world. Without such projects, hazel and other scrub would rapidly engulf the limestone pavement areas.

## Visiting Sheshymore

There are no safe car parking areas along the roadways near Sheshymore, and it is on private farmland so not suitable for visiting.

# Mushroom Rocks

The great number of mushroom rocks or mushroom stones included in the County Geological Sites of Clare may seem like overkill, but with only around 70 of them known in the country as a whole, County Clare's rich representation of them deserves recognition. Offaly has as many, with the remainder scattered in only a few counties, like Roscommon and Galway. These rocks have always been considered as the result of former lakes dissolving away the lower part of the mushroom, the pedestal, leaving a cap undissolved by the lake waters. Such a combination of temporary lakes, perhaps impounded by ice sheets or by ridges of glacial moraine, is easily envisaged in the chaotic landscape following the last Ice Age. There are many that do not conform to the classic mushroom shape and simply have extensive undercut lips. Alternative hypotheses exist, including the most likely one, that these were dissolved away by acid soils or acid bog that have since been removed or which have shrunk away. The truth of every mushroom stone may never be known but there is great fascination in analysing each case.

Crossard Stone, near Corofin is one of the most 'mushroomy' of all the stones.

Ballykinnacorra North, near Corofin is one of the larger mushroom rocks.

One of the 4 Rinnamona stones is easily visible from the roadside in the water.

This is the largest of several stones at Coad near Inchiquin Lough.

Elmvale Mushroom Stone

Gortlecka Mushroom Stone

Turkenagh Mushroom Stones (at Ballyeighter in the Mullaghmore National park)

The Killinaboy Stone, easily visible from the roadside, is probably a remnant of a much larger suite.

## Mushroom rocks

Mushroom rocks are a rare geological phenomenon, with only about 70 examples known in Ireland, with many of these in County Clare. They have traditionally been regarded as the result of temporary lakes dissolving away the lower part of large limestone exposures, leaving an upper cap resting on a narrow pedestal in a mushroom shape. However, a great many do not fit the classic mushroom shape, and are weirdly shaped rocks characterised by undercut lips that suggest they have been below a water level. It is very easy to envisage temporary lakes existing for periods after the Ice Age, as ice melted and was impounded both by ice and dams of glacial moraine, in a chaotic landscape. It has proved difficult to prove direct correlation of levels of undercut lips on multiple stones within clusters of them in the same area. Hence, another possible scenario for their development is that the base was dissolved by acid rich peat bogs or soils that have since been eroded away. The jury is undecided and research continues on these fascinating rocks. For a more detailed picture of their national distribution, their origins and some associated folklore, there is a dedicated website: www.ucd.ie//gpep/mushroomstones/index.html

## CAVES

A cave in general terms is any underground hole that is big enough for humans to get into. The vast majority of caves, throughout the world, are naturally formed. They are created by slightly acidic rain water dissolving limestone. The rain seeps into bedding planes or joints and gradually enlarges them. Active caves are ones where water still flows through them, like most of the Burren caves. If the groundwater has since found new paths, a cave can become inactive or relict, and may become filled with mud, such as Vigo Cave.

# Coolagh River Cave

The Coolagh River sinks underground into cave passages which may quickly flood to the roof level with rain.

### Geological Interest

The Coolagh River Cave is a mature cave system with many subterranean and subaerial karst features. It is a dendritic cave system (branched like a tree) with several stream sinks / swallow holes. The Coolagh River sink is at a karst window, at the end of a blind valley. The Coolagh River Valley, which continues southwards as a normally dry valley within the site, is also one of the major surface features of the Burren. A classic collapse doline (Poulnagun) intercepts the Coolagh River stream. The drainage is proven to resurge at Poulsallagh on the coast to the west (see page 30).

### Visiting Coolagh River Cave

Whilst the cave is of scientific importance it is also an especially dangerous cave, which can flood to the roof extremely rapidly in response to any rain on the land surface. Very little of the sinks and blind valleys of the complex cave system can be seen from adjoining roads.

# Glencurran Cave

The entrance to Glencurran Cave, which is now gated

Helen Sheridan in Glencurran cave illustrates how low the crawling space is within the cave.

## Geological Interest

Glencurran Cave is a significant cave with a diversity of interest. It is a challenging cave for recreational speleology, since most of it has been dug to gain access to 700m of passage. It is largely, an earth filled, wide cave passage, with short sections of active stream cave. It has considerable geological and speleological potential as the most likely intersection to an undiscovered cave between Castletown River Sinks in the Carran Enclosed Depression and the supposed risings at Fergus River Cave. The cave entrance is on the side of the Glencurran dry valley. It also has considerable archaeological importance, with recent excavations in the short entrance area showing episodes of activity in the cave from Neolithic to late Medieval times.

## Visiting Glencurran Cave

The cave is well hidden by dense hazel scrub and difficult to find but it is unlikely to be of interest for general public visits. This cave is visible from within the Burren National Park, but the entrance is in private ownership. It is now grilled to protect the Lesser Horseshoe Bats, which are rare and endangered and are a protected species under the European Communities (Birds and Natural Habitats) Regulations 2011.

Excavations by Marion Dowd recovered evidence of Bronze Age religious rituals and Early Medieval occupation.

# Fergus River Cave

The Fergus River Cave is also a stream rising and heavily vegetated.

## Geological Interest

The Fergus River Cave is one of the oldest known in Ireland, with calcite deposits dated at greater than 350,000 years old. It contains more than 3km of largely abandoned streamway which floods in very wet conditions. Some of the water comes from the sink in the Carran enclosed depression. The cave is an abandoned rising for the Fergus River. It is notable also for mud stalagmites and for glacially derived sediments. Throughout the Burren and the Aran Islands, occasional erratic rocks of Galway Granite like those in Fergus River Cave are found, and they are evidence of the ice sheets that carried them over from Connemara.

## Visiting Fergus River Cave

The cave is unsuitable for any general visits, as it is on private land and also difficult to locate. It is dangerous even for experienced cavers in flood conditions, or after heavy rainfall.

# Vigo Cave

## Geological Interest

Vigo is a significant cave, approximately 200m long, unrelated to present day topography and containing entrance and deep cave sediments. Based on radiometric dating (using radioactive isotopes such as uranium and thorium) of calcite deposits it has a minimum age of 6000 years. The cave is unusual as it runs almost in a straight, SSW direction beneath the Namurian Shale cover. Although the precise nature of the cave's formation is obscure it is clear from the evidence above that its origins must be related to a topography very different to that of the present day. It has one of the best, undisturbed cave entrance areas in Ireland with considerable potential for fruitful archaeological and palaeoenvironmental excavation. The complementary interior cave sediments together with the distinctive morphology of the ancient cave make it a valuable karst heritage landform.

## Visiting Vigo Cave

As the cave is on private farmland it is not suitable for general visits. In any case, there is very little to see at the surface.

Vigo Cave

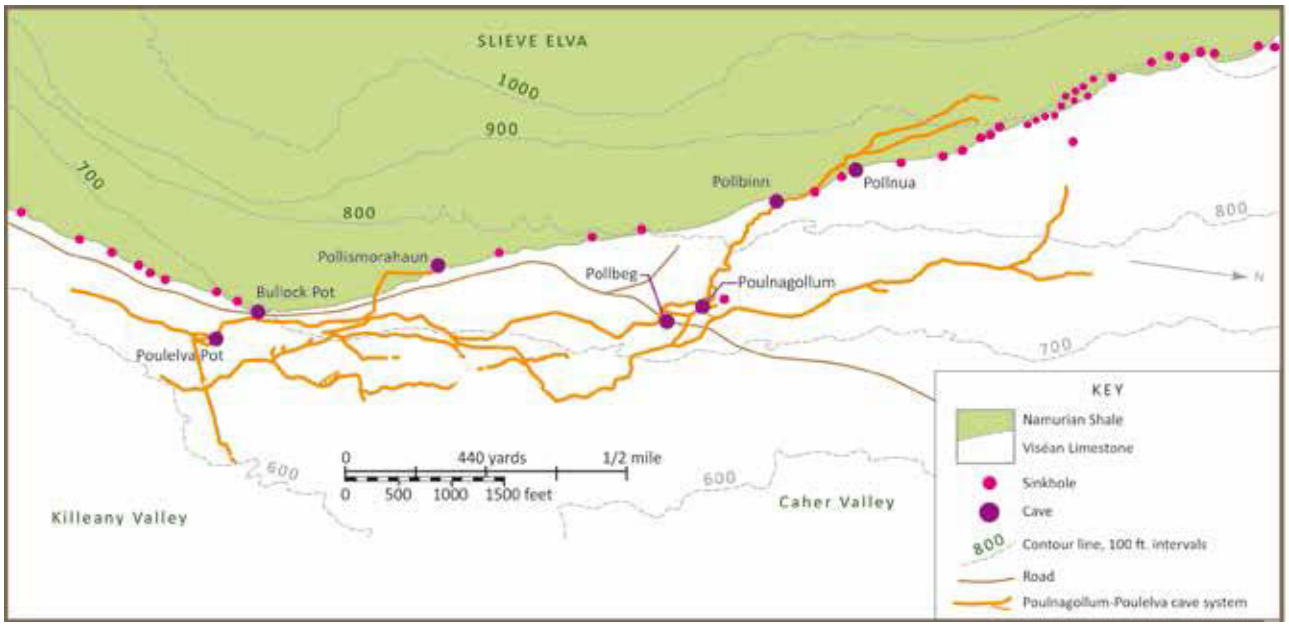
## Cave Formation

In the simplest definition, a cave is any underground space big enough for a human to enter. With only a few special exceptions, nearly all caves are naturally formed in limestone by water dissolving the rock. Most rain water, and groundwater that has passed through soils, tends to be acidic. Acids react with limestone, which is composed of calcium carbonate. The reaction gives off carbon dioxide and takes away calcium bicarbonate in solution.

The slow operation of this process over thousands of years can create sizeable cave passages. With some exceptions, most caves in the Burren are active stream passages that have formed in the last 10,000 years or so, since the Ice Age ended and ice sheets covering the area melted away.

However, in some areas such as around Mullaghmore there are few caves even though there is bare rock as far as the eye can see. In others, such as around Slieve Elva and Lisdoonvarna there are hundreds of caves. This can be explained by examining the role of the cap of shale rocks in the latter areas. In bare limestone areas, acid water penetrates every crack and joint and expands them, creating the classic limestone pavement, but not many caves. In the area where rainfall is onto shale rocks, it is concentrated into streams on the surface. When these pass from shale to limestone they are vigorous in dissolving limestone in concentrated points, and because the acidity is constantly renewed, caves and potholes (vertical shafts) can be formed quickly.

The location of many caves today is in the exact area of the margin of the shale rocks, and active streams continue to enlarge those caves. By analysing the location of other caves across a wide area of the Burren, geologists can see where the shale cover was formerly, before the last episode of glaciation eroded off the weak shale rocks which covered much of the High Burren.




The location of sinkholes in the limestone reflects the drainage of streams off the shale of Slieve Elva. The Poulnagollum-Poulelva cave system was developed earlier when the shale covering was larger, before the last advance of ice across the area.

# Doolin Green Holes

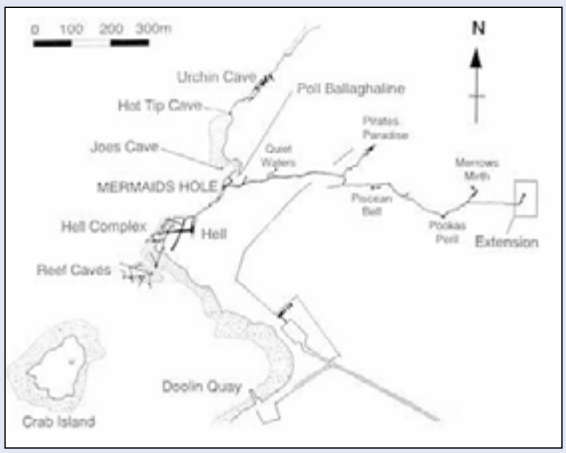
Looking southwest towards Crab Island

## Geological Interest

The Doolin Green Holes are cave passages that formed at a lower sea level than today when the water was trapped in huge ice sheets across the Earth's northern hemisphere. Since their formation, the caves have been inundated by post-glacial sea-level rises. Also of interest here are the photokarren and phytokarst. These erosional features, which are absent in the darkest parts of the cave, are the first of their kind to be recorded outside of the tropics. They are produced by the boring and solutional activity of algae, which has proved to be the main factor in coastal limestone erosion rather than chemical solution which is dominant in freshwater or subaerial settings.

## Visiting Doolin Green Holes

The site is a popular place for visitors generally to stroll to the Point from Doolin Pier. As with any limestone pavement areas, visitors must exercise sensible caution near sea cliffs, on the uneven rocks surfaces and particularly in windy or stormy weather. The caves themselves are only accessible to experienced cave divers in suitable calm sea conditions, through a rift (a narrow fissure) known to cave divers as 'Hell' on the headland.




Outline survey of submarine cave passages

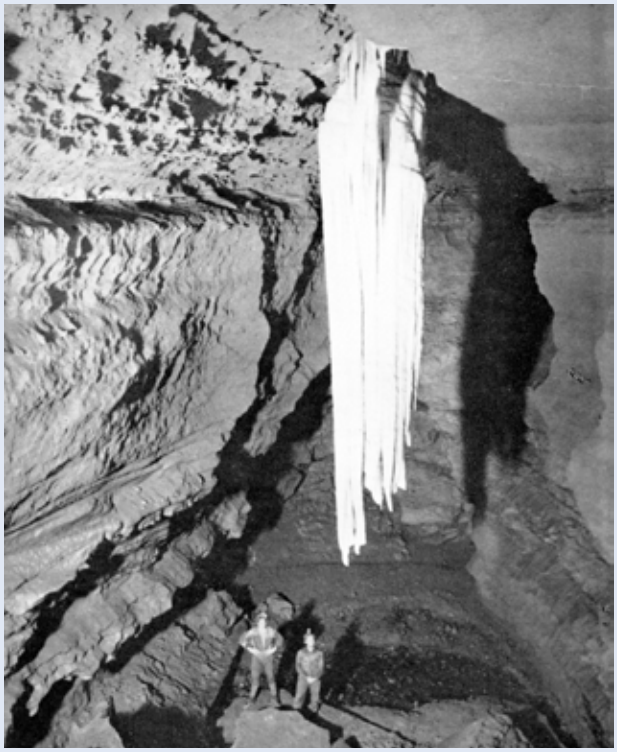
# Pol an Ionain (now open to the public as Doolin Cave Showcave)

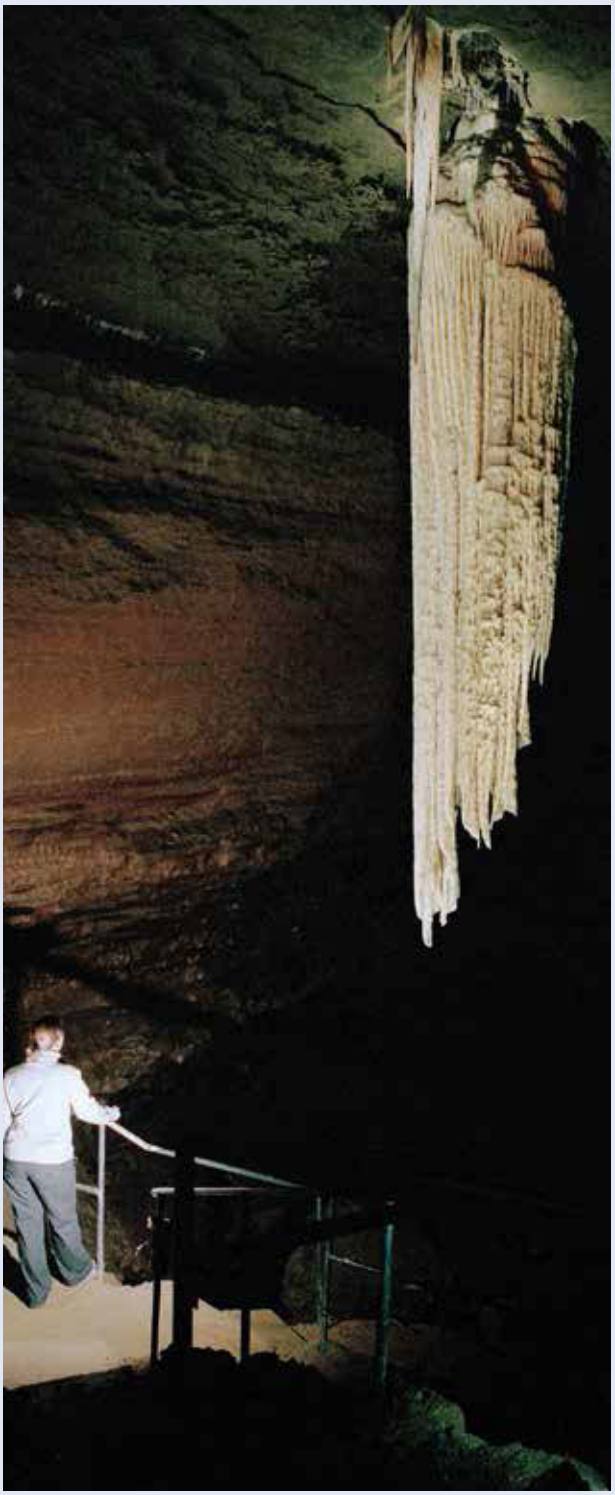
## Geological Interest

The cave is an ancient chambered cave, containing varved sediments (alternating layers of light and dark sediment, possibly from annual cycles of change) and a renowned stalactite (known as 'the Great Stalactite'), 6.541m long, which was once reputed to be the largest free hanging stalactite in the world. The sediments are potentially of great importance as a record of environmental and climatic changes over the time the cave has existed. As the cave contains the largest single chamber of the Burren caves, this accumulation of sediment is of great potential in analysis of landscape evolution, and Pol an Ionain, as an isolated chamber, has a good sequence of undisturbed deposits. These deposits have not yet been dated but are suspected to be relatively ancient since the chamber is large and unrelated to present day hydrogeological conditions.

## Visiting Pol an Ionain

The cave has been commercialised as a showcave. Visitors should consult local tourism information for opening hours and entry fees.

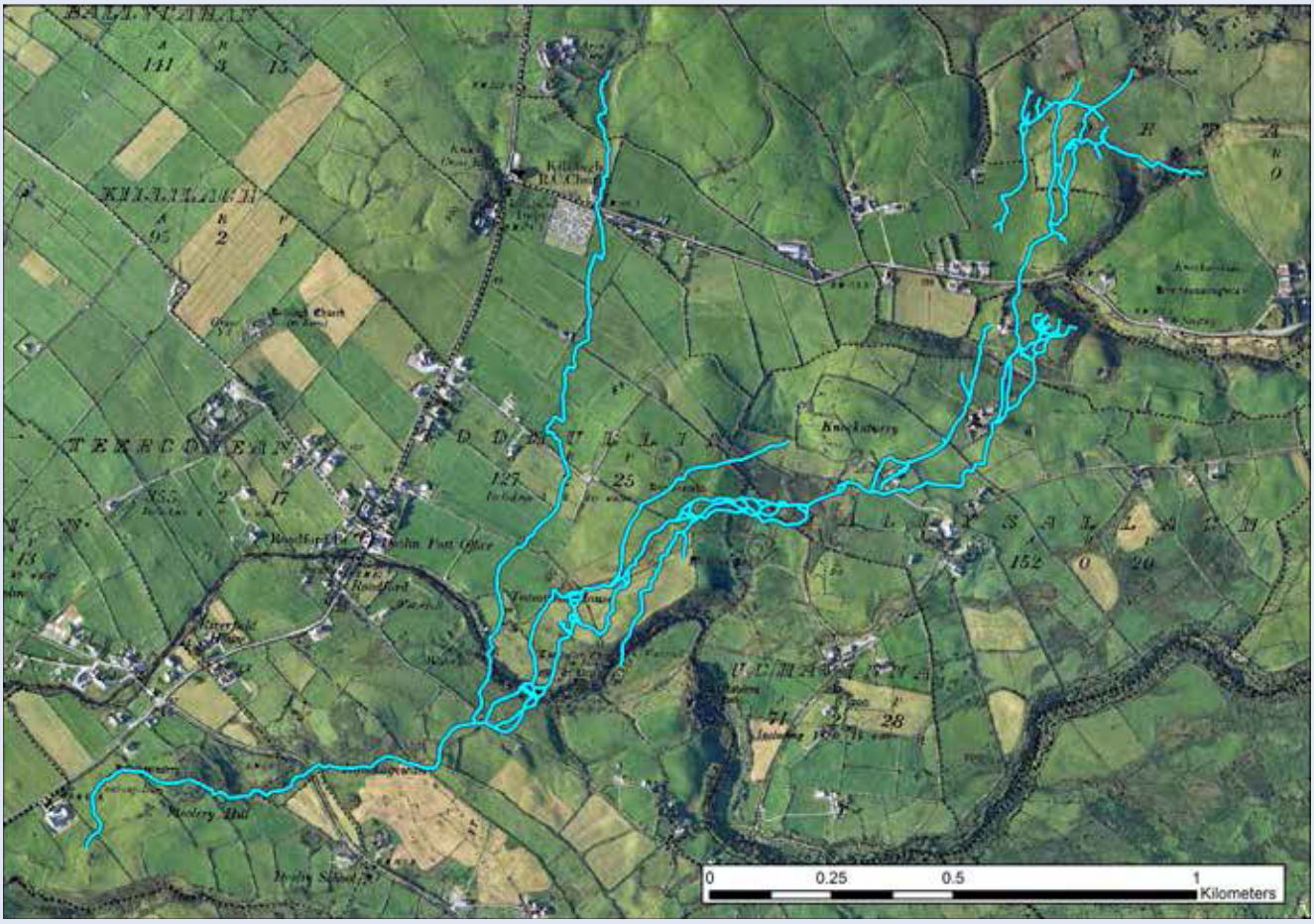




The Great Stalactite in Pol an Ionain hangs in splendid isolation.

Left: reproduction of cave and stalactite photo from Tratman (see page 63) taken before 1969.

# Doolin Cave




The underground route of Doolin Cave is superimposed on the Ordnance Survey six inch to the mile map and aerial photograph of Doolin to indicate its complexity. Many small branches have been omitted.

## Geological Interest

Doolin Cave, a dendritic (branching like a tree) network of more than 10 km of stream passages, is an active cave system, which has preserved various stages of cave development. The cave system developed as parts of the surface Aille River system formed underground routes that unite in a large single conduit. The entire Aille River sinks into the cave in its lower part in low water conditions. Access for cavers to the lower reaches is by Fisherstreet Pot in between Doolin and Roadford. This is a vertical shaft down to the main river.

## Visiting Doolin Cave

As a serious caving trip, with its attendant dangers, cavers should visit the cave in the company of experienced local cavers, with landowner permission. For the general public, only small windows into the system are visible from public roadways but the underground route can be traced on the surface.

NOTE: There is room for confusion, as this cave has always been called Doolin Cave or Doolin River Cave, and is unrelated to Pol an Ionain, that the showcave operators promote as Doolin Cave.

# St. Brendan's/Poulnagollum

The vegetation of rushes, grassland and forestry plantations on shale is a marked contrast to the bare limestone and pavement vegetation.

## Geological Interest

The St. Brendan's — Poulnagollum site includes St. Brendan's Well near Lisdoonvarna, the main rising for a significant area of karstic drainage focused on the Poulnagollum – Poulelva cave system on the eastern side of Slieve Elva. This is Ireland's longest cave system. With approximately 14km of total passage, much of which is active streamway, this cave exhibits many features of interest revealing a complex history of development. The most obvious control is the input of streams sinking at the limestone – shale margin along the break in slope below Slieve Elva. The two major potholes of Poulnagollum and Poulelva themselves probably reflect former major sinks at the shale margin in a preglacial or interglacial period.

St. Brendan's Well is located about 1 mile east of Lisdoonvarna along Gowlaun Stream. The lower Clare Shales are exposed in this stream overlying the Carboniferous Limestone. These deep-water marine shales define the base of the Namurian – this is the traditional junction between the Upper and Lower Carboniferous. One of the more notable features is the occurrence of a faunal band rich in goniatites. It is one of the few places in Ireland in which this horizon is exposed.

## Visiting St. Brendan's Well - Poulnagollum

As the longest cave system in Ireland, the Poulnagollum – Poulelva caves are routinely visited by experienced cavers and cavers should consult locally for current information on safe access with permission for the various entrance options. St. Brendan's Well is on private farmland and landowner permission should be sought for geological groups.

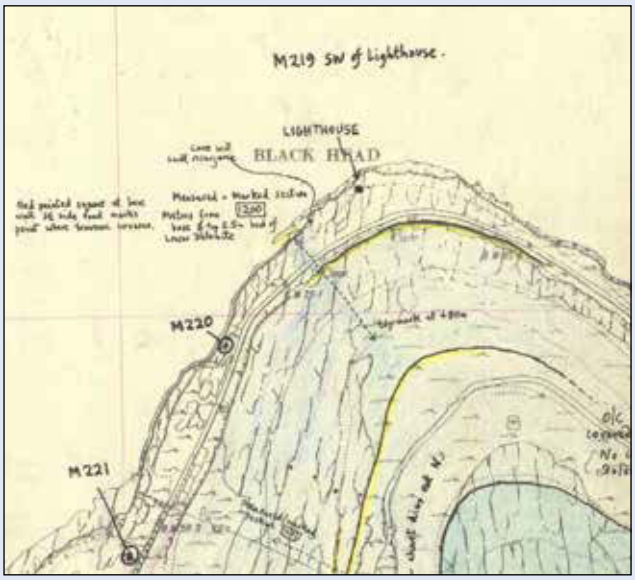
St. Brendan's Well area has easily-eroded shale, sitting on top of the limestone beds.

## Limestones and fossils

Much of the focus of sites in North Clare has been on how the Carboniferous Limestone has been modified by water to produce karstic landforms such as caves, enclosed depressions, mushroom rocks and others, but the limestone has an intrinsic interest that is included in the following sites. In particular at Black Head and at the Council Quarry, fossil corals studied there do tell us much about the environments at the time the rock was being deposited. Toonagh Quarry is an excellent reminder of how we also make use of rocks, and the vital role they play in providing the lifestyles we have come to expect.

# Black Head

Fossil corals are actually difficult to spot.




This map is a small extract of the detailed geological field maps of Conor MacDermot who mapped this area for the Geological Survey of Ireland.

The lighthouse at Black Head lies on extensive limestone pavement.

### Geological Interest

Limestone pavement with well-developed karst features is really obvious here. It is a good place for palaeontologists to see an evolutionary transition in Carboniferous corals from one form to another. The limestone inland from the road is mapped as a different unit from that below the road, as it is different in composition (it is dolomitic) and in the fossil corals it contains. There is also a good storm beach on the cliff top of boulders tossed up by storms.

### Visiting Black Head

When travelling around the coast road from Ballyvaughan, Back Head itself is marked by the lighthouse. There is poor parking at this landmark point on the coast road, but traditionally permissive access to the bare rock pavements is accepted. Please use the stile provided and follow the *Leave No Trace* guidelines. Caution must be taken near sea cliffs and terraces in the limestone bedrock.

# County Council Quarry

The floor of the County Council Quarry is now mainly used for storage of rock and chippings for road making.

## Geological Interest

Carboniferous limestones are exposed at the County Council Quarry, located 1.7km outside Lisdoonvarna. These well-bedded, dark grey limestones are rich in fossils. Fossils found at this site include crinoids, bryozoans and corals. These corals, in particular the coral *Orionastraea rete,* correlate with specimens found outside Ireland and help with a detailed age correlation for palaeontologists. Basal Namurian Clare Shales overly these Viséan limestones.

## Visiting County Council Quarry

The quarry is no longer active, but is used as a store for road materials so no access is possible without permission.

# Groundwater in Co. Clare

A significant proportion of public water supply in Clare comes from groundwater sources. In 1999-2000 a Groundwater Protection Scheme for the county was completed by the Geological Survey of Ireland. In May 2012 the Clare scheme was integrated into a full national Groundwater Protection scheme and mapping. Considerable revisions were made to the original scheme, particularly in assessing risk in areas where the bedrock is close to surface. Much of the Burren has been classified as aquifer that is extremely vulnerable to pollution, and Burren groundwater is a regionally important aquifer area in Clare. In karst areas there is rapid transmission of water through conduits in the bedrock, and little time for any pollutants, whether chemical or biological, to be attenuated by microbial action. So the problem of dumping of rubbish in the countryside, but especially in sinkholes in karstic areas is a great risk to water supplies. Long tradition of 'out of sight, out of mind', is unacceptable today, and requires attention wherever it occurs.

The County Council and the GSI have defined source protection zones around public supply wells. That for Ennis includes a zone of contribution that is nearly one third of the county in area. An interesting recent development has been the pilot extension of this approach to some of the smaller Group Water Supply schemes in Clare.

# Toonagh Quarry, Ennis

Limestone rock is widely used as aggregate, for chemical processes and other purposes as well as to make concrete blocks for building our homes and schools. Such rock quarrying is of great importance to the economy of County Clare.

## Geological Interest

This active limestone quarry, off the main Ennistymon road 3.5km north from Ennis on the Corofin road, is the best representative section in the county, other than karstic exposures in the Burren, for the typical Clare Burren Formation. The broad dip of the beds, and features of the overall sequence of beds can be seen in an always changing quarry. The high quarry faces allow a clearer picture of the way the rocks are oriented in three dimensions.

## Visiting Toonagh quarry

As an active working quarry there are safety issues which clearly mean that general public access is not possible, except possibly as an organised group by arrangement, with the permission of the operators.

## Limestone pavement protection

Karstic or water-worn limestone has an attractive and very tactile appeal to visitors, but a serious problem in the Burren area is the amount of despoliation of limestone pavement by unaware people playing with the rocks. The turning of slabs and wedging of them as uprights in the expanded joints (grikes) of the pavement is a widespread problem, as is the building of cairns of stones.

The attractiveness of water-worn limestone has long made it an attraction for gardeners. Pressure on Irish limestones such as in the Burren have probably increased since effective actions in Britain to protect their limestone pavement areas have taken effect, although the UK demand has probably reduced due to wide educational campaigns within the gardening community and including many TV gardening personalities. The designation of considerable areas of the Burren as Special Area of Conservation (SAC) under the EU Habitats Directive or proposed Natural Heritage Areas (pNHA) provides a measure of protection against wholesale removal of limestone pavement, but ironically outside of protected areas, there was some large-scale destruction of other limestone pavement areas in the past. Nowadays much of the farming community in the Burren is engaged with the Farming for Conservation Programme. It builds on the Burren LIFE Project 2005-2010, which was a partnership involving the NPWS, Teagasc and the Burren IFA. The new programme expands the trials to many farms, recognising the critical role of farmers in managing the land in the best manner for conservation of habitats and species, which helps maintain the underlying karst geology. The limestone pavement areas and calcareous grasslands are World renowned for their botanical diversity.

Such rock piles are vandalism, not art, in a natural landscape.

In past decades, the field clearance of limestone pavement and possibly mushroom rocks, was encouraged by EU farming policy and subsidies, but fortunately conservation awareness amongst farmers is now very high.

# West Clare

## – ancient deltas and coastal landforms

Spectacular rock structures are seen all around Loop Head.

The terrain of West Clare provides a strong contrast to the bare limestones of the Burren. Countless beds of shale, siltstone and sandstone provide the geological foundation with poor drainage and wet soils. Different vegetation and rushy fields clearly mark the boundary between limestone and shales from the Lisdoonvarna area across to Corofin but the whole of West Clare is characteristically quite different in appearance from the Burren region.

The Burren was probably all covered by the same rocks as are found in West Clare, but erosion has since largely removed them. As a succession of rocks, they represent delta environments which filled in a marine basin or shallow sea across the Shannon region. Muddy rivers carrying silt and sand into the Shannon Trough basin (see map on page 8) deposited their sediments in the limestone sea. A look at the Gulf of Mexico, and the Mississippi Delta, today provide a realistic comparison for Clare 330 million years ago.

It is probably a little known fact, but many hundreds of visitors to west Clare each year come from industrial and academic research units related to the oil industry. This is because the rocks displayed on the coast are comparable to what geologists and geophysicists are attempting to interpret from drilling exploratory wells in the seas around the world, especially in the Gulf of Mexico. West Clare is one of the few places where such rocks are displayed on land, with three dimensional sections visible on the coast. Preserving the sections for such purposes and developing solid links with the petroleum industry could be developed further and be advantageous for all concerned. One such measure is being undertaken by a team from UCD, part-funded by Griffiths Geoscience Awards through the Geological Survey of Ireland, and supported by Statoil. The team have been drilling boreholes 'behind the outcrop'. This means inland, away from the coastal sections, so that a more three dimensional picture is presented, and associated geophysical tools such as 'wireline logs' can be assessed. After a detailed feasibility study, it is planned that a geology centre where visiting groups can also examine these boreholes will also be built in the area, thus growing the geotourism potential of West Clare, as well as providing more education and outreach opportunities.

Sand volcano at the Bridges of Ross

# Roadford, Doolin

Small concrete building remains and spoil heaps can be seen from the road at Roadford.

## Geological Interest

In the river about 500m above Roadford, an outcrop of rock phosphate occurs at the base of the Namurian Clare Shales overlying the Carboniferous limestone. Phosphate mining has taken place here from 1924 to 1947, although there is little now remaining to indicate the works apart from overgrown spoil heaps and some building remains. The phosphate deposits were localised concentrations, which were concentrated enough to become viable to mine here. Some phosphatic nodules may be found in the shale exposures in the general area. They are also often concentrated at the base of stream caves locally. Although mining heritage remains are sparse, the unusual nature of this deposit makes it of some importance. Today this is part of the hidden heritage of the Doolin landscape.

In addition, the location of Doolin Cave underneath the Aille River has been used in karst text books as an example of the disconnected nature or heterogeneity of limestone drainage. However, since the removal of phosphate deposits from the Aille river bed, sinking of the stream into the underlying Doolin Cave (not the tourist showcave whose proper name is Pol an Ionain) has begun, suggesting that the impermeable phosphate layer was actually the controlling factor, which allowed a surface river to flow above and across the underground cave river.

## Visiting Roadford

Underground access is impossible due to collapses of the adits (mine tunnels) and flooding. Much of the mining heritage interest is visible from the public roads. Otherwise, the site is on private land and not suitable for visiting.

## Phosphate Mining

Phosphate has long been extracted from the ground, around the world, for use as a fertiliser. Clare has a little known history of phosphate mining that is unique within Ireland. In 1924 Judge Michael Comyns, an amateur geologist, found a horizon of phosphatic shale at Noughaval, 12 km east of Doolin. He got planning permission to open a quarry and extracted phosphate in opencast workings. No real trace of these is seen now as they have been restored to agriculture. He then worked the phosphate from the beds and banks of the Aille River at Toomullin in Doolin. They diverted the river with earth banks to get at the phosphate rock.

In 1939 the workings were compulsorily taken over by Mianrai Teoranta, the Government's Mining Company. Due to wartime restrictions on supplies from Africa and America, the demand for fertilisers meant that the mining was taken underground at Roadford, and at its height, 700 men were employed. The mine closed in 1947 as it was more expensive than imports which had become available again.

Doolin: general view of quarry workings on right bank of Aille River, 1942

Doolin: main adit, Mianrai Teoranta Mine, 1942. Phosphorite bed exposed at each side of adit mouth.

Toomullin: phosphate workings — bed near crusher, with about 8 foot depth of overburden

Bed exposed in Aille River

All photos by D.W. Bishopp, Director of the Geological Survey of Ireland in 1941.

# Bridges of Ross

The sea has eroded some of the rock folds and left natural arches.

Excellent exposures of rock show the 3D architecture of a large slide of unconsolidated sediment.

## Geological Interest

The Ross Sandstone Formation consists of sandstone, siltstone and thinly bedded black shales. Slumping is common at many horizons throughout the formation, the most spectacular of which, the Ross Slide, occurs at the Bridges of Ross. Slumping is the term used to describe a type of sediment slide where the material moves downslope as a single unit resulting in highly deformed structures within the sediment. The Ross Slide consists of several metres of siltstone and overlying sandstone displaying a range of deformational features including folds. Sand volcanoes are present on the upper surface of the overlying sandstone unit. These impressive features are formed by the extrusion of fine-grained sediment suspended in water as the sediments were compacted. Also of interest at this site is a sea bridge which has developed as a result of modern erosion by the sea.

## Visiting the Bridges of Ross

Public access from the car park to the coastal exposures is accepted, but visitors must exercise great caution near cliffs and unfenced holes in the ground.

# Magowna

## Geological Interest

The junction between the Carboniferous Limestone and the Clare Shales can be seen in the waterfall, almost half a kilometre northwest of Magowna Castle. This site demonstrates well the contrast between the two different rock types. This exposure does not provide any diagnostic faunal evidence with which to date the rocks but their age can be assumed from the relationships between the two rock types. Various microfossils have also been found at this site.

## Visiting Magowna

Due to being on private farmland, and with the access and exposure being poor due to vegetation for some distance upstream and downstream of the contact, this site is not suitable for visiting.

A waterfall, less than 3m high occurs at the geological boundary.

# Spanish Point

## Geological Interest

The coastal section at Spanish Point consists of well-bedded sandstones, siltstones and mudstones of the Upper Carboniferous (Namurian) Central Clare Group. Sedimentary structures are well preserved here and include cross-bedding, cross-laminations and symmetrical wave ripples. A marine band is present on the north side of the Spanish Point bay, with a prominent fossil soil (palaeosol) horizon 2.5m below it. This has rootlets and dessication cracks. The fossil soil horizon formed on a temporary patch of dry ground between water channels in the delta.

Looking along the shoreline, it is easy to see that thicker beds of sandstone are more resistant to erosion by the sea and form ribs into the waves.

## Visiting Spanish Point

There is a public car park and no access issues to the coastal rock exposures. Visitors should exercise caution with tides on a rocky coastline.

Sandstone beds at Spanish Point show many rippled surfaces, formed hundreds of millions of years ago.

# Doolin to Hags Head (Cliffs of Moher)

A classic view of the Cliffs of Moher

## Geological Interest

A coastal section with a remarkable development of sand volcanoes in Carboniferous beds over-lying slumped shales and sandstones. The 'Fisherstreet Slide' is a distinctive sheet, 30 metres thick, found along several kilometres of the cliff section. The entire sheet moved as a sedimentary slide, and now contains a wealth of soft-sediment deformation features. It is part of the Gull Island Formation which extends from Doolin southwards. The Central Clare Group comprises the bulk of the cliffs from O'Brien's Tower southward, and beyond towards Loop Head. The cliffs also illustrate cyclothems which are repeated sequences of mudstone, siltstone and sandstone, formed by normal processes in the deltaic environment that these rocks were formed in. The cyclothems are normally separated by thin marine bands with distinctive goniatite fossils. These marine bands are the result of a short period flooding event and allow correlation of rocks and events across a wide area.

Some ledges of the sandstones also contain a wealth of trace fossils, apart from the very well-known Liscannor Flags, which is full of fossilised worm burrows. Many of these flags are used as walls and footpaths around the centre and O'Briens' Tower. The vertical sea cliffs in Upper Carboniferous shales and flagstones are of iconic status as an international tourist attraction—this area is of enormous amenity value. The cliff ledges also provide homes for more than 40,000 sea birds. Biodiversity relies upon geodiversity!

The winged fossil insect from cliffs near Doolin

The cliffs at Doolin have yielded a rare neopteran pterygote insect, which possessed wings that could be folded over the insect's body. These wings were a major evolutionary advancement allowing the insect to access confined spaces in plants and rocks for food and shelter. This is the earliest such example of this type of insect in Ireland and Britain.

## Visiting Doolin to Hags Head

The Cliffs of Moher are explained and presented within the visitor centre at the Cliffs and this includes accessible explanations of the geology. This provides the best access, other than walking the entire distance from one end or the other. In general, health and safety concerns around the Cliffs have meant that viewing the rocks close up is not easily possible, as it once was, but a walk to the south especially, away from the visitor access point will provide a sense of the wild grandeur with every different vista. Better still, take a boat trip to see the cliffs.

The Cliffs of Moher looking southwest, with ripple marks in the foreground

# The Liscannor Stone Industry

Despite machinery to lift, move and saw the stone, many traditional techniques are still used routinely.

Historical pictures from around 1911 show stone was mined as well as quarried. Photo from United Stone Firm brochure.

Liscannor stone slabs were traditionally used for roofing sheds and some houses.

The Liscannor Stone is a distinctive Irish building stone that is found only in the succession of rocks between Doolin and Miltown Malbay. It is marked by the meandering trace fossils which occur on and through each split layer. The rock is extracted as flags – large thin sheets or slabs that are ideal for paving. It has also been used locally for roofing of vernacular dwellings and farm buildings. In some of the fields close to the Cliffs of Moher, slabs of Liscannor Stone have traditionally been used for making field boundaries when turned on their side. All around the Cliffs of Moher visitor centre paths, good examples of the stone can be seen used this way.

The trace fossils were made by an organism that we have no trace of now, but it may have been a sea snail (a gastropod), but more likely it was perhaps a worm with no hard parts to preserve. It burrowed through the shallow surface of the original silt sediment presumably to feed on organic detritus.

Today several different businesses supply stone throughout Ireland, and even for export, based on quarrying techniques that have changed little over centuries. Modern machinery and saws mean that it can be customised for different orders. A free audio-visual presentation on the history and exploitation of the Liscannor Stone is available in the Rock Shop at Lahinch.

Working of some quarries is intermittent with slabs used as walls to keep cattle out.

# Loop Head

Cliffs on the south side of Loop Head, show many dramatic views.

## Geological Interest

The rocks between Loop Head and Ross village represent the type section of the Upper Carboniferous Ross Sandstone Formation. There are a very wide range of sedimentary structures seen in the rocks which, by comparison with areas of the world where such sediments are being deposited today, give detailed information of the sedimentary environments of this place 315 million years ago. Some very obvious features are sand-filled channels that are up to 10m deep and 100m wide. All of these rocks were probably deposited in a deep-marine trough or sub-marine fan where occasional storms deposited thick sandstone beds. At Loop Head and along the coast many fold structures can be seen in the cliffs. These rocks were folded towards the end of the Carboniferous by a period of mountain building called the Variscan Orogeny. There are numerous features of coastal erosion, such as arches, stacks, storm beaches, blowholes and cliff patterns that are totally influenced by the geological structures.

## Visiting Loop Head

There is a car park for visitors very close to the actual headland and good views along the approach road. Great caution must be exercised near cliff edges, especially in windy conditions.

# Gull Island, Tullig Point and Trusklieve section

Illaunglass near Trusklieve

## Geological Interest

The coastal section of rocks around Gull Island and Tullig Point displays some of the best sections in Clare of the Shannon Group and Central Clare Group sedimentary rocks which infilled the Clare Basin in the Namurian, and which now are the foundation of most of south west and central County Clare. Inland, these rocks are almost never exposed, except in small quarries and stream beds.

This cliff section is characteristic for the Gull Island Formation of the Shannon Group. Above it, the Tullig Sandstone, with a goniatite marine band at the top of the unit, is followed northwards by more sandstones and siltstones of the Central Clare Group. There is a large slump at Tullig Point. These rocks were formed at the same time as those seen in the lower part of the Cliffs of Moher. There is an extensive range of sedimentary structures, and also tectonic structures, many of which were formed at the time of deposition, and these record the sediment instability on the basin slopes. There are slides, growth faults and slumps present. Key sections are at Gull Island to Tullig Point and at Illaunglass and Pouladav.

## Visiting Gull Island to Tullig Point

Much of this coastal stretch is private land and should only be visited if landowner permission is obtained. Very few parts are accessible by road, though some boreens to the cliffs are open. Great caution must be exercised on cliff edges if visiting publicly accessible areas.

# Foohagh Point

Faults can be seen in this cliff face going up at about 45 degrees from left to right.

## Geological Interest

A spectacular growth fault can be seen in the cliff face at Foohagh Point. A growth fault is a fault that moves at the same time as sediment is being deposited causing the sediment to thicken towards the fault. The growth fault at Foohagh Point displaces sandstones, siltstones and mudstones within the sequence of the Upper Carboniferous (Namurian) Central Clare Group. The pale coloured sandstones of this formation display clear thickening towards the fault.


## Visiting Foohagh Point

Much of this site can be seen from the public road along the coast west of Kilkee. A public car park on the west edge of Kilkee Bay allows access to some of the rocks in that section.

# Doonaha

Superb sand volcanoes can be found at Doonaha.

## Geological Interest

The 3km of coastal rock exposures comprises micaceous sandstones (sandstones with a lot of small shiny flakes of the mineral mica in them), siltstones and shales. Of importance at this site are the trace fossils preserved in the Upper Carboniferous, Namurian rocks. These starfish traces represent the only Namurian starfish traces in Ireland. Two occurrences are known and they are the only fossils found in this otherwise barren sequence of sandstones and siltstones.

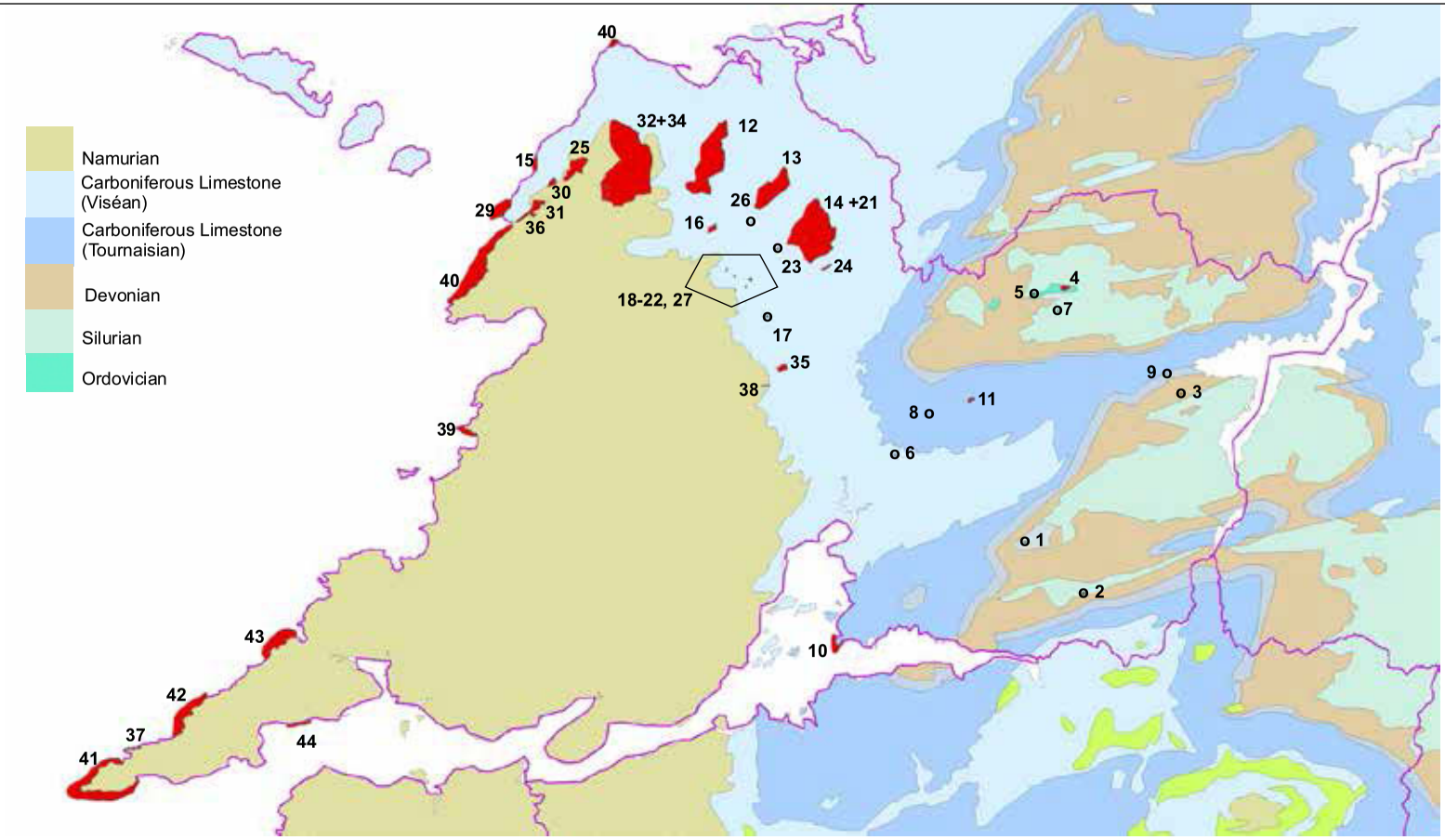
The rocks are part of the Gull Island Formation, which includes the Fisherstreet Slide at its base. The presence of superb sand volcanoes at Doonaha indicates similar evidence of sedimentary instability. However, there are many other sedimentary and structural features of interest easily visible in the exposures.

## Visiting Doonaha

Access to the rocks is easy with parking for the small beaches. Caution must be taken with tides, in order not to get cut off along the rocks at the bottom of the cliffs.

Folded beds are picked out as patterns on the foreshore when the tide is out.

Starfish traces from Doonaha

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# A Brief History of County Clare Geology

The older rocks in Clare are exposed in the hilly regions in the east of the county. These rocks were deposited during Ordovician times when most of what is now central Ireland lay on the deep ocean floor of a long vanished ocean called the Iapetus Ocean. This vast ocean separated northwest and southeast Ireland from before 500 million years ago until the end of the Silurian, approximately 419 million years ago. The axis of the Iapetus Ocean ran along a roughly southwest-northeast trending line through central Ireland from the Shannon Estuary to Clogher Head in Co. Louth. The Ordovician and Silurian rocks in the Clare area were deposited on the northwestern side of Iapetus in deep waters.

The next oldest rocks exposed in Clare are from the Silurian Period, approximately 10 million years younger. The contact between the two formations is a fault. Graptolite fossils found within them have been used to date the rocks of these formations. Graptolites are good zonal fossils, i.e. they can be used to ascertain the age of rocks, due to the abundance of species with relatively short life spans and their wide geographical distribution. A deep water fauna of very small fossils is also known from Ballyvorgal South in the western part of these Ordovician rocks.

Mid-Silurian rocks are the most extensive in the East Clare area. These sediments are represented in the geological record by Slieve Bernagh and the Cratloes. At sites such as Ballycar South in the Cratloes, pebbly deposits of submarine channels have provided a diverse shelly fauna to palaeontologists. The slates found in Slieve Bernagh and near Broadford originated as mud and silt on the floor of Iapetus but as earth movements brought the northwestern and southeastern margins of Iapetus together, closing the once immense ocean, increased temperature and pressure altered the mudstones and siltstones to slates, which developed a sheet like cleavage (preferential planes of splitting). This period of mountain building which took place during late Silurian – early Devonian times is known as the Caledonian orogeny. The slates were worked in the past around Broadford for roofing purposes.

The closure of the Iapetus Ocean saw the amalgamation of two landmasses to form the Old Red Sandstone Continent, during the Devonian. Ireland's position within this landmass, which covered most of northwest Europe, had a latitude and climate similar to that of the Sahara desert today. Most of the land lay above sea level. Terrestrial processes, such as wind and river systems dominated. The Old Red Sandstone Continent remained throughout the Devonian from about 419 to 359 million years ago. In the Clare area evidence for this period is found in the mountainous regions in the east of the county, namely the Cratloe Hills, the Broadford Mountains, Slieve Bernagh and Slieve Aughty. The Old Red Sandstone deposits in these areas rest unconformably on the older rocks and have been gently folded. The deposits consist of yellow/brown, coarse-grained sandstone, pebbly sandstone and conglomerate and are fluvial in origin. An excellent place to see this relationship clearly is at the top of Ballycroum Hill, near Feakle.

At the beginning of the Carboniferous sea level began to rise. The shoreline moved northwards from Cork, flooding the land as it passed. During this time Ireland had a latitude of 10° and experienced a tropical climate much like that of the modern day Bahamas. This gradual marine transgression is recorded in the Upper Devonian and Lower Carboniferous rocks in the Clare area.

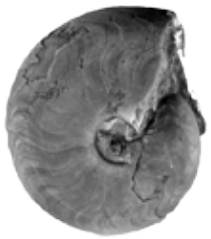
Sandstones and mudstones of the early Carboniferous record shallow water conditions and the onset of the Carboniferous transgression. The overlying muddy limestone and calcareous shales reflect slightly deeper water conditions. As sea level continued to flood the land less clay was available for deposition and cleaner, crinoid-rich limestones were deposited.

The growth of Waulsortian carbonate mud-mounds succeeded them and covered much of central Ireland, although they are not common in Clare, but Rineanna Point exhibits them. These mud-mounds, often called reefs but quite unlike modern day coral reefs, formed as individual mounds on the sea-floor at depths of at least 200m. They contained an abundance of life including bryozoans and crinoids. Muddy limestones, deposited in beds, surrounded these mounds.

Younger limestones record a transition from shallow-water shelf to deeper water limestones that were deposited in a basin called the Shannon Trough. Places like Tuamgraney in East Clare demonstrate the Carboniferous limestone as well as the main Burren, and sites such as Toonagh Quarry near Ennis.

The Upper Carboniferous Namurian rocks succeeding the Viséan limestones were deposited in the Shannon Trough. Deep-water marine shales (the Clare Shales) define the base of the Namurian and they are overlain by sandstones from submarine fans. There are many features such as slumped horizons and dewatering structures such as sand volcanoes within this succession that suggest high rates of basin subsidence as well as high sedimentation rates. Siltstones and sandstones of slumped continental slope and shelf origin were the next sequence to infill the basin.

By latest Namurian times the rate of deposition was so great that the sedimentary basin got very shallow, and then deltaic depositional environments followed, much like that of the modern day Mississippi. These deltaic conditions are recorded by rootlet horizons and coal seams. Intermittent rises in sea-level saw the deposition of marine shales often containing goniatites which can be used to correlate horizons across the basin as well as providing a means to date the age of the rocks.



A goniatite fossil

A period of mountain building at the end of the Carboniferous deformed rocks across Ireland and Europe. The rocks in the Clare area were uplifted, gently folded and faulted during this orogeny, known as the Variscan orogeny. For much of the following 300 million years Ireland was mostly a land area dominated by erosion rather than sedimentation. Eroded sediment was carried offshore and deposited in ocean basins.

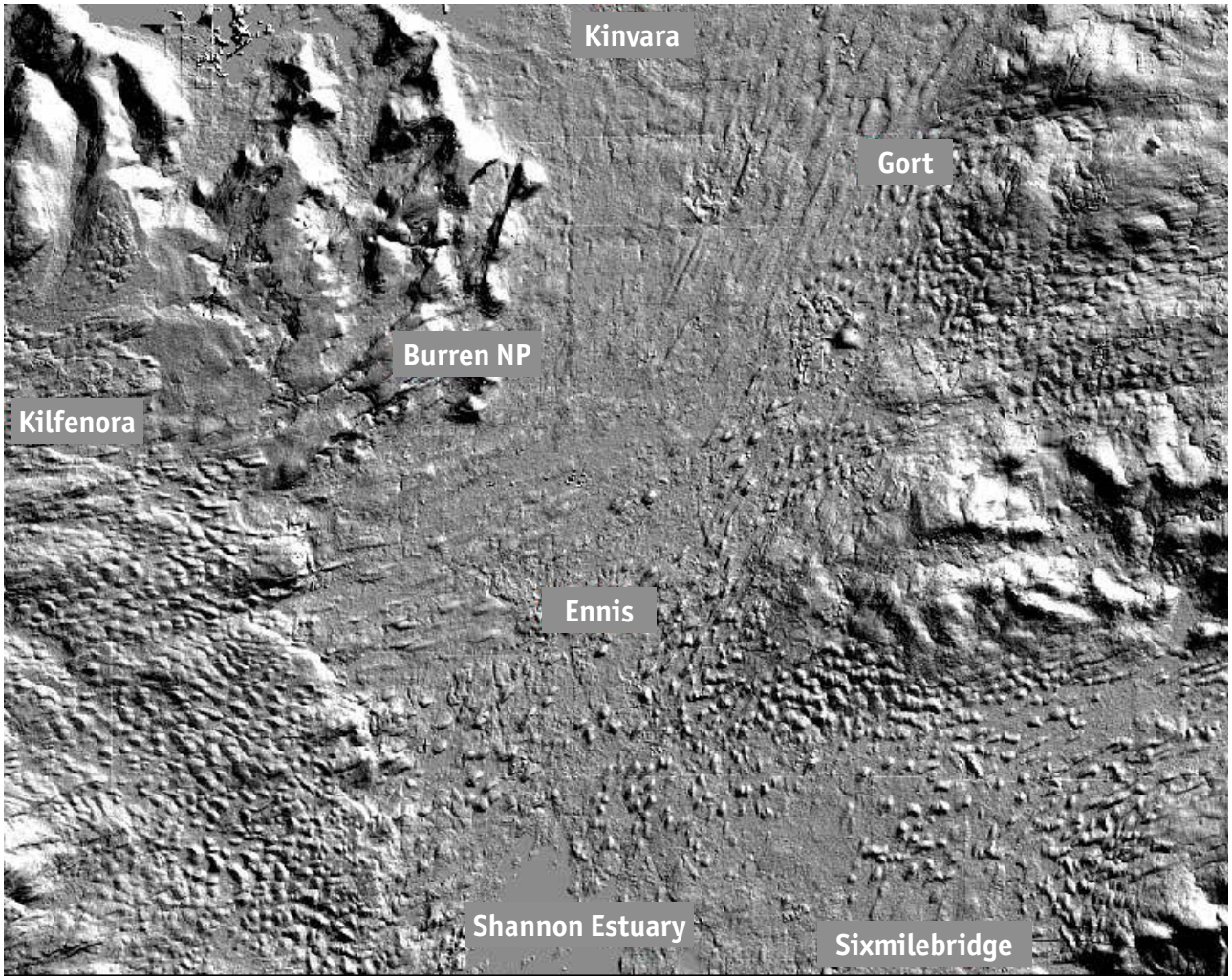
The last 1.6 million years of Earth history is known as the Quaternary Period. The Quaternary can be further subdivided into two epochs, the Pleistocene (or Ice Age), which ended approximately 10,000 years ago, and the Holocene (10,000 years ago to present day).

During Pleistocene times Ireland's climate oscillated between arctic and temperate conditions. During the colder stages huge sheets of ice covered much of Ireland. The surface sediments and associated landscapes that we see today were formed largely during the last Ice Age. In the Clare area, however, there is evidence to suggest that at least two glaciations have affected the region, the latter event leaving more of a mark on the land. Glacial deposits are generally thinner in areas of higher ground and thicker in lower lying regions.

The huge sheets of ice present during the colder stages of the Pleistocene scoured the landscape as they moved often leaving 'scratches' or striations on the rocks, which, where preserved, can still be seen today. These striations can give us an idea of the direction in which the ice was moving. Boulders or erratics transported far from their source area by glacial ice are often seen strewn about the landscape.

The scale and effect of glaciation is sometimes better appreciated by viewing the landscape with remote sensing techniques. The following image is a digital elevation model of the central Clare area, illuminated from the north

In many parts of the Burren, bright green grass fields abut against bare rock – in most cases the fields of grass have glacial till with soil below the surface, as wedges against the valley sides.




A digital elevation model image of Central Clare, illuminated from the north-east to illustrate the drumlin fields.

east. It clearly shows drumlin fields to the south of the Burren in the bottom left portion of the image. These are oriented east-north east to west-south west in direction, reflecting the ice flow at its maximum to the south west. These drumlins have accumulated to form what is known as ribbed moraine, which gives a north west to south west trend to the drumlin features, when seen at this scale. In the centre of the image, linear south south west directed features reflect a tongue of ice during deglaciation which was still flowing from Gort towards Ennis. Unoriented drumlins in the south east of the image may reflect the free drainage under ice sheets on limestone north of Sixmilebridge.

In areas where thick glacial deposits overlie the limestone, limestone pavement has not developed. This would suggest that most of the karst features in the Clare area formed after the last glaciation. However, there are many larger karst systems (e.g. Poulnagollum and the Carran Depression) that are too deep and extensive to have formed in the last thousand years. These systems must have started to form well before the last glaciation, possibly even before the glacial period began, some possibly having origins in the Tertiary period. The pattern of high ground in the Burren and the lowland karst nearer Gort is related to the time at which the overlying shale cap was removed and its protective effect withdrawn. The High Burren only lost its Namurian shales during the last glaciation event, whereas the lowlands were exposed to erosion and weathering of the limestone itself much earlier.

In Ireland, karstification takes place on limestone. Rainwater, which is slightly acidic from carbon dioxide dissolved from the air, can dissolve limestone on contact until it becomes saturated with bicarbonate ions. If the rainwater falls on rocks other than limestone, and flows as a stream or percolates through soils it may become much more acidic and much more aggressive in its solution of the limestone rock. This dissolution of limestone is what creates a host of distinctive landforms in karstic areas.

In areas such as the Mullaghmore National Park, or at Sheshymore where bare limestone rock was left exposed after the last glaciation, water soaking away into joints and fractures has enlarged them to create the classic limestone pavement, with upstanding blocks called clints separated by enlarged joints called grikes, that provide the microclimates which host certain plants characteristic of the Burren. The surface solution forms a wide range of karren features – the flutings and runnels on surfaces, and the kamenitza, crinkly edged bowls on flat surfaces. A classic measure of the rate of limestone solution is found where an erratic rock such as Galway Granite or sandstone is left on the limestone by glaciation. Acting as an umbrella, the limestone underneath does not get dissolved and the erratic may be found on a pedestal of limestone today, showing how much the limestone surface has been lowered by solution in about ten thousand years.

In other areas where streams accumulate on other rock types and then meet with limestone they often form caves and potholes, as the acidic water is focused in its attack on the limestone. The classic place for cavers to seek new caves is along the margin of the shale deposits overlying the limestone. By following this scarp, many caves have been located and most of the Burren caves are formed in the last ten thousand years by streams passing off the shale onto the limestone. The classic place for this pattern is the Pollnagollum – Poulelva system, where numerous streams flowing off the Namurian sandstones and shales of Slieve Elva contribute to Ireland's longest cave system.

Karst is characterised by underground drainage, with sinking streams and springs, often connected by cave passages. Enclosed depressions from small dolines to the major sites like the Carran depression are also typical, plus a wealth of other distinctive landforms. Most of the turloughs of the Gort-Kinvara lowlands lie in Galway, but the Burren includes these seasonal lakes where high water table in winter leads to a lake which is dry in the summer. Immediately south of the exposed limestone in the Burren are many classic landforms where karst is seen as windows through the shale deposits. Other landforms in the Burren reflect former positions of the shale margin, but which have been modified by the last glaciation.

Rivers too have played a big part in shaping the landscape, although it is much harder to interpret the history of these across landscapes so modified by glaciation. The Shannon Estuary represents a very large ria, or flooded estuary, as sea level rose after the Ice Age. The gorge of the Shannon River at Killaloe at the south end of Lough Derg has long been a matter for debate as to why the river does not drain westward at Scarriff, with superimposed drainage and river capture models put forward as explanations.

This brief outline of the geological history of County Clare can only hint at the complexity of the story, and the references listed in this book will help you take things further if you have been intrigued by the special landscapes of County Clare.

Erratic boulder

## Shortlist of Key Geological References

Some key titles that are highly recommended for your use are the following:


ARCHER, J.B., SLEEMAN, A.G. and SMITH, D.C. 1996. *Geology of Tipperary and adjoining parts of Laois, Kilkenny, Offaly, Clare and Limerick, to accompany the Bedrock Geology 1:100,000 Scale Map Series, Sheet 18,* Tipperary. Geological Survey of Ireland.

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SLEEMAN, A., McCONNELL, B. and GATLEY, S. 2004. *Understanding Earth Processes, Rocks and the Geological History of Ireland*, Geological Survey of Ireland, Dublin.

SLEEMAN, A.G. and PRACHT, M. 1999. *Geology of the Shannon Estuary. A geological description of the Shannon Estuary region including parts of Clare, Limerick and Kerry, to accompany the Bedrock Geology 1:100,000 Scale Map Series, Sheet 17, Shannon Estuary.* Geological Survey of Ireland.

SLEEMAN, A.G., SCANLON, R.P., PRACHT, M. and CALOCA, S. 2008. *Landscape and Rocks of the Burren.* A special sheet in the Bedrock Geology 1:50,000 Map Series, Geological Survey of Ireland, Dublin. (usually about €5 from local outlets)

TRATMAN, E.K. 1969. *The Caves of North-West Clare, Ireland.* David and Charles, Newton Abbot, Devon. 256pp.

WILLIAMS, M and HARPER, D. 1999. *The Making of Ireland. Landscapes in Geology.* Immel Publishing, London.

# Want to find out more?

The original audit of 2005 on which this book is based is available for download from the geological heritage pages of the website of the Geological Survey of Ireland: www.gsi.ie

## Burren and Cliffs of Moher Geopark

The Geopark is one of 3 in Ireland, and is a major presence in raising awareness of the geological heritage of the area. Through direct provision of training, events, activities and a network of community based activities it is the best way into the landscape for a large portion of the county. www.burrengeopark.ie

## Tourist attractions

Some key tourist attractions in Co. Clare are geological in their fundamental nature. We recommend that you visit the Atlantic Edge visitor centre at the Cliffs of Moher. Aillwee Cave is a long established attraction near Ballyvaughan and Doolin Cave is a more recent show cave that it is possible to visit. For souvenirs, books, gems and fossils a visit to the Rock Shop in Liscannor might be rewarding.

## Guided walks

There are local guides offering guided walks in the Burren and other parts of Clare, but you are advised to search the web or contact tourist offices to see what is available to suit your needs.

## Websites

- www.gsi.ie
- www.geoschol.com
- www.earthscienceireland.org

## Caving

If you have visited Aillwee Cave or Poll an Ionain (now accessible to visitors as Doolin Cave) and been thrilled enough to want to do some 'wild' caving, then the only really safe way to do this is to join a recognised caving club and go underground in the company of experienced cavers, who have explored the cave of choice before. There are many dangers for the inexperienced beginner, which are all avoidable by caving with an experienced group. It is easy to get lost in the long and complex cave systems in Clare. Some caves will fill to the roof with water within minutes of rainfall outside. Many have horizontal passages and vertical drops or pitches which are only passable with suitable equipment and training.

The Speleological Union of Ireland is the umbrella body for cavers and details of caving clubs will be found via the website www.cavingireland.ie. In addition, outdoor centres such as the Burren Outdoor Education Centre have a long tradition of providing courses and training in caving, especially for school groups.

## Studying geology

Most geologists are graduates of a recognised University, with many also being members of the professional body, the Institute of Geologists of Ireland (IGI). If you want to study some basic geology without the commitment of a full time degree, there are few options. One good option is the Diploma course run both by University College Cork (UCC) and National University of Ireland, Galway (NUIG), which can be done by distance learning. Other University Departments such as TCD and UCD in Dublin also run occasional short courses.

The Burren and Cliffs of Moher Geopark and the Burren Outdoor Education Centre run an evening course in February/ March 'Stone, Water & Ice – an introduction to the geology of the Burren'. Contact edoyle@burren.ie for details.

## Amateur associations

Several groups exist, such as the Irish Geological Association (IGA), the Galway Geological Association, the Cork Geological Association and the Belfast Geologists Society which run a programme of lectures and field excursions in Ireland, and sometimes further afield. Membership is always a friendly mix of professional and amateur enthusiasts, and these fieldtrips are a great place to learn more in the best 'classroom' – the geological sites. There are also many special interest groups of a similar nature for specific areas of geology.

- Irish Geological Association: www.geology.ie
- Cork Geological Association: http://corkgeology.homestead.com/cga.html
- Belfast Geologists Society: http://www.belfastgeologists.org.uk/
- Galway Geological Association: http://galwaygeology.weebly.com/
- Irish Quaternary Association: http://www.iqua.ie/

## About the author

My day job is as Assistant Keeper for Natural History in the National Museum of Ireland, working as the geological curator for the national geological collections. Working on this book was a very pleasurable task, after having been involved in the original geological heritage audit of 2005.

After a day rushing around all of County Clare trying to get some final photographs for this book, when the promised clear weather turned out to be one of those days when the grey of the sky merges with the grey of the sea and the grey of the Burren limestone, still I could only reflect on how good it was to be there again. Some lyrics from the great Andy Irvine sprang to mind, reflecting my mood.

*My heart's tonight in Ireland in the sweet County Clare*

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