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The Geological Heritage of County Westmeath

An audit of County Geological Sites in County Westmeath 2019

Robert Meehan, Ronan Hennessy, Matthew Parkes and Siobhán Power

An Chomhairle Oidhreachta
The Heritage Council

Westmeath County Council
Comhairle Chontae na hIarmhí

Geological Survey Ireland is a division of the Department of Communications, Climate Action &Environment

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The County Westmeath Geological Heritage Project was supported by

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Ireland | Éireann
An Roinn Cumarsáide, Gníomhaithe ar son na hAeráide agus Comhshaoil
Department of Communications, Climate Action & Environment

WESTMEATH COUNTY COUNCIL
Comhairle Chontae na hIarmhí

This report is a contribution to the
County Westmeath Heritage Plan 2018-2023
and to the County Westmeath Biodiversity Action Plan 2014 – 2020

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Site Name
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Site name
Not represented in County Westmeath

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Executive Summary

County Westmeath is not widely known for its geological heritage, although for many people the county's landscape, with prolific eskers and picturesque lakelands, is widely appreciated. Although bedrock is not generally well exposed, Westmeath still has an extensive and diverse range of geological heritage sites. The County Council's support for this audit is critical in raising the profile of geological heritage in County Westmeath and for maximising its potential for foreign and domestic tourism and for natives alike.

This report documents what is currently understood by the Irish Geological Heritage Programme (IGH) of the Geological Survey Ireland to be the most important geological sites within County Westmeath. It proposes them as County Geological Sites (CGS), for inclusion within the County Development Plan (CDP). The audit provides a reliable study of sites to replace a provisional Geological Survey Ireland listing based on desk study which was adopted in the current 2014-2020 CDP.

County Geological Sites do not receive statutory protection like Natural Heritage Areas (NHA) but receive an effective protection from their inclusion in the planning system. Some of the sites described in this report are considered to be of national importance as a best representative example of a particular geological formation or feature. They will be provisionally notified to the National Parks and Wildlife Service (NPWS) by Geological Survey Irelandfor designation as a Natural Heritage Area (NHA) once due survey and consultation with landowners is complete. In parts of the county, many of the sites fall within existing pNHAs and SACs where the ecological interest is actually founded upon the underlying geodiversity.

The commission of this audit and adoption of the sites within the CDP ensure that County Westmeath follows a now established and effective methodology for ensuring that geological heritage is not overlooked in the general absence of allocated resources for progress with geological NHAs at national level. It brings County Westmeath to the forefront of geological conservation in Ireland.

This report is written in non-technical language (with a glossary for unavoidable geological terminology) as a working document for use by the Heritage Officer and the Planning officers of Westmeath County Council. It should also be made available via the Council website for the people of County Westmeath. A chapter of the report includes recommendations on how to best present and promote the geological heritage of County Westmeath to the people of the county. It will also inform the work of the IGH Programme and be made available through the Geological Survey Ireland website www.gsi.ie.

The preliminary sections, summary geological history and accompanying map, timescale and stratigraphical column particularly may be used as they stand to preface a booklet or as website information in the development of this work, and for information, as seen fit by the Heritage Officer, and as funding permits. The contents also provide the essential ingredients for a public-oriented book or other publications on the geological heritage of County Westmeath, if the funding can be found to produce them.

1. County Westmeath in the context of Irish Geological Heritage

This report brings County Westmeath to the forefront of geological heritage within Ireland, as the majority of the counties have now commissioned such an audit within the scope of the county-based Heritage Plan, and Westmeath has a very interesting suite of sites which have not previously been audited. By providing reliable data in a very cost-effective manner, it is hoped that the remaining local authorities, including those without an incumbent Heritage Officer, will follow what is now a tried and trusted methodology. In the absence of significant political and economic resources available at a national level to the relevant bodies for conservation of geological heritage as Natural Heritage Areas (NHA), audits such as this one represent a significant level of progress in defining and safeguarding Ireland's geological heritage. In essence, County Geological Site audits are the only effective geological conservation at present, but only with advisory capacity (within the context of County Development Plans) and no real statutory protection where it is required, although the statutory County Development Plan provides capacity to preserve sites where necessary.

It also represents a significant commitment on the part of the Local Authority to fulfil its obligations to incorporate geology into the spectrum of responsibilities under the Heritage Act 1995, the Planning and Development Act 2000, Planning and Development Regulations 2001, and the Wildlife (Amendment) Act 2000 and the National Heritage Plan (2002). Geological Survey Ireland views partnerships with the local authorities, exemplified by this report, as a very important element of its strategy on geological heritage (see Appendix 1).

The Irish Geological Heritage Programme (IGH) in Geological Survey Irelandcomplements other nature conservation efforts of the last decade, by assessing Ireland's geodiversity. Geodiversity is the foundation of the biodiversity addressed under European Directives on habitats and species by the designations of Special Areas of Conservation (SAC) and on a national scale by the introduction of Natural Heritage Areas (NHA) as the national nature conservation method (so far only a suite of bog sites have been designated). As a targeted conservation measure to protect the very best of Irish geology and geomorphology the IGH Programme fills a void which has existed since the end of the Areas of Scientific Interest scheme, as listed by An Foras Forbartha in 1981.

The IGH Programme does this by identifying and selecting the most important geological sites nationally for designation as NHAs. It looks at the entire spectrum within Irish geology and geomorphology under 16 different themes:

IGH THEMES

1. Karst
2. Precambrian to Devonian Palaeontology
3. Carboniferous to Pliocene Palaeontology
4. Cambrian-Silurian
5. Precambrian
6. Mineralogy
7. Quaternary
8. Lower Carboniferous
9. Upper Carboniferous and Permian
10. Devonian
11. Igneous intrusions
12. Mesozoic and Cenozoic

13. Coastal geomorphology
14. Fluvial and lacustrine geomorphology
15. Economic geology
16. Hydrogeology

The philosophy and rationale for NHA designation of geological sites has been well documented in several publications (Parkes and Morris 2001; Parkes 2008; Gatley and Parkes 2016, 2018), and is not reiterated here since County Geological Sites are the present concern. Future possible designation of geological NHAs would be by Geological Survey Ireland's partners in the Programme, the National Parks and Wildlife Service (NPWS). Once designated, any geological NHAs will be subject to normal statutory process within the County Westmeath Planning Department and other relevant divisions. **However, compared to many ecological sites, management issues for geological sites are generally fewer and somewhat different in nature. The subsequent section considers these issues**.

From a national perspective, all candidate geological NHAs are of national importance. Many other sites may be of more local importance or of particular value as educational sites or as a public amenity. All of these various important sites are proposed for County Geological Site (CGS) listing in the County Development Plan.

Currently, in 2018, a Master List of candidate CGS and NHA sites is being used in Geological Survey Ireland, originally compiled with the help of Expert Panels for all the 16 IGH themes. For several themes, the entire process has been largely completed and detailed site reports and boundary surveys have been done along with a Theme Report. Due to various factors, none have yet been formally designated. In County Westmeath, some karst sites like Loughandonning Mushroom Rock were so far considered to be of national importance and had been put forward as a Natural Heritage Area (NHA) for the IGH1 Karst Theme. Therefore, inclusion of all sites as County Geological Sites (CGS) in County Westmeath's planning system will ensure that they are not inadvertently damaged or destroyed through lack of awareness of them outside of the IGH Programme in Geological Survey Ireland.

The sites proposed here as County Geological Sites (CGS) have been visited and assessed specifically for this project, and represent our current state of knowledge. It does not exclude other sites being identified later, or directly promoted by the Council itself, or by local communities wishing to draw attention to important sites for amenity or education with an intrinsic geological interest. New excavations, such as major road cuttings or new quarries, can themselves be significant and potential additions to this selection.

It was not possible within the scope of this study to identify landowners except in a few sites, but it is emphasised that CGS listing here is not a statutory designation, and carries no specific implications or responsibilities for landowners. It is primarily a planning tool, designed to record the scientific importance of specific features, and to provide awareness of them in any decision on any proposed development that might affect them. It thus also has an educational role for the wider public in raising awareness of this often undervalued component of our shared natural heritage.

1.1 Westmeath County Geological Sites

Site Name	Designation	IGH Primary	IGH Secondary	IGH Third	GIS Code
Ballycor Mushroom Rocks	County Geological Site	IGH1			WH001
Calliaghstown-Milltown Esker	County Geological Site	IGH7			WH002
Cappalahy Esker	County Geological Site	IGH7			WH003
Clonthread Mushroom Rock	County Geological Site; may be recommended for Geological NHA	IGH1			WH004
Deerpark Quarry	County Geological Site; may be recommended for Geological NHA	IGH8	IGH15		WH005
Dun na Si Amenity and Heritage Park	County Geological Site	IGH1	IGH7	IGH16	WH006
Finnea-Murrens Esker	County Geological Site	IGH7			WH007
Fore Hills	County Geological Site; recommended for Geological NHA	IGH1	IGH7	IGH16	WH008
Hill of Uisneach	County Geological Site	IGH1	IGH7		WH009
Horseleap Esker	County Geological Site; recommended for Geological NHA	IGH7			WH010
Kilbeggan Esker	County Geological Site; may be recommended for Geological NHA	IGH7			WH011
Kilbeggan Racecourse Esker	County Geological Site	IGH7			WH012
Knockastia Hill and Quarry	County Geological Site	IGH8			WH013
Lough Derravaragh	County Geological Site	IGH7	IGH8	IGH14	WH014
Lough Bane and Lough Glass	County Geological Site	IGH7	IGH14		WH015
Lough Lom	County Geological Site	IGH1	IGH16		WH016
Loughandonning Mushroom Rock	County Geological Site; recommended for Geological NHA	IGH1			WH017
Mount Temple Esker	County Geological Site; recommended for Geological NHA	IGH7			WH018
Mullingar Bypass	County Geological Site	IGH8			WH019
Portnashangan Quarry	County Geological Site	IGH8			WH020
Rahugh Ridge	County Geological Site; recommended for Geological NHA	IGH7			WH021
River Inny	County Geological Site	IGH8			WH022
Rock of Curry and Hill of Mael	County Geological Site	IGH12			WH023
South Westmeath hummocks	County Geological Site	IGH7			WH024
Split Hill and Long Hill Esker Complex	County Geological Site; recommended for Geological NHA	IGH7			WH025
Streamstown Esker	County Geological Site	IGH7			WH026
Tullin Mushroom Rock	County Geological Site	IGH1			WH027
Tyrrellspass Kettle Hole	County Geological Site	IGH7			WH028

1.2 Combined, Renamed and Rejected sites

A range of sites had been previously flagged for consideration in the IGH Master Site List, and some were assessed as unsuitable for County Geological Site status in this audit. Similarly a range of additional sites were assessed in the audit, based on the authors' expert knowledge of County Westmeath's geology. Other sites were visited *on spec* during fieldwork. The rejected sites are listed below with brief notes as to why they were assessed as unsuitable for inclusion. It should be noted that in a number of cases in Westmeath, especially with eskers, the original expert panel process of creating a Master Site List has created some of the issues described below. Some of the sites were poorly defined in the first instance and there were multiple names for the same esker in different parts, for example.

Lough Patrick
Lough Patrick is a small lake near Multyfarnham that is surrounded by peat and relatively deep glacial till deposits, which again overlie karstified limestone bedrock. As a major spring nearby feeds the Group Water Scheme for Multyfarnham, it was considered that the lake itself may have karstic elements associated with it, and potential sinking stream outlets or losing sections. Upon surveying the lake and the basin around it during the drought of summer 2018, it was found that no karstic elements are seen, and the lake seems simply to be a ponded waterbody sitting over deep Quaternary sediments, with no discernible direct hydrogeological connection to the underlying bedrock.

Lough Patrick

Fore, Fore Hills, Shores of Lough Lene
The Shores of Lough Lene (IGH16 Hydrogeology) site and Fore Hills (IGH7 Quaternary) site have been combined with the Fore (IGH16 Hydrogeology) site to capture the main geological, geomorphological and hydrogeological aspects of interest in the area. The site themes (IGH1 Karst, IGH7 Quaternary, IGH16 Hydrogeology) have been expanded to include aspects of the area's karst limestone landscape.

Ballinalack
The known mineral deposits at Ballinalack have been in the geological literature for many decades. The economic geology theme expert panel included Ballinalack as a potential NHA site to be evaluated. The Ballinalack deposit has been drilled and is a zinc-lead deposit of the same general geology as the Tara Mines in Navan, Co. Meath. From multiple exploration boreholes, it has a proven resource of many million tonnes. However, there is no surface expression of the mineralisation that would be suitable for a County Geological Site.

Derrygolan Esker
The Derrygolan Esker is a small, low esker which extends for approximately 900m in Derrygolan Townland, adjacent to the county boundary with Offaly, and just over 4 kilometres northeast of Tullamore. The esker is a smaller, tributary esker of the larger and more extensive, and more striking, Ballyduff Esker-Rahugh Ridge.

As the esker is low in elevation and difficult to distinguish from the surrounding landscape, and as there are no good sections exposing unique sedimentology within the feature either, the site has been rejected in favour of other more interesting and easily discernible esker features throughout Westmeath.

The low elevation ridge that is the Derrygolan Esker

Kilbeggan Hand Pumps
The Irish Geological Heritage Master List for Westmeath had an entry in the Hydrogeology theme for hand pumps at Kilbeggan. While two unusual hand pumps are present in Market Square in the centre of the town, there is no historical information on these; even in consultation with Kitty Fagan, Westmeath's oldest resident (95) and an active member of the local Historical Society, nothing was revealed. In consultation with management of Locke's Distillery, also, no association with the distillery was unearthed either (most of their water comes from the Brosna and the rest from a concreted-over well). As no geological or hydrogeological data could be found on the wells associated with the pumps, therefore, the site was rejected.

One of the hand pumps in the Market Square in Kilbeggan Town

Ballymore Esker
No esker actually exists in Ballymore Village, and the closest such feature is included as a site in the Calliaghstown-Milltown Esker. As the 'Ballymore Esker' site does not actually exist, therefore, it is rejected.

Ballynagarbry Esker
No esker actually exists in Ballynagarbry Townland near Moate. The closest such esker feature is included as a site as the Mount Temple Esker. As the 'Ballynagarbry Esker' site does not actually exist, therefore, it is rejected.

Ballyduff Esker-Rahugh Ridge
This esker is also included in the Irish Geological Heritage Master List as the 'Rahugh Ridge (Kiltober Esker)', and that nomenclature will therefore be followed as both townlands in this naming are in Westmeath (the site is now called the Rahugh Esker). The second naming of the same feature, with a townland in Offaly (Ballyduff) within, is therefore rejected.

West of Athlone
'Esker landscapes' west of Athlone were included in the Irish Geological Heritage Master List for County Westmeath. However, as the area west of Athlone is in County Roscommon, these 'esker landscapes' are not in County Westmeath, and the inclusion of the site as part of the County Westmeath Geological Heritage Audit is therefore rejected.

Kinnegad
A 'Waulsortian Quarry' at Kinnegad was included in the Irish Geological Heritage Master List for County Westmeath. However, as the area around Kinnegad within County Westmeath has no bedrock quarries therein, and as the nearest major quarry into Waulsortian limestone bedrock is at Killaskillen in County Meath, the inclusion of the site as part of the County Westmeath Geological Heritage Audit is therefore rejected.

Lagan Cement Quarry
The 'Lagan Cement Quarry' near Kinnegad is the same quarry mentioned above at Killaskillen in County Meath; therefore the inclusion of the site as part of the County Westmeath Geological Heritage Audit is also rejected.

Gainestown Church Font
Following a request to examine an unusual church font at Gainestown, just south of Mullingar Town, from the County Westmeath Heritage Officer, the site was surveyed and the font assessed. If was found that the font is comprised of local, relatively impure limestone (most probably Lucan Formation, or 'Calp' limestone), and is therefore not of any real geological significance, or have any element of uniqueness, in the area.

The church font at Gainestown, Mullingar

Swallow Lough
Despite a mix of map and air photographic evidence indicating bodies of water and other-times dry conditions, and a suggestive name, this site is not of any significant geological heritage interest. Whilst there was previously a lake, it did not fluctuate in level and was not a turlough, which was a suspicion. From information supplied by a former landowner, the lake was drained (probably in the 1980s) by the drainage activities of a neighbouring farmer.

Tyrrellspass Road Cutting
A long, deep road cutting has recently been exposed just east of Tyrrellspass, as part of the construction process for the M6 Motorway. However this cutting has been graded at a relatively low angle, and is covered with broken rock/scree. No clean section into the bedrock itself is visible. Upon this basis, as the exposure is poor and not informative, the site is rejected.

The road cutting along the M6 Motorway just east of Tyrrellspass Village

Kiltober Esker
This esker is also included in the Irish Geological Heritage Master List as the 'Rahugh Ridge (Kiltober Esker)', and that nomenclature will therefore be followed as both townlands in this naming are in Westmeath (the site is now called the 'Rahugh Esker'). The naming of the same feature as the 'Kiltober Esker' is therefore rejected.

2. Westmeath Council Policies regarding geological heritage

The completion of this geological heritage audit will ensure that the largely desk-based study and listing of County Geological Sites (Appendix 13 in the current 2014-2020 Plan) is superseded in the next County Development Plan by a robust selection of sites that are important in County Westmeath. Whilst some are candidates for NHA designation in the future if the geological NHAs ever become a reality, new sites that are purely of local importance have been added. Equally some sites have been rejected after proper field auditing.

The policies of Westmeath County Council, laid out in the County Development Plan 2014-2020 (page 94 – 96) are quite robust and detailed, which is very positive for geological heritage. There are detailed, positive policies regarding eskers and peatlands in addition to the essential geological issues covered in these policies, and partly delivered through this audit:

P-GEO 1	To consult the Geological Survey Ireland when undertaking, approving or authorising developments which are likely to impact on County Geological Sites or involve significant ground excavations.
P-GEO2	To protect and enhance the geological and geomorphological heritage of the county.
P-GEO3	To protect geological NHAs as they become designated during the lifetime of the plan.
P-GEO4	To encourage and promote, where appropriate, public access to geological and geomorphological sites and avoid inappropriate development through consultation with the Geological Survey Ireland, subject to environmental and habitats assessment. It is anticipated that this will also encourage the creation of heritage awareness in the county.
P-GEO5	To undertake an audit of the Geological Sites of the County in partnership with the Geological Survey Ireland, in order to document sites of geological interest in which protection measures would be applied.

3. Geological conservation issues and site management

Since **geodiversity is the often forgotten foundation for much of the biodiversity** which has been identified for conservation through SAC or NHA designation, it is unsurprising that many of the most important geological sites are actually in the same areas as SAC and pNHA sites. In these areas, the geological heritage enhances and cements the value of these sites for nature conservation, and often requires no additional designation of actual land areas, and ideally, a citation of the geological interest.

Broadly speaking, there are two types of site identified by the IGH Programme. The first, and most common, includes small and discrete sites. These may be old quarries, natural exposures on hilly ground, coastal cliff sections, or other natural cuttings into the subsurface, such as stream sections. They typically have a feature or features of specific interest such as fossils or minerals or they are a representative section of a particular stratigraphical sequence of rocks. **The second type of site is a larger area of geomorphological interest, i.e. a landscape that incorporates features that illustrates the processes that formed it**. The Quaternary theme and the Karst theme often include such sites. In County Westmeath, the Fore Hills, the South Westmeath hummocks, the Rahugh Esker and the Mount Temple Esker are examples of these.

It is also important from a geological conservation perspective that planners understand the landscape importance of geomorphological features which may not in themselves warrant any formal site designation, but which are an integral part of the character of County Westmeath. For example, the Rock of Curry and Hill of Mael are considered to be remnant tower karst, the product of Tertiary deep weathering of limestone landscapes then scoured and modified by glaciation. Although not clear enough to be definitive, a range of hills including Mullaghmeen to the north east are probably created in the same way, and share some characteristics.

A lack of awareness in the past, has led to the loss of important geological sites and local character throughout the country. In County Westmeath a Landscape Characterisation Assessment was completed and incorporated into the County Development Plan 2008-2014, and carried through to the current plan. This provides a tool for planners to help maintain the character of the County and informs things like wind energy strategy. However, it is a methodology that could be considered to place inadequate value on the underlying geodiversity in defining landscape character areas. The Strategic Environmental Assessment within the County Development Plan also provides tools. In addition, the now routine pattern of consultations with Geological Survey Ireland, either by the planning department or by consultants carrying out Environmental Impact Assessment, plus strategic environmental assessment (SEA), has greatly improved the situation. **The 2006 survey of Eskers in Westmeath (Tubridy and Meehan 2006) was a very forward-thinking development in prevention of losses and recognition of the importance of these iconic landforms**.

There are large differences in the management requirements for geological sites in comparison to biological sites. Geological features are typically quite robust and generally few restrictions are required in order to protect the scientific interest. In some cases, paradoxically, the geological interest may even be served better by a development exposing more rock. **The important thing is that the relevant planning department is aware of the sites and, more generally, that consultation can take place if some**

development is proposed for a site. In this way, geologists may get the opportunity to learn more about a site or area by recording and sample collection of temporary exposures, or to influence the design so that access to exposures of rock is maintained for the future, or occasionally to prevent a completely inappropriate development through presentation of a strong scientific case.

In many counties, working quarries may have been listed because they are the best representative sections available of specific rock sequences, in areas where exposure is otherwise poor. No restriction is sought on the legitimate operation of these quarries. However, maintenance of exposure after quarry closure is generally sought in agreement with the operator and planning authority in such a case. At present, working quarries like Deerpark Quarry near Castlepollard are now included as County Geological Sites in County Westmeath. These issues are briefly explored in a set of Geological Heritage Guidelines for the Extractive Industry, published jointly by Geological Survey Ireland and the Irish Concrete Federation (Parkes 2008; Gatley and Parkes 2018).

A new quarry may open up a window into the rocks below and reveal significant or particularly interesting features such as pockets of fossils or minerals, or perhaps a karstic depression or cave. Equally a quarry that has finished working may become more relevant as a geological heritage site at that stage in its life. It may need occasional maintenance to prevent overgrowth of vegetation obscuring the scientific interest, or may be promoted to the public by means of a viewing platform and information panel.

Waste dumping

An occasional problem throughout the country, including in County Westmeath, is the dumping of rubbish in the countryside. The dumping of waste is not only unsightly and messy, but when waste materials are dumped in areas where rock is exposed, such as in quarries or disused gravel pits, they may leach into the groundwater table as they degrade. This can cause groundwater pollution and can affect nearby drinking water supplies in wells or springs. Groundwater Protection Schemes (DELG 1999) help to combat pollution risks to groundwater by zoning the entire land surface within counties into different levels of groundwater vulnerability. County Westmeath was included in a national scheme for Groundwater Protection in 2012, thus ranking the county land surface into vulnerability categories of ‘Extreme’, ‘High’, ‘Moderate’ and ‘Low’, and helping planners to assess which developments are suitable or not in some areas of County Westmeath.

New exposures in development

One less obvious area where the Local Authority can play a key role in the promotion and protection of geology is in the case of new roads. **Wherever major new carriageways are to be built,** or in other major infrastructural work, it should be a policy within the Planning Department, that **where new rock exposures are created, they be left open and exposed** unless geotechnical safety issues arise (such as where bedding dips are prone to rock failure). The grading and grassing over of slopes in cuttings is largely a civil engineering convenience and a mindset which is difficult to change. However, it leads to sterile and uninteresting roads that look the same throughout the country. Leaving rock outcrops exposed where they are intersected along the road, improves the character and interest of the route, by reflecting the geology and landscape of the locality. Sympathetic tree or shrub planting can still be done, but leaving bare rocks, especially where they show interesting features, not only assists the geological profession, but creates new local landmarks to replace those removed in the construction of the roadway. This can also

potentially save money on the construction costs. It may also contribute to road safety by providing diversity of surroundings to maintain drivers' attention.

In Westmeath, the deep cutting in the bedrock on the N4 Mullingar by-pass to the north of the town is a great example of this issue. When first cut it provided geologists within Geological Survey Ireland a rare exposure to log assisting with mapping the poorly exposed Carboniferous geology of the district. It then provided a new landmark and an excellent place for anybody to see an open gentle fold in the beds (an upfold or anticline) as they drove through. The dip of the beds changed as the axis of the fold was crossed. For reasons unknown it was planted with trees and all geological interest obscured, but in recent years these trees have been removed and the rocks nearly exposed again. However, further clearance of critical sections is required to show off the geological structure to its best potential.

UNESCO Global Geoparks

An extremely interesting development in geological heritage, not just in Europe but internationally, has been the rapid recent growth and adoption of the Geopark concept. A **Geopark is a territory** with a well-defined management structure in place (such as Local Authority support), **where the geological heritage is of outstanding significance and is used to develop sustainable tourism opportunities**. Initially it was largely a European Geoparks Network (EGN) but since 2004 has expanded worldwide as the Global Geoparks Network (GGN) and were elevated to full United Nations Educational, Scientific and Cultural Organisation (UNESCO) in 2015. A fundamental theoretical basis of the Geopark is that it is driven from the bottom up – the communities in the Geopark are the drivers of the project and are the main beneficiaries. Geopark branding therefore helps promote the geological heritage resource so that the community can benefit from it. However, significant management support from local authorities, such as the County Council, has proven to be virtually essential across the network.

In Ireland there are three UNESCO Global Geopark members.. One is the cross-border Marble Arch Caves UNESCO Global Geopark in Fermanagh and Cavan [www.marblearchcaves.net and www.cavancoco.ie/marble-arch-caves-global-geopark]. The Copper Coast Unesco Global Geopark in Waterford also joined the Network in 2001 [www.coppercoastgeopark.com]. A now well established addition has been the Burren and Cliffs of Moher UNESCO Global Geopark in County Clare [www.burrengeopark.ie]. In addition there are aspirant groups exploring the work and infrastructure required for applications in other areas, the most advanced of which is Joyce Country & Western Lakes geopark in Mayo and Galway.

It is an action of the Biodiversity Action Plan 2014-2020 (No. 97, page 66) under the theme of 'Raising Awareness' to 'Seek to establish the Esker Geopark in conjunction with Offaly County Council, subject to compliance with the Habitats Directive'. This objective is also expressed plainly within the County Development Plan. This is a very desirable ambition, but it should not be undertaken lightly. The bar to reach UNESCO Global Geopark status is set very high, and to achieve this would require a sustained commitment from both Westmeath and Offaly County Councils, as well as considerable investment in geological tourism, trails, education and protection in order to demonstrate the functions of a Geopark. Even if that investment was delivered, there are rules on a national territory basis about how many candidate Geoparks can apply at any one time. This process and support for

candidate Geoparks is provided by the Geological Survey Irelandand the Geological Survey of Northern Ireland.

3.1 Eskers

A Note on Esker Conservation in County Westmeath

What is an esker?

Eskers are long, sinuous ridges of glaciofluvial sands and gravels. The term “esker” is an English rendering of the Irish word *eiscir* which means a high ridge separating two flat areas. They range from a few tens of metres to over a hundred kilometres in unbroken length, and range locally from a few metres to over 50m in height, and from ten metres to hundreds of metres in width at their base. Eskers have been reported from all over mid-latitudes, and are common in Ireland, Britain, Scandinavia, Canada, Alaska, the northeastern U.S., and Patagonia.

Since eskers are made up of highly permeable sand and gravel, they are frequently excavated for construction. They have been considered an endangered geomorphological species in many parts of the world for some time (notably, southern Quebec and Finland), since they have been used either to develop roadways, offering natural elevated, dry terrain, or they have been ripped up for gravel to build nearby roads. The latter has been the case in Ireland for some time, and recent efforts have focussed on conserving eskers for their geomorphological, habitat, groundwater and educational resource.

How are eskers formed, geologically?

Eskers are usually the infillings of ice-walled river channels. Just as rivers on land carry and deposit sediment, meltwater that flows in the openings beneath, above and within a glacier also carries and deposits sediment. Tunnels near the base of retreating glaciers fill with transported sediments, which remain as sandy or gravelly ridges that look like raised, upside-down stream beds after the glacier melts away.

Eskers in Ireland.

A large system of esker landforms spans the ‘Irish Midlands’, or central lowland portion of the country. These ridges have been the subject of geomorphological and geological study since the mid-nineteenth century. The eskers are composed of sorted, layered sediments but range in size, orientation and morphology, generally related to the movement patterns and ice margin locations of the last ice sheet to cover the country.

Esker conservation and the aggregate industry

Aggregates can only be extracted where they occur. This means extraction is limited to certain geological areas, which are often areas of inherent beauty or value because of the relationship between geology and the landscape. This is a problem particularly with eskers, as they are upstanding, dry ridges of sand and gravel which can be easily quarried, and yet are important in the landscape topographically, ecologically and historically.

Many of the best examples of eskers in County Westmeath have been extensively quarried, to such an extent that little of them actually remain anymore. In particular, significant portions of the Streamstown and Kilbeggan Eskers have been removed. It is imperative that the balance is found between geological heritage conservation and aggregate extraction in the future, to ensure that the best examples of our eskers are protected. The Irish Geological Heritage Audit of County Westmeath should help in this process.

3.2 Mushroom Rocks

A Note on Mushroom Rock Conservation in County Westmeath

What is a mushroom rock?

Mushroom rock is a term for any limestone bedrock that has been subject to dissolution weathering and erosion processes that leave upstanding rocks with an upper section unaffected, with a lower section that is undercut, with overhanging lips. In a well-developed example this may result in an isolated mushroom shaped rock. In others, a variety of sculpted shapes are seen.

How are mushroom rocks formed, geologically?
It is believed that the primary mechanism was that the undercut sections, or 'stalks' on mushroom rocks were dissolved in lake waters that submerged them up to the level of any overhang. These were probably short-lived lakes of glacial meltwater at the end of the last Ice Age and afterwards, but that through natural erosion, they drained before the present day, leaving upstanding mushroom rocks. The lakes would have had to have had continual flushing of their waters in order that they did not become saturated with bicarbonate and unable to further dissolve limestone. This requirement means that in some cases, such as along the River Shannon, they may simply have been subject to regular inundation in a larger floodplain than is the case in a modern modified flow regime.

A secondary mechanism of dissolution below bog or soil has been shown to be likely in some examples, but that there has been shrinkage or removal of the bog or soil to expose the mushroom rock at surface today.

Mushroom rocks in Ireland.

Depending on how they are counted, there are between 70 and 100 mushroom rocks in Ireland, although some are clusters of closely related stones in one location. They have been inventoried by John Feehan and Louise Dunne, who have taken detailed height measurements of the 'lip' heights to try and confirm a local lake water level in former times.

Most of the known mushroom rocks are found in Counties Clare, Roscommon and Offaly. Westmeath has several important examples which are included in this audit, including newly recognised ones at Clonthread and Ballycor.

Mushroom rock conservation and threats to them

The biggest threat to mushroom rocks is a lack of awareness of their geological interest and importance as evidence of the most recent landscape development. They can very easily be destroyed in 'land improvement' or field clearance for reseeding by landowners or farmers. There are examples of such damage in other counties.

The inclusion of mushroom rocks as County Geological Sites in County Development Plans, with policies for the protection of such sites is the best protection in current circumstances, although the audit process has allowed conversations with some of the landowners which has either reinforced their appreciation of what they have, or else made them aware of it.

4. Summary and Recommendations

4.1 Proposals and ideas for promotion of geological heritage in County Westmeath – Heritage Plan

This section examines the existing objectives in the County Westmeath Heritage Plan (2018-2023) relating to geological heritage in any way, and provides specific suggestions as to how these may be implemented, supported or enhanced by the audit of geological heritage sites in the county.

Objective 1. Raise awareness of heritage and increase understanding of its value

1.1 Disseminate information on all aspects of the heritage of the County through the use of digital technologies, via social media and all appropriate means.
Audit action: The audit data will be made available to all through Geological Survey Ireland website, but ideally would be disseminated through the heritage pages of the Council's website.

1.2 Support and organise conferences, talks, seminars and events on heritage themes relevant to the conservation and promotion of Westmeath's heritage.
Audit action: The report authors are willing to contribute talks and other efforts in the promotion of Westmeath's geological heritage.

1.3 Promote accessibility by hosting and supporting public events at heritage sites, both publicly and privately owned.
Audit action: The report authors have already contributed Heritage Week events and are willing to do so in the future, further interpreting the geological heritage at sites described herein.

1.4 Promote wider awareness of all aspects of heritage through participation in national programmes and events such as Heritage Week, Water Day, National Biodiversity Week, Tree Week, Decade of Commemorations, Creative Ireland and other appropriate events that may arise during the life of the Plan.
Audit action: The report authors have already contributed Heritage Week events and are willing to do so in the future, further interpreting the geological heritage at sites described herein.

Objective 2. Record heritage and disseminate data

2.1 Audit existing surveys/inventories of heritage in Westmeath. Address knowledge gaps by developing and implementing a prioritised programme for research and surveys, in partnership with local, regional and national bodies. Where practical, collate and make available relevant survey data generated through public projects.
Audit action: It is important to note that some previous audits or inventories (e.g. of eskers) will include a significant element of geological heritage, but it may not always be fully recognised as such when the audit was primarily biological or architectural, for example, in nature.

2.2 Carry out an audit of County Geological Sites in partnership with Geological Survey Ireland, with the results informing how best to promote, conserve and develop geosites and geological heritage in Westmeath.
Audit action: The audit and report provides full delivery of this action.

2.3 Develop and support projects which record memorials in historic graveyards, in line with best practice and employing relevant technologies where appropriate.
Audit action: The authors of the audit report may be able to advise on, for example, stone sources and rock types, used in historical graveyards.

2.5 Support the participation of individuals and communities in recording heritage data of all types (natural, built, cultural, tangible and intangible) by providing information, guidance and structured training.
Audit action: The authors of this audit report could provide relevant training courses in geological heritage, data recording and other disciplines, on request.

Objective 3. Promote best practice in Conservation and management of heritage

3.1 Support the implementation of actions in the County Westmeath Biodiversity Action Plan 2014-2020 (BAP) and support the review and update of this plan as required.
Audit action: The authors of this audit report could provide support in ensuring that the geodiversity which frequently underpins the biodiversity is adequately addressed or considered in biodiversity actions.

3.2 Support the preparation of Habitat Management Plans for Natura 2000 sites and other relevant sites in the County.
Audit action: The authors of this audit report could provide support in ensuring that the geodiversity which frequently underpins the biodiversity is adequately addressed or considered in biodiversity management plans and actions for SACs, pNHAs and other sites.

3.3 Support the conservation and development of the architectural heritage of the County through the provision of appropriate expertise by Westmeath County Council.
Audit action: This audit report could provide data regarding historical stone sources for significant buildings, and the expertise in finding replacements for conservation work.

3.4 Implement conservation and management plans prepared to date *(Athlone Town Walls and Defences Conservation Plan, Fore Special Heritage Area Management Study)* and others that are completed during the life of the Plan. Liaise with stakeholders, including landowners, to support the preparation of conservation management plans for key sites including, but not exclusive to, Kilbixy and Ardnurcher.
Audit action: For special places such as Fore, the geological heritage information must be incorporated into any overall plan or study.

3.5 Engage with key stakeholders to consider proposals for and explore the feasibility of working towards developing nature conservation areas and biodiversity access projects at key locations such as the River Inny Basin, while also taking into consideration the rich archaeological and cultural heritage of this area.

Audit action: Geodiversity plays a significant part in the Inny Basin and Lough Derravaragh and should not be overlooked in any plans, with this audit providing data on key features and sites for geological heritage.

3.10 Continue to support the promotion of Uisneach as one of the Royal Sites of Ireland, by means such as the proposal for the designation as a UNESCO World Heritage Site and /or other appropriate initiatives. (The Royal Sites of Ireland are on the Irish Tentative List of properties for future nomination to the UNESCO World Heritage List).
Audit action: Geological heritage data underpinning the landscape importance of Uisneach is provided in this audit, which should contribute to WHS or other initiatives.

Objective 4. Promote enjoyment and accessibility of heritage

4.1 Where physical access is limited, explore new technologies to bring understanding of archives, heritage objects and sites to a wider audience by using digitisation, modelling and related technologies and making these accessible on-line where possible / appropriate.
Audit action: The audit report may provide data and a starting point in site specific projects.

4.2 Liaise with the Tourism Officer and other relevant partners to publish a list with accompanying maps of heritage sites which are open to the public in Co. Westmeath.
Audit action: Limited data on land ownership for County Geological Sites is supplied separately to the Heritage Officer with this report.

4.4 Research and develop heritage trails in partnership with the Tourism Officer and relevant community groups, landowners and other stakeholders/organisations.
Audit action: The audit report provides some data on sites and on the geology of the county which may be included within trails.

4.5 Liaise with relevant sectors in the development of greenways/walking trails/cycling routes to ensure that such projects are developed in a sustainable manner and that every opportunity is taken to promote the natural and built heritage and its interpretation along such routes.
Audit action: The audit report provides some data on sites and on the geology of the county which may be included within trails.

4.7 Encourage and assist museums in the County to work towards the Heritage Council's Museums Standards and Accreditation Programme (MPSI).
Audit action: One author [MP] may be able to assist any museums with any geological collections or projects in the scope of his professional work.

Objective 5: Promote community participation in heritage plans and projects

5.1 Build the capacity of local communities to engage in sustainable heritage projects by providing the necessary advice, information and training.
Audit action: The authors of this audit report could provide relevant training for communities in geological heritage, data recording and other disciplines, on request.

5.2 Identify and promote heritage projects where professional heritage groups and communities can work together with shared responsibility to increase community capacity development.
Audit action: The authors of this audit report are open to contact re projects or ideas.

5.4 Promote *Citizen Science* programmes which aim to involve everyone in the collection of data on natural heritage.
Audit action: The authors of this audit report are open to contact on proposals for projects.

4.2 Proposals and ideas for promotion of geological heritage in County Westmeath – Biodiversity Action Plan

This section examines the existing objectives in the County Westmeath Biodiversity Action Plan (2014-2020) relating to geological heritage in any way, and provides specific suggestions as to how these may be implemented, supported or enhanced by the audit of geological heritage sites in the county. Section 2.3 and many other sections refer to geology, especially in connection with habitats like peatland, limestone pavement and eskers. Listed below are the key actions in the plan, where this audit, or further input from the authors, should provide some assistance with delivering the actions.

PROTECTING AND DEVELOPING THE ECOLOGICAL NETWORK

- Identify Core **Nature Conservation Sites**.
- Liaise with quarry owners to protect and enhance wildlife habitats within **quarry** sites.
- Prepare policy and guidance for **afteruse of cutaway and cutover bogs, gravel pits and quarries** for consideration of the Strategic Policy Committee, subject to compliance with the Habitats Directive.
- Establish a site inventory of important **geological and natural heritage sites outside of designated areas** in county Westmeath.

RAISING AWARENESS

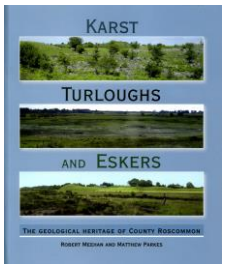
- Prepare guidance documents on best practice for biodiversity issues in extant **quarries.**
- Seek to establish the Esker Geopark in conjunction with Offaly County Council, subject to compliance with the Habitats Directive.

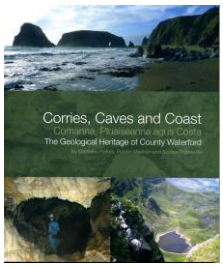
4.3 Ideas for projects

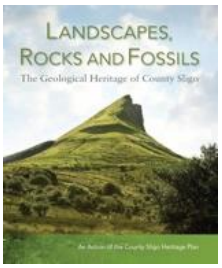
Leaflets
No existing leaflets on the geological heritage of County Westmeath are known, other than the Geoschol one included as an appendix here. There is some scope for other and

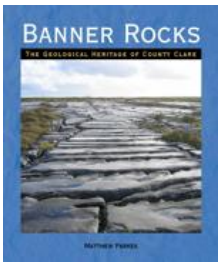
different leaflets. Any leaflets produced could simply be made available as PDF downloads on the Council's website to avoid large costs of printing.

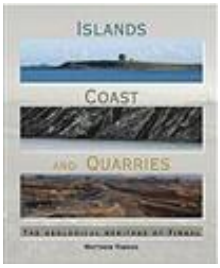
There is scope for guides at different levels of detail and accessibility to non-specialists. A wide range of leaflets, booklets, books and other media are all feasible, but the research and production of appropriate text and images is a difficult task to do well without appropriate experience, and adequate time and resources. It is suggested that **with only modest editing and reorganisation the main content of this report would distil into a good general short guide to the geological heritage of County Westmeath**, in a broadly similar style to those books produced for Sligo, Fingal, Waterford, Roscommon and Clare following audits in those counties.











Guides
There are no known specific guides including sections on the geology of County Westmeath. The 1:100,000 GSI map and reports for Sheets 12, 13, 15 and 16 cover County Westmeath and are an essential resource.

There is scope for guides at different levels of detail and accessibility to non-specialists. A wide range of leaflets, booklets, books and other media are all feasible, but the research and production of appropriate text and images is a difficult task to do well without appropriate experience, and adequate time and resources. It is suggested that **with only modest editing and reorganisation the main content of this report would distil into a good general guide to the geological heritage of County Westmeath**, in a broadly similar style to those books produced for Sligo, Fingal, Waterford, Roscommon, Clare and Longford following audits in those counties.

Signboards
Simple explanatory or interpretive signboards may be advisable at key geological heritage locations, but if these are considered, their locations and individual siting should be very selective, since a proliferation of different interest groups may provoke a 'rash' of panels all over the county. The Planning Section should clearly have a controlling input, in conjunction with the Heritage Office. It is most likely that a panel combining various heritage interests at a place is preferred to single interest panels. It is important to consult with potential partners in the planning stage so that duplication does not occur.

The successful integration of text and graphics on information panels is a fine art, and the IGH Programme can offer input if signs are planned for key visitor localities. The authors of this report are also able to write, review or provide content on geological heritage for any proposed panels.

Museum exhibitions
As a result of the work to produce this report, the material for a panel based exhibition has been largely compiled. With some extra research covering human dependence on geology

and resources, an interesting exhibition can be put together for display in the Westmeath Council Offices, County Library branches or other venues. The model followed was that used for Carlow, Dun Laoghaire-Rathdown, Waterford, Wicklow, Longford etc. Images of those and other similar ones can be seen on the Geological Heritage/Exhibitions section of Geological Survey Ireland website [www.gsi.ie]. It is our experience that when used in locations such as County Offices they can provide a popular attraction that enhances ordinary business visits to conduct other affairs.

New media
There are increasing numbers of examples of new methods of promoting Earth Sciences, via mobile phone applications and other electronic media. Self-guiding apps on specific sites would be one of these, such as those produced by Ingenious Ireland for Dublin city geology and the app for tourists in the Burren and Cliffs of Moher Geopark. Plans for such products would require some considerable effort to produce and imaginative effort, to link sites in any coherent ways, other than simply by their county. An 'Esker' theme is the most obvious trail idea.

Geoschol website [www.geoschol.com]
Geoschol is an educational project, now essentially represented by a website, which was largely aimed at producing educational materials on geology for primary schools. A four page pdf summarising the geology and some highlights of County Westmeath is already part of the available material (see Appendix 6). Working links to the Heritage section of County Westmeath Council's website, as well as to other heritage websites, should be established.

Geological Heritage Research Archive
If the Heritage Officer wanted to do something similar to that produced in the Burren and Cliffs of Moher Geopark, with downloadable (or links to) free access papers, then a lot of groundwork is already provided by the reference lists in this audit. Making available technical references of direct relevance to County Westmeath geology and geomorphology will assist many users and researchers into the future. However, the literature is very specialist in nature, such that a geological heritage section with a select bibliography pdf on the Heritage web pages for Westmeath might suffice for most users with a general interest in their local heritage.

Maps
It is hoped that geological heritage sites as a data layer might be adopted by the Ordnance Survey of Ireland in their future map editions of the 1:50,000 Discovery Series, for all counties where an audit has been completed (similar to the East-West Mapping maps of Wicklow, Mayo etc. which include such data from GSI).

Heritage Council Heritage Viewer
HeritageMaps.ie is a web-based spatial data viewer, co-ordinated by the Heritage Council, and working with the Local Authority Heritage Officer network, which focuses on the built, cultural and natural heritage around Ireland and off shore. This viewer allows you to look at a wide range of built and natural heritage data sets in map form. The outlines of and data on each individual County Geological Site in Westmeath could be made visible on the HeritageMaps.ie viewer once the audit is completed. (www.heritagemaps.ie)

5. A summary of the Geology of County Westmeath

5.1 Paragraph summary

Although there are some poorly exposed older rocks at Sion Hill and west of Moate, virtually all of the bedrock geology of Westmeath comprises Carboniferous Limestone from around 330 million years ago, when a warm tropical sea covered Ireland. In the Mesozoic Era, especially in the last 50 million years this limestone was exposed as land and subject to intense weathering leading to some karstic landscape features like relict towers at the Rock of Curry. The Ice Ages of the last couple of million years removed much but left perhaps the best spread of eskers in the country covering Westmeath and Offaly. Sands and gravels were deposited in linear ridges from meltwater tunnels under the ice sheets. From 10,000 years ago when the ice had gone, mushroom rocks and turloughs formed in temporary lakes or wide river basins. Peat bogs started growing in low-lying depressions and the landscape of today emerged.

5.2 Simple summary

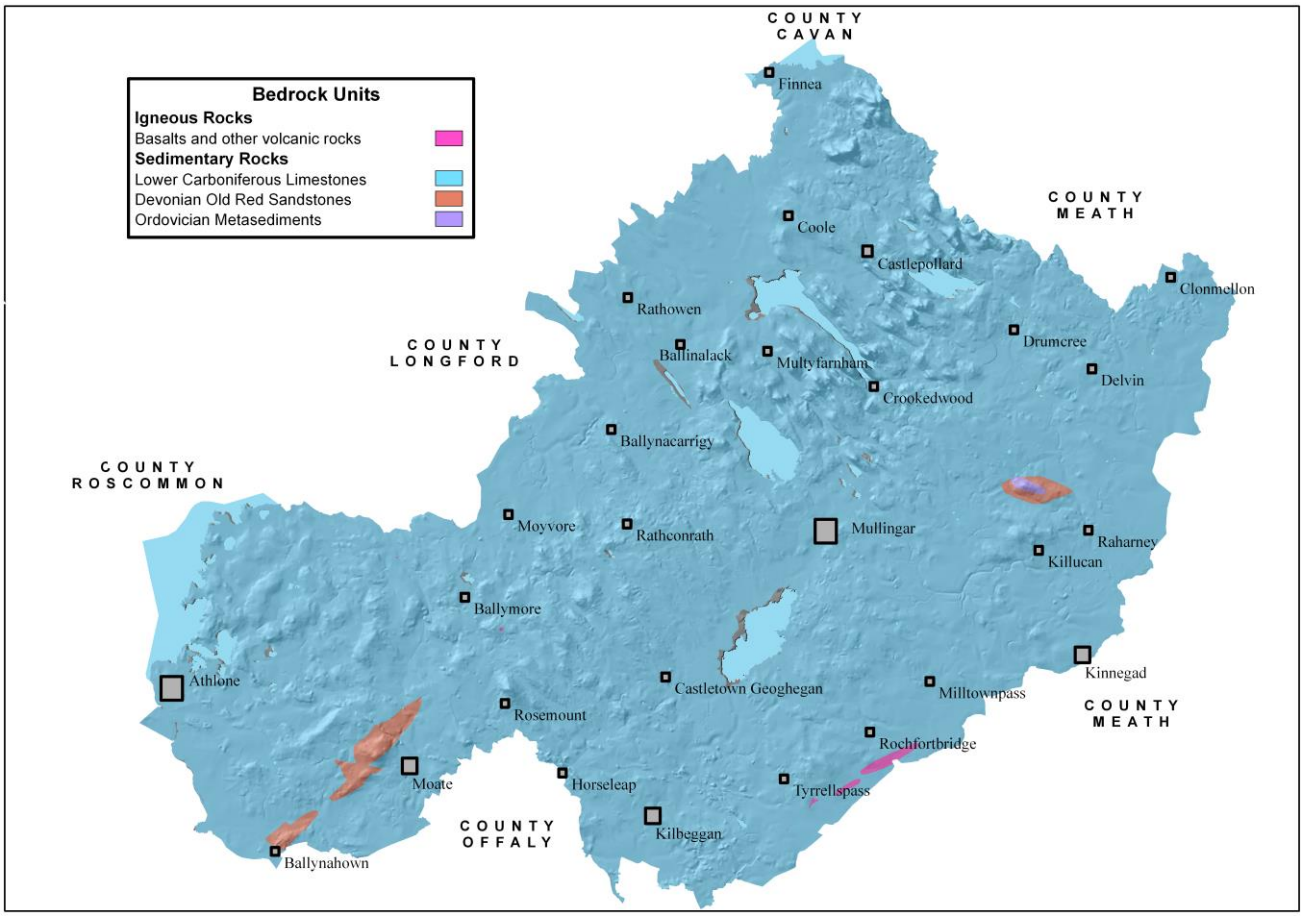
The very oldest rocks known in the county are marine sandstones of Ordovician age, about 485 million years ago, found around the summit of Sion Hill, north of Killucan. Younger rocks, of Devonian age around 400 million years ago, are also found under the lower slopes of Sion Hill and further west in low hills between Ballinahown and just north of Moate. These sandstones and conglomerates, with some volcanic ash layers, were deposited on a low flood plain. Ireland was in tropical realms at this time, but on the margins of a supercontinent which had a desert type of climate.

The dominant rock types in Westmeath belong to the early part of the Carboniferous, between about 360 and 330 million years ago. At that time the region was covered by a shallow tropical sea (Ireland was just south of the Equator then). The sea teemed with life, with animal communities changing as sea levels changed. Also different marine environments formed different types of limestone. Carbonate mud banks or “reefs” (Waulsortian Limestones) developed as upstanding mounds on the sea floor across parts of Westmeath (and much of the Midlands of Ireland). Growth of these mounds was probably due to the rapid accumulation of fine carbonate mud produced by unknown organisms. A rich fauna and varying micro-organisms lived on the mounds. In other parts deeper water basins had what is known as Calp limestone. This developed from occasional flows into the basins of limey sediments from shallow water, with quiet periods of mud sedimentation in between each flow event. This leads to beds of regular limestone separated by thin black shale layers.

Carboniferous limestones are often easily dissolved by surface water or groundwater. This has resulted in the development of many karst features involving underground drainage especially in the Fore area (Seven Springs). Isolated hills like the Rock of Curry and Hill of Uisneach are thought to be residual tower karst landscapes (like that seen today in parts of China and SE Asia). They would have been extensively glaciated in the next major influence on the landscape of Westmeath.

The last development occurred during the last 1.6 million years when ice ages came and went. The last one ended about 10,000 years ago, giving Westmeath some of the finest glacial deposits of sand and gravel across the lowlands. Eskers (the international name for

these features comes from the Irish name '*eiscir*') formed throughout the county. The formed from rivers flowing beneath the ice, leaving a long narrow ridge of sand and gravel. Around 10% of the county is covered by either eskers or associated outwash deposits of sand and gravel where the rivers came out from under the ice. This is partly why, although low-lying, Westmeath has a very undulating or hummocky terrain in many parts. In some parts, temporary lakes were dammed in by ice and glacial deposits to allow mushroom rocks to form, by dissolving the limestone below the water level leaving a limestone cap on a stalk.



A simplified geology map of County Westmeath outlining the main geological units.

The final stage of landscape evolution has been the growth in the last 10,000 years of raised bogs in wet depressions in the landscape. Groundwater in Westmeath is also an important part of its geology. Water from Lough Lene flows to the River Deel and hence to the Boyne and the Irish Sea. Underground drainage goes to the springs at Fore and onto the River Shannon and the Atlantic, making it an unusual feature. In this more recent time, two turloughs have also formed in Westmeath, at Dún na Sí Amenity and Heritage Park in Moate, and at Lough Lom near Castletown-Geoghegan.

AGE (Million Years Ago)	ERA	PERIOD	EVENTS IN WESTMEATH	IF THIS TIMESCALE WAS A DAY LONG ...
2.58	Cenozoic	Quaternary	Several ice ages smothering Westmeath, followed in the last 10,000 years by the spread of vegetation, growth of bogs and arrival of humans. Deposition of till (boulder clay) in crag-and-tails, drumlins and till plains, as well as sands and gravels in eskers, fans and deltas. Dissolution of limestone beneath Quaternary sediments.	The ice ages would begin 38 seconds before midnight
66		Palaeogene	Erosion, especially of limestone. Caves, cavities and underground streams developing in isolated localities throughout Westmeath.	The Palaeogene period begins at 11.40 pm
145	Mezozoic	*Cretaceous*	*Erosion.* *No record of rocks of this age in Westmeath.*	11.15 pm
201		*Jurassic*	*Uplift and erosion.* *No record of rocks of this age in Westmeath.*	The age of the dinosaurs, starting at 10.55 pm
252		*Triassic*	*Desert conditions on land.* *No record of rocks of this age in Westmeath.*	10.42 pm
299	Palaeozoic	*Permian*		10.30 pm
359		Carboniferous	Land became submerged, limestones with some shales and sandstones deposited in tropical seas across the majority of the area of Westmeath. Limestones remaining today are pure and unbedded in the south and west of the county, with areas of muddier limestones in the north, centre and east.	Much of Westmeath's current rocks (limestone, sandstone and shale) deposited around 10.10 pm
419		*Devonian*	Caledonian mountain building. 'Old Red' sandstones deposited in a northeast to southwest trending line between Ballynahown and just north of Moate.	'Old Red' Sandstone deposited at 9.52 pm
443		Silurian	Shallow seas, following closure of the Iapetus Ocean. *No record of rocks of this age in Westmeath.*	Starts at 9.42 pm
485		Ordovician	Metaconglomerates, slates, and volcanic rocks form at Sion Hill, near Raharney.	Begins at 9.28 pm
541		*Cambrian*	Opening of the Iapetus Ocean. *No record of rocks of this age in Westmeath.*	Starts at 9.11 pm
2500	Proterozoic	*Precambrian*	*Some of Irelands oldest rocks deposited in Mayo and Sligo.*	Beginning 11.00 am
4000	Archaean		*Oldest known rocks on Earth.*	Beginning 3.00 am
4600			*Age of the Earth.*	Beginning 1 second after midnight

The Geological Timescale and County Westmeath

6. Acknowledgements

The authors would like to gratefully acknowledge the assistance of Melanie McQuade, Heritage Officer from Westmeath County Council in the development of this project. Funding from the Heritage Council and Westmeath County Council is also acknowledged. We also acknowledge the many members of the IGH Programme Expert Panels who helped define the sites which were considered for County Geological Site status.

Kitty Fagan, Kilbeggan Historical Society
Hugh Gaynor, Manager, Locke's Distillery, Kilbeggan
Justin Moffat, Uisneach Tours, Hill of Uisneach
Vincent Gallagher, Geological Survey Ireland
Peter Farrell, who gave valuable information on and permission to visit land at, Lough Lom
The Massey Family
Alison and Charlie Couper
Louise Dunne

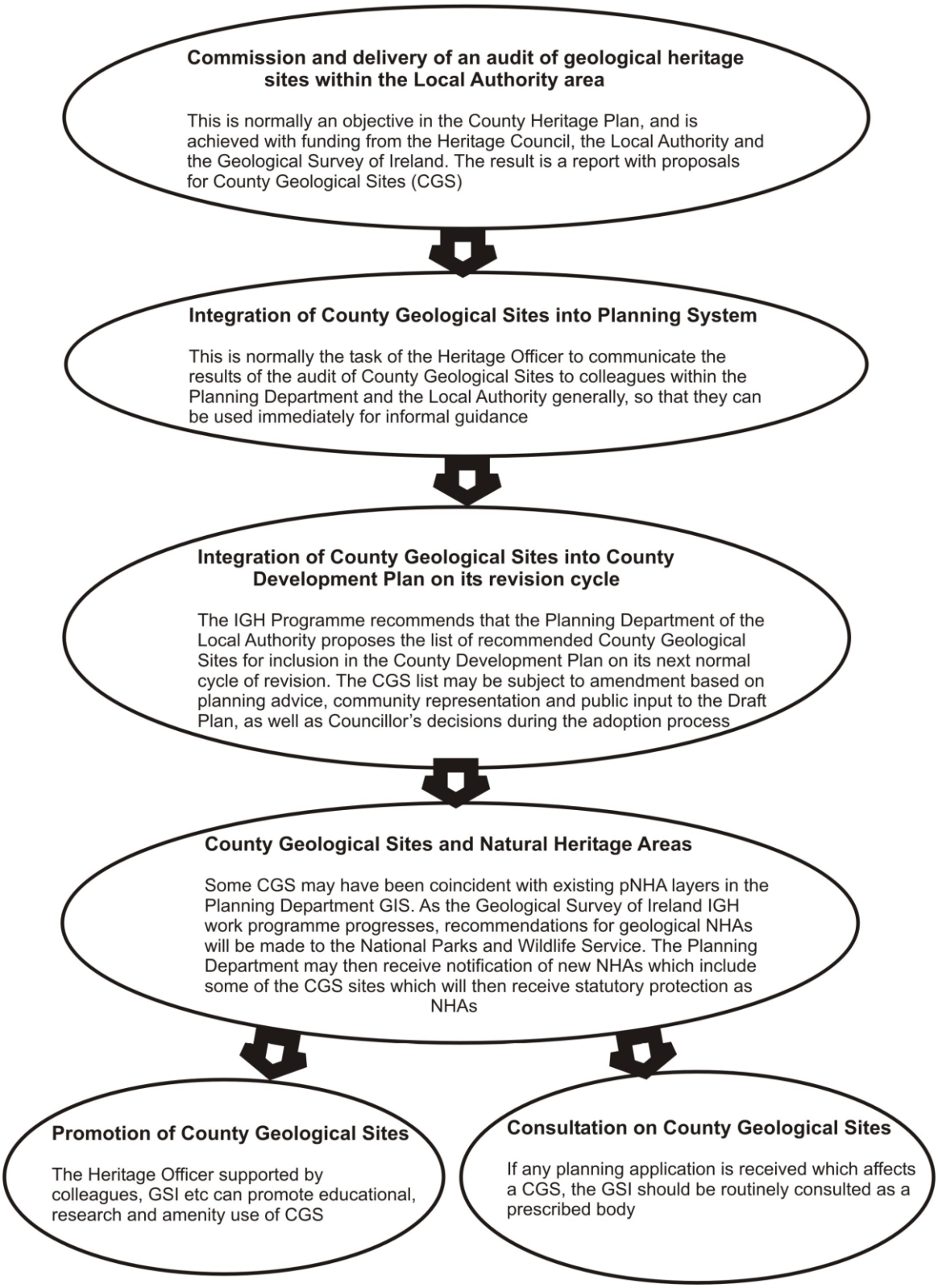
Appendix 1 – Geological heritage audits and the planning process

This appendix contains more detail on the legal framework behind geological heritage audits conducted by County Councils, and the process that operates as a partnership between the Geological Heritage and Planning Programme of Geological Survey Ireland and the local authority Heritage Officer.

Geology is now recognised as an intrinsic component of natural heritage in three separate pieces of legislation or regulations, which empower and require various branches of Government, and statutory agencies, to consult and take due regard for conservation of geological heritage features: the Planning and Development Act 2000 [e.g. Sections 212 (1)f; Part IV, 6; First Schedule Condition 21], the Planning and Development Regulations 2001, the Wildlife (Amendment) Act 2000 (enabling Natural Heritage Areas) and the Heritage Act 1995. The Planning and Development Act 2000 and the Planning Regulations, in particular, place responsibility upon Local Authorities to ensure that geological heritage is protected. Implementation of the Heritage Act 1995, through Heritage Officers and Heritage Plans, and the National Heritage Plan 2002, allow County Geological Sites to be integrated into County Development Plans.

The chart below illustrates the essential process, established by the Irish Geological Heritage Programme in Geological Survey Ireland, over the course of numerous county audits since 2004.

County Geological Sites - a step by step guide



Appendix 2 - Bibliography – Geology of County Westmeath

Shortlist of Key Geological References

This reference list includes a few **key** papers, books and articles on the geology and geomorphology of County Westmeath that are recommended as access points to County Westmeath's geological heritage.

AALEN, F.H.A., WHELAN, K. and STOUT, M. (eds) 1997. *Atlas of the Irish rural landscape.* Cork University Press, Cork.

DUNNE, L. and FEEHAN, J., 2003. *Ireland's Mushroom Stones. Relics of a Vanished Lakeland*. UCD, Department of Environmental Resource Management.

DUNNE, L. and FEEHAN, J., 2003b. The origin and significance of mushroom stones in lowland karst regions. *Irish Journal of Earth Sciences*, **20**: 33–40.

GATLEY, S., SOMERVILLE, I., MORRIS, J.H., SLEEMAN, A.G. and EMO, G. (Ed. A.G. SLEEMAN), 2005. *Geology of Galway-Offaly. A geological description of Galway-Offaly and adjacent parts of Westmeath, Tipperary, Laois, Clare and Roscommon to accompany the bedrock geology 1:100,000 scale map series, Sheet 15, Galway-Offaly*. Geological Survey of Ireland.

HOLLAND, C.H. (ed.) 2001. *The Geology of Ireland*. Dunedin Academic Press, Edinburgh.

JUKES, J.B., KINAHAN, G.H.K., BAILY, W.H. and Du NOYER, G.V., 1859. *Explanation of Sheet 137 (Formerly Quarter Sheet 40 N .E.) of the Maps of the Geological Survey of Ireland*. Memoirs of the Geological Survey Ireland54pp.

McARDLE, P. 2008. *Rock around Ireland*. A guide to Irish Geology. Science Spin Discovery 2. Albertine Kennedy Publishing. 112pp.

McCONNELL, B., PHILCOX, M, E. and GERAGHTY, M. 2001. *Geology of Meath. A Geological Description to Accompany the Bedrock Geology 1:100,000 Scale Map Sheet 13, Meath.* Geological Survey of Ireland.

MORRIS, J.H., SOMERVILLE, I.D. and MacDERMOT, C.V. 2003. *Geology of Longford-Roscommon*. *A Geological Description to Accompany the Bedrock Geology 1:100,000 Scale Map Sheet 12.* Geological Survey of Ireland.

SLEEMAN, A.G., McCONNELL, B.J. and GATLEY, S. 2004. *Understanding Earth processes, rocks and geological history of Ireland*. Geological Survey of Ireland.

WHITTOW, J.B. 1975. *Geology and scenery in Ireland*. Penguin Books Ltd, Middlesex, England

WYSE JACKSON, P.N., PARKES, M.A. and SIMMS, M.J. 2010. *Geology of Ireland: county by county*. Geoschol Books, Dublin. 144pp.

Full Geological references

The following is a reference list of papers, books, articles and some unpublished reports etc. relating to the geology and geomorphology of County Westmeath. Some papers that refer to regional geology may or may not be specifically relevant to County Westmeath.

GEOLOGICAL REFERENCES ON A NATIONAL OR REGIONAL TOPIC WITH INFORMATION CITED ON SITES OR AREAS IN WESTMEATH

ANDREW, C.J. 1986. A diagrammatic representation of the Courceyan stratigraphy of the Irish Midlands. In: *The Geology and Genesis of Mineral Deposits in Ireland* (eds Andrew, C.J., Crowe, R.W.A., Finlay, S., Pennell, W.M. and Pyne, J.F.). Irish Association for Economic Geology, Dublin , 331-340.

ANDREW. C.J., CROWE, R.W.A., FINLAY, S., PENNELL, W.M and PYNE, J.F. (eds). 1986. *The Geology and Genesis of Mineral Deposits in Ireland.* Irish Association for Economic Geology, Dublin, 771 pp.

BROWN, C. and WILLIAMS, B., 1985. A gravity and magnetic interpretation of the structure of the Irish Midlands and its relation to ore genesis, *Journal of the Geological Society of London*, **142**, 1959-1975.

BRUCK, P.M., GARDINER, P.R.R., MAX. M.D. & STILLMAN, C.J. with contributions from BALL, D., CLAYTON, G., HAUGHEY, N., SEVASTOPULO, G.D. & BURNETT, R., 1989. *Thermal maturation levels in the Devonian and Carboniferous rocks in Ireland.* Geological Survey Ireland36pp and map.

CLARINGBOLD, K., FLEGG, A., MAGEE, R. and VONHOF, J., 1994. The Directory of Active Quarries, Pits and Mines. *Geological Survey of Ireland, Report Series,* **94/4,** 111pp.

CLAYTON, G. HIGGS, K., KEEGAN, J.B. and SEVASTOPULO, G.D., 1978. Correlation of the palynological zonation of the Dinantian of the British Isles, *Palinologica,* **1**, 137-147.

COLE, G.A.J. 1922. *Memoir and map of localities of minerals of economic importance and metalliferous Mines in Ireland.* Memoirs of the Geological Survey of Ireland, 155 pp.

COPE J.C.W., INGHAM, J.K. and RAWSON, P.F. (eds) 1992. Atlas of Palaeogeography and Lithofacies. *Geological Society of London, Memoir* **13**,153pp.

CÓZAR, P., SOMERVILLE, I.D., ARETZ, M. and HERBIG, H.G. 2005. Biostratigraphical dating of upper Viséan limestones (NW Ireland) using foraminiferans, calcareous algae and rugose corals. *Irish Journal of Earth Sciences* **23**, 1-23.

DALY, D., 2004. *Making geology relevant to the people of Ireland: the role of groundwater*. John Jackson Lecture. Occasional Papers in Science and Technology 28. Royal Dublin Society.

De BRIT, T.J. 1989. Timing structural events and basement emplacement using extensional veins and cements in the Carboniferous of north central Ireland*. Irish Journal of Earth Sciences* **10**, 13-31.

DELG/EPA/GSI, 1999. *Groundwater Protection Schemes*. Document prepared jointly by the Geological Survey Ireland(GSI), the Environmental Protection Agency, and the Department of Environment, Heritage and Local Government. Available from http://www.gsi.ie

DEHANTSCHUTT ER, J.A.E. 1994. Aspects of the sedimentology of the Waulsortian banks of the Dublin Basin, Ireland. (Abstract), In: *European Dinantian Environments II-Developments in Lower Carboniferous Geology* (ed Jones, G.Ll.) University College Dublin, Ireland, 6-8th September 1994, p. 46.

DEHANTSCHUTTER, J.A.E., 1995. Aspects of the sedimentology and stratigraphy of the Waulsortian mudbanks of the Dublin Basin, Republic of Ireland. Unpublished Ph.D. thesis, University of Dublin, Trinity College, Ireland, 270 p.

DEVUYST, F.X. and LEES, A., 2001. The initiation of Waulsortian buildups in Western Ireland, *Sedimentology,* **48**, 1121-1148.

DREW, D.P. and JONES, G.Ll., 2000. Post-Carboniferous Pre-Quaternary karstification in Ireland. *Proceedings of the Geologists' Association* **111**, 345-307.

GATLEY, S. and PARKES, M.A., 2017. The selection and characters of a geosite—examples from Ireland. *Geoheritage*. https://doi.org/10.1007/s12371-017-0275-7

GATLEY, S. and PARKES, M.A., 2016. Earth science conservation in Ireland—a reappraisal. *Irish Journal of Earth Sciences, 34*, 79-89.
GIESECKE, C.L. 1832. *A Descriptive Catalogue of a New Collection of Minerals in the Museum of the Royal Dublin Society*. To which is added an Irish Mineralogy. Dublin.
GOODWILLIE, R.N., 1972. A Preliminary Report on Areas of Scientific Interest in County Westmeath. Unpublished report to Westmeath County Council. An Foras Forbartha, Dublin.
GRAHAM, J.R., 2001. Variscan Structures *In*: C.H. Holland (Ed), *The Geology of Ireland.* Dunedin Academic
GREGG, J.M., JOHNSON, A.W., SHELTON, K.L, SOMERVILLE, l.D. and WRIGHT,W. 2001. Dolornitization of the Waulsortian Limestone (Lower Carboniferous) Irish Midlands. *Sedimentology* **48**, 745-766.
GRIFFITH, R., 1838. *Second Report of the Commissioners appointed to consider and recommend a general system of railways for Ireland*.
HIGGS, K.T., CLAYTON, G. and KEEGAN, J.B. 1988. Stratigraphic palynology of the Lower Tournaisian rocks of Ireland. *Geological Survey IrelandSpecial Paper* **7**, 1-93.
HISTON, K. and SEVASTOPULO, G.D. 1993. Carboniferous nautiloids and the bathymetry of Waulsortian limestones in Ireland. Proceedings of the Geologists' Association **102**, 149-154.
HITZMAN, M., 1992. *Bedrock geological maps of the Carboniferous of Central Ireland (1:100,000 scale.O.S. Sheets 12. 13, 15, 16, 17, 18 and 19*. Geological Survey of Ireland.
HOWES, M.J., BOLAND, M.A., FLEGG, A.M. and MacKENNA, K., 1988. Quarry directory of active quarries and pits in Ireland. *Geological Survey IrelandReport Series* RS88/3.
JOHNSTON, I.S., 1976. *The Conodont Biostratigraphy of some Lower Carboniferous (Courceyan Stage) rocks of Central Ireland*. Unpublished Ph.D. thesis, University of Dublin.
JOHNSTON, J.D., COLLER, D., MILLAR, G. and CRITCHLEY, M.F., 1996. Basement structural controls on Carboniferous-hosted base metal mineral deposits in Ireland, *In* : *Recent Advances in Lower Carboniferous Geology* (eds) Strogen, P., Somerville, I.D., and Jones, G.Ll.), Geological Society, Special Publication, No. **107**, 1-21.
JONES, G.LL. and SOMERVILLE, I.D., 1996. Irish Dinantian biostratigraphy: practical application. *In*: Strogen, P., Somerville, I.D. and Jones, G.Ll (eds). *Recent Advances in Lower Carboniferous Geology*. Geological Society, Special Publication, No. **107**, 253-262.
JONES, G.Ll., SOMERVILLE, I.D., and STROGEN, P. 1988. The Lower Carboniferous (Dinantian) of the Swords area: sedimentation and tectonics in the Dublin Basin, Ireland. *Geological Journal* **23**, 221- 248.
JONES, G.V. and BRAND, S.F. 1986. The setting, styles of mineralization and mode of origin of the Ballinalack Zn-Pb deposit. In: *Geology and Genesis of Mineral Deposits in Ireland* (eds C.J. Andrew, R.W.A. Crowe, S. Finlay, W.M. Pennell and J.F. Pyne). Irish Association for Economic Geology, Dublin, 355- 375.
KELLEY, S. and BLUCK, B. 1989. Detrital mineral ages from the Southern Uplands using 40Ar - 39Ar laser probe. *Journal of the Geological Society of London*, **146**, 401-404.
KELLEY, S. and BLUCK, B. 1990. Discussion on detrital mineral ages from the Southern Uplands using 40Ar-39Ar laser probe. *Journal of the Geological Society of London*, **147**, 883-884.
KELLING, G., DAVIES, P. and HOLROYD, J. 1987. Style, scale and significance of sand bodies in the Northern and Central Belts, southwest Southern Uplands. *Journal of the Geological Society of London,* **144**, 787-805.
KELLY, J.G.and SOMERVILLE, I.D. 1992. Arundian (Dinantian) carbonate mudbanks in North-West Ireland. *Geological Journal* **27**, 221-242.
KANE, R., 1844. *Industrial Resources of Ireland.* Dublin. pp. xii + 417.
KENNAN, P.S., McARDLE, P., GALLAGHER, V., MORRIS, J.H., O'CONNOR, P.G., O'KEEFE, W.G., REYNOLDS, N.A. and STEED, G.M. 1987. A review of recent isotope research in mineralisation in Ireland. *Geological Survey IrelandBulletin*, **4**, 1-10.
KINAHAN, G. H., 1878. *Manual of the Geology of Ireland.* Dublin.
KINAHAN, G.H., 1886. Irish marbles and limestones. *Scientific Proceedings of the Royal. Dublin Society*, **5**, 372- 444.
KINAHAN, G.H., 1889. Economic geology of lreland. *Journal of the Royal Geological Society of Ireland. Jr.* **8**.

LEES, A., 1964. The structure and origin of the Waulsortian (Lower Carboniferous) 'reefs' of west-central Eire. *Philosophical Transactions of the Royal Society London, 2***47B**, 483-531.
LEES, A. and MILLER J., 1985. Facies variation in Waulsortian buildups: Part 2: Mid Dinantian buildups from England and North America, *Geological Journal,* **20**, 159-180.
LEES, A. and MILLER, J., 1995. Waulsortian Banks, *Special Publications of the International Association of Sedimentologists*, **23**, 191-271.
LEONARD, W.B. and CRUISE, R.J. 1873. *Explanatory Memoir to accompany sheets 78, 79 and 80 of the maps of the Geological Survey Irelandincluding portions of Counties Roscommon, Leitrim, Longford, Cavan and Meath. Dublin*, Memoir of the Geological Survey of Ireland,44pp.
LEWIS, H. and COUPLES, G.D., 1999. Carboniferous basin evolution of central Ireland –simulation of structural controls on mineralization. *In*: McCaffrey, K.J.W., Lonergan, L and Wilkinson, J.J. (eds). *Fractures, Fluid flow and Mineralization* Geological Society, Special Publication No. **151**, 233-245.
MacDERMOT, C.V. and SEVASTOPULO, G.D., 1972. Upper Devonian and Lower Carboniferous stratigraphical setting of Irish Mineralization. *Geological Survey IrelandBulletin*, 1, 267-280.
M'COY, F. 1846. *Synopsis of the Silurian Fossils of Ireland*. Dublin University Press, 68pp, 4 pls. [includes Addenda by J.W. Salter, pp. 71-72, pl. 5].
M'COY, F. 1862. *A synopsis of the characteristics of the Carboniferous Limestone fossils of Ireland*. Second Edition. Williams and Northgate. 274pp.
MILLER, J., 1986. Facies relationships and diagenesis in Waulsortian mudmounds from the Lower Carboniferous of Ireland and N. England. *In*: (eds) Schroeder, J.H. and Purser, B.H. *Reef diagenesis*, Springer-Verlag, Berlin, 311-335.
MORRIS, P. and MAX, M.D., 1995. Magnetic crustal character in Central Ireland. *Geological Journal*, **30**, 49-68.
MORRIS, J. and PARKES, M.A., 2004. Where do we go from here? Geological Heritage Declarations, 1991-2002, 319-329 *In* Parkes, M. (Editor) 2004. Natural and Cultural Landscapes The Geological Foundation. Proceedings of a Conference 9-11 September 2002, Dublin Castle, Ireland. Royal Irish Academy, Dublin.
MURPHY, F.C., ANDERSON, T.B., DALY, J.S., GALLAGHER, V., GRAHAM, J.R., HARPER, D.A.T., JOHNSTON, J.D., KENNAN, P.S., KENNEDY, M.J., LONG, C.B., MORRIS, J.H. , O'KEEFFE, W.G., PARKES, M., RYAN, P.D., SLOAN, R.J., STILLMAN, C.J., TIETZSCH-TYLER, D., TODD, S.P. and WRAFTER, J.P., 1991. Appraisal of Caledonian suspect terranes in Ireland. *Irish Journal of Earth Sciences,* **11**, 11-41.
MURPHY, T., 1955. A Vertical Force Magnetic Survey of the Counties Roscommon, Longford, Westmeath and Meath. *Geophysical Bulletin* **11**, 1-14
NEVILL. W.E. 1958. The Carboniferous knoll-reefs of east-central Ireland. *Proceedings of the Royal Academy* 58B, 285-303.
NAGY, ZS. R., SOMERVILLE, I.D., BECKER, S., GREGG, J. M., WRIGHT, W. JOHNSON, A.W. and SHELTON, K. L., 2001. Petrology and biostratigraphy of carbonate rocks from the ?lower to upper Viséan (Lower Carboniferous) Milford Formation, Co. Carlow, Ireland. Abstracts, *Geological Society of America* Annual Meeting, Boston, November 5-8, 2001, A-443.
PARKES, M.A, 2008. A history of geoconservation in the Republic of Ireland, pp 237-248. *In* Burek, C.V. and Prosser, C.D. (eds) *The History of Geoconservation*. Geological Society, London, Special Publications, 300.
PARKES, M.A. and SLEEMAN, A.G. 1996. *Catalogue of the Type, Figured and Cited Fossils in the Geological Survey of Ireland.* x +124pp. Geological Survey of Ireland, Dublin.
PARKES, M.A. and Gatley, S., 2018. Quarrying and Geoconservation in the Republic of Ireland—the Effectiveness of Guidelines for Operators. *Geoheritage.* https://doi.org/10.1007/s12371-018-0291-2
PEACH, B.N. and HORNE, J. 1899. The Silurian Rocks of Britain. Volume I. Scotland. *Memoir of the Geological Survey of the United Kingdom*, 749pp.
PHILCOX, M.E., 1984. *Lower Carboniferous lithostratigraphy of the Irish Midlands*, Irish Association for Economic Minerals. Special publication, 89pp.
PHILCOX, M.E., BAILY, H., CLAYTON, G. and SEVASTOPULO, G.D. 1992. Evolution of the Carboniferous Lough Allen Basin, Northwest Ireland. In: Basins on the Atlantic seaboard:

petroleum Geology, sedimentology and basin evolution. (ed Parnell, J*.). Geological Society of London, Special Publication,* **62**, 203-2 15.
PRACHT, M., SOMERVILLE, I.D., and WANG, Y. 2015. A revised Mississippian lithostratigraphy of County Galway (western Ireland) with an analysis of carbonate lithofacies, biostratigraphy, depositional environments and palaeogeographic reconstructions utilising new borehole data. *Journal of Palaeogeography*, **4,** 1, p1-26.
SEVASTOPULO G. D. 1982. The age and depositional setting of the Waulsortian Limestones in Ireland. In: Symposium on the Environmental Setting and Distribution of the Waulsortian Facies (eds Bolton, K., Lane H.R. and LeMone, D.V.). El Paso Geological Society and University of Texas at El Paso, 17-33.
SEVASTOPULO, G.D. and WYSE JACKSON, P.N., 2001. Carboniferous (Dinantian). *In:* Holland, C. H. (ed.). *The Geology of Ireland,* Dunedin Academic Press, Edinburgh, 241-288.
SLEEMAN, A. G., 1990. *Preliminary Geological Map of the Rathdowney District.* 1:100,000 scale Geological Map, Special Edition, Geological Survey of Ireland
SOMERVILLE. I.D. 2003. Review of Irish Lower Carboniferous (Mississippian) mud-mounds: depositional setting, biota, facies and evolution. In: *Permo-Carboniferous Carbonate Platforms and Reefs* (eds Ahr, W. Harris, A.P., Morgan, WA. and Somerville, I.D.). Society for Economic Paleontologists and Mineralogists, Special Publication, 78. American Association for petroleum Geologists, Memoir, **83**, 223-229
SOMERVILLE, I.D. and COZAR, P., 2002. Depositional setting and palaeoecology of *Siphonodendron* biostromes in Upper Viséan of SE Ireland. *Abstracts 46th Annual Meeting Palaeontological Association, Cambridge, December 15-18, 2002.*
SOMERVILLE, I.D. and COZAR, P., 2005. Late Asbian to Brigantian (Mississippian) foraminifera from southeast Ireland: comparison with northern England assemblages. *Journal of Micropalaeontology*, **24**: 131–144.
SOMERVILLE, I.D., JONES, G.Ll., and PHILCOX, M.E., 1996. *Supra-Waulsortian Workshop*. Irish Association for Economic Geology. Dublin, p. 1-78.
STROGEN, P., 1974. The sub-Palaeozoic basement in Central Ireland. *Nature* **250**, 562-563.
STROGEN, P., JONES, G.Ll. and SOMERVILLE, I.D. 1990. Stratigraphy and sedimentology of Lower Carboniferous (Dinantian) boreholes from west Co. Meath, Ireland. *Geological Journal* **25**, 103-137.
THORN, R. and COXON C. 1992. Hydrogeological Aspects of Bacterial Contamination of Some Western Ireland Karstic Limestone Aquifers. *Environmental Geology and Water Science*, **20** (1), 65-72.
WRIGHT W. SOMERVILLE, I.D., GREGG, J. M., JOHNSON, A .W. and SHELTON, K.L.2003. Dolomitization and Nomorphism of Irish Lower Carboniferous (Early Mississippian) limestones: evidence from petrographic and isotopic data. In: *Permo-Carboniferous Carbonate Platforms and Reefs* (eds Ahr, W., Harris, A.P., Morgan, W.A. and Somerville, I.D.). Society for Economic Paleontologists and Mineralogists, Special Publication, 78. American Association for petroleum Geologists, Memoir, **83**, 223-229

Appendix 3 - Bibliography – County Westmeath Quaternary References

Quaternary References

Due to the very extensive influence of glaciation on the Irish landscape, and the relative accessibility for study there is an enormous body of literature on the Quaternary, or Ice Age geology of Ireland, and Westmeath. The references in Appendix 3 cover this. They are split into references specifically covering sites or features in County Westmeath, and a section of national or regional papers that have some data from or on County Westmeath included.

QUATERNARY REFERENCES WITH DIRECT REFERENCE TO WESTMEATH

ADAMS, A.L., 1878. On the recent and extinct Irish mammals. *Scientific Proceedings of the Royal Dublin Society*, **2**, 45-86.

BEESE, A.P., BRUCK, P.M., FEEHAN, J. and MURPHY, T., 1983. A silica deposit of possible Tertiary age in the Carboniferous Limestone near Birr, County Offaly, Ireland. *Geological Magazine*, **120(4)**, 331-340.

BOWEN, D.Q., PHILIPPS, E.M., McCABE, A.M., KNUTZ, P.C. AND SYKES, G.A., 2002. New data for the last glacial maximum in Great Britain and Ireland. *Quaternary Science Reviews*, **21**, 89-101.

BRADSHAW, R.H.W., 2001. The Littletonian Warm Stage – Post 10,000 BP. In: Holland, C.H., A *Geology of Ireland: Second Edition*. Scottish Academic Press, Edinburgh, pp. 429-442.

BRADSHAW, R.H.W. and BROWNE, P., 1987. Changing patterns in the post-glacial distribution of *Pinus sylvestris* in Ireland. *Journal of Biogeography*, **14**, 237-248.

CASELDINE, C. and HATTON, J., 1996. Early land clearance and wooden trackway construction in the third and fourth millennia BC at Corlea, Co. Longford. *Biology and Environment: Proceedings of the Royal Irish Academy*, **96B**, 11.19.

CASELDINE, C., HATTON, J., HUBER, U., CHIVERRELL, R. and WOOLLEY, N., 1998. Assessing the impact of volcanic activity on mid-Holocene climate in Ireland: the need for replicate data. *The Holocene*, **8**, 105-111.

CHARLESWORTH, J.K., 1928. The glacial retreat from central and southern Ireland. *Quarterly Journal of the Geological Society of London*, **84**, 293-344.

CHARLESWORTH, J. K., 1931. The eskers of Ireland; their distribution, origin and human significance. *Geography*, **16**, 21-27.

CHARLESWORTH, J.K., 1963A. Some observations on the Irish Pleistocene. *Proceedings of the Royal Irish Academy*, **62B**, 295-322.

CHARLESWORTH, J.K., 1963b. *Historical geology of Ireland*. Oliver and Boyd, 565 pp..

CHARLESWORTH, J.K., 1973. Stages in the dissolution of the last ice sheet in Ireland and the Irish Sea Region. *Proceedings of the Royal Irish Academy*, **73B**, 79-85.

CLARK, C. D. AND MEEHAN, R.T., 2001. Subglacial bedform geomorphology of the Irish Ice Sheet reveals major configuration changes during growth and decay. *Journal of Quaternary Science,* **16** (5), 483-496.

CLARK, C.D., MEEHAN, R.T., HATTESTRAND, C., CARLING, P., EVANS, D. and MITCHELL, W., 2001. Palaeoglaciological investigations exploiting remote sensing, elevation models and GIS**.** *Slovak Geological Magazine*, **7(3),**313.

CLOSE, M.H., 1867. Notes on the General Glaciation of Ireland, *Journal of the Royal Geological Society of Ireland*, **1**, 207-242.

COXON, P. AND BROWNE, P., 1991. Glacial deposits of central and western Ireland. In Ehlers, J., Gibbard, P.L. and Rose, J. (Editors), Glacial deposits in Great Britain and Ireland. Balkema, Rotterdam, pp. 355-365.

COXON, P. and MCCARRON, S., 2009. Cenozoic, Tertiary and Quaternary. In: Holland, C.H. and Sanders, I.H. (Editors) *The Geology of Ireland*. Second Edition, 355-396.

CRUSHELL, P., 2000. Irish Fen Inventory – a review of the status of fens in Ireland*. Irish Peatland Conservation Council*, Dublin, 100 pp.

DELANEY, C.A., 1995. Sedimentology of Late Devensian deglacial deposits in the Lough Ree area, central Ireland. Unpublished PhD Thesis, University of Dublin, Trinity College.
DELANEY, C., 2001. Morphology and sedimentology of the Rooskagh esker, Co. Roscommon. *Irish Journal of Earth Sciences* **19**, 5-22.
DELANEY, C., 2002. Esker formation and the nature of deglaciation: the Ballymahon esker, Central Ireland., *North West Geography* **1**, 23-33.
DELANEY, C., 2002. Sedimentology of a glaciofluvial landsystem, Lough Ree area, Central Ireland: implications for ice marginal characteristics during Devensian deglaciation. *Sedimentary Geology* **149**, 111-126.
DELANEY, C.A., 2008. Seasonal controls on deposition of late Devensian glaciolacustrine sediments, Central Ireland. In *Glacial Sedimentary Processes and Products* Hambrey, M., Christoffersen, P., Glasser, N., Jansen, P., Hubbard, B. and Siegert, M. (Editors) Special Publication, International Association of Sedimentologists: Blackwell, Oxford, 146-163.
DOWLING, L.A. AND COXON, P., 2001. Current understanding of Pleistocene stages in Ireland. *Quaternary Science Reviews*, **20**, 1631-1642.
DUNNE, L. and FEEHAN, J., 2003a. *Ireland's Mushroom Stones: Relics of a vanished Lakeland*. Environmental Institute, UCD, Dublin. 28pp.
DUNNE, L. and FEEHAN, J., 2003b. The origin and significance of Mushroom Stones in Ireland. *Irish Journal of Earth Sciences*, **20**, 33-40.
FEEHAN, J., 2004. *A long lost wilderness. The future of the North Midlands Peatlands*. ERM in collaboration with the National Wetlands Park Committee, 45pp.
FEEHAN, J., 2007. Periglacial ventifacts in Ireland. *Irish Geography*, **40(2)**, 206-209.
FEEHAN, J., 2013. *The Geology of Laois and Offaly*. Offaly County Council in association with Laois County Council and the Geological Survey of Ireland, 405pp,
FEEHAN, J. and O'DONOVAN, G., 1996. *The Bogs of Ireland*. The Environmental Institute, University College Dublin.
FEEHAN, J., O'DONOVAN, G., RENOU-WILSON, F. and WILSON, D., 2008. *The Bogs of Ireland: an introduction to the Natural, Cultural and Industrial Heritage of Ireland Peatlands* (Revised Edition). The Environmental Institute, University College Dublin.
FINCH, T.F., 1977. *Soils of County Westmeath*. An Foras Taluintais, Dublin, 107 pp.
FINCH, T.F., 1988. *Soils of County Longford*. An Foras Taluintais, Dublin, 4 pp.
FINCH, T.F., 1990. The lithological characteristics of the glacial deposits of County Longford, *Irish Geography*, **23(1)**, 38-42.
FREDENGREN, C., KILFEATHER, A. and STUIJTS, I., 2010. *Lough Kinale: Studies of an Irish lake*. Lake Settlement Project: Discovery Programme Monograph Number 8, Wordwell, 284 pp.
GEISSEL, H., 2006. *A road on the long ridge: in search of the ancient highway of the eiscir riada*. CRS Publications, 72pp.
GIBSON, P., 2007. *Heritage Landscapes of the Irish Midlands*. Geography Publications, Dublin, 340 pp.
GOODWILLIE, R., 2003. Vegetation of turloughs. In: Otte, M.L. (Editor) *Wetlands of Ireland*. University College Dublin Press, pp. 135-144.
HICKEY, C., LEE, M., DREW, D., MEEHAN, R.T. AND DALY, D., 2002. Lowland karst of North Roscommon and Westmeath. *International Association of Hydrogeologists (Irish Group) Field Guide.* Geological Survey of Ireland, 28pp.
HOOIJER, A., 1996. *Floodplain hydrology: an ecologically oriented study of the Shannon Callows, Ireland*. Unpublished PhD. Thesis, Vrije Universiteit Amsterdam.
JONES, G. Ll., 2000. Ancient karst or palaeokarst in Ireland. In: Daly, D., Drew, D., Deakin, J., Ball, D., Parkes, M. and Wright, G. (Editors) *The Karst of Ireland*. Geological Survey of Ireland, Dublin, pp.4-7.
KILROE, J.R., 1907. The River Shannon: its present course and geological history. *Proceedings of the Royal Irish Academy*, **26B**, 74-96.
KNIGHT, J., 2006. Geomorphic evidence for active and inactive phases of late Devensian ice in north central Ireland. *Geomorphology*, **75**, 4-19.

McCABE, A.M., 1985. Glacial geomorphology. In: Edwards, K.J. and Warren, W.P., (Editors), *The Quaternary history of Ireland*, pp. 67-93. Academic Press, London.
McCABE, A.M., 1987. Quaternary deposits and glacial stratigraphy in Ireland. *Quaternary Science Reviews*, **6**, 259-299.
McCABE A.M., 1989. The distribution and stratigraphy of drumlins in Ireland. In Ehlers J, Gibbard PL, Rose J. (eds), *Glacial deposits in Great Britain and Ireland*. Balkema, Rotterdam, 421-435.
McCABE A.M., 1991. The distribution and stratigraphy of drumlins in Ireland. In: Ehlers J, Gibbard PL, Rose J. (Editors), *Glacial deposits in Great Britain and Ireland*. Balkema, Rotterdam, 421-435.
McCABE, A.M., 2008. *Glacial Geology and geomorphology: The Landscapes of Ireland*. Dunedin Academic Press, 274pp.
MEEHAN, R.T., 1998. The Quaternary Geology and last glaciation and deglaciation of northwest Meath and adjacent parts of Westmeath and Cavan. Unpublished PhD Thesis, National University of Ireland, Dublin
MEEHAN, R.T., 1999. Directions of ice flow during the last glaciation in counties Meath, Westmeath and Cavan. *Irish Geography*, 32(1):26–51.
MEEHAN, R.T., 2000a. Kells and adjacent areas, County Meath Ireland. *Glacial Landsystems Working Group Field Guide*, Teagasc, Dublin.
MEEHAN, R.T. 2000b. Evidence for several ice marginal positions in east central Ireland, and their relationship to the Drumlin Readvance Theory. In Ehlers, J. (Editor) *Extent and Chronology of Worldwide Glaciation*, INQUA Commission on Glaciation, Work Group 5, Special Publication, PP.193-195.
MEEHAN, R.T., 2005. *Report on geological component of eskers in Westmeath*. Unpublished report for Westmeath County Council.
MEEHAN, R.T., 2006. A regional glacial readvance in Ireland: self-promulgating theory, or science-based reality? In Knight, P.G., Glacier Science and Environmental Change. *Blackwell Scientific Publishing, pp. 264-266.*
MEEHAN, R.T., 2010. The geology and hydrogeology of the Moate Cowpark locality. Unpublished report for Midlands Amenity Park Feasibility Study. 24pp.
MEEHAN, R.T., 2017. Glacial geomorphology of the last Irish ice Sheet. In Coxon, P., McCarron, S. and Mitchell, F.J.G. (Editors) *Advances in Irish Quaternary Studies*. Springer, Amsterdam, pp. 67-99.
MEEHAN, R.T. and WARREN, W.P., 1999. *The Boyne Valley in the Ice Age.* Meath County Council and Geological Survey of Ireland, Dublin. 92pp.
MIR PELLICER, X., WARREN, W.P.. and SHEEHY, M., 2005. *Eskers and associated glaciofluvial sand and gravel deposits in north County Offaly*. Report on behalf of the Heritage Council and Offaly County Council, Geological Survey of Ireland, Dublin.
MIR PELLICER, X. and P. GIBSON, 2011. Electrical resistivity and Ground Penetrating Radar for the characterisation of the internal architecture of Quaternary sediments in the Midlands of Ireland. *Journal of Applied Geophysics,* **75**, 638-647.
MIR PELLICER, X., ZARROCA, M. and GIBSON, P., 2012. Time-lapse resistivity analysis of Quaternary sediments in the Midlands of Ireland. *Journal of Applied Geophysics,* **82**: 46-58.
MIR PELLICER, X., WARREN, W.P., GIBSON, P. and LINARES, R., 2012. Construction of an evolutionary deglaciation model for the Irish Midlands based on the integration of morphostratigraphic and geophysical data analyses. *Journal of Quaternary Science*, **27(8)**, 807-818.
MITCHELL, F.J.G., 2009. The Holocene. In: Holland, C.H. and Sanders, I.H. (Editors) *The Geology of Ireland*. Second Edition, 397-404.
MITCHELL, F. and DELANEY, 1997. The Quaternary of the Irish Midlands. Irish Association for Quaternary Studies (IQUA) Field Guide Number 21.
MICHELL, G.F, 1957. The Pleistocene Epoch. In: Meenan, J and Webb, D.A. (Editors) *A view of Ireland*. PP. 33-39.
MITCHELL, G.F., 1981. The Quaternary – until 10,000 BP. In: Holland, C.H. (Editor) *A geology of Ireland*. Scottish Academic Press, Edinburgh, pp. 235-258.

MITCHELL, G.F., 1998. The Ice Age. Chapter 2 of Mitchell, G.F. and Ryan, M., *Reading the Irish Landscape*, Townhouse Press, pp. 35-80.
SOLLAS, W.J.,1896. A map to show the distribution of eskers in Ireland. *Scientific transactions of the Royal Dublin Society* **5** Series 2, 795-822.
SYNGE, F.M., 1983. The Quaternary Period: the Ice Age and its deposits. In: Feehan, J. (Editor) *Laois – An Environmental History*, 49-57.
SYNGE, F.M. and STEPHENS, N., 1960. The Quaternary period in Ireland-an assessment, *Irish Geography*, **4**, 121-130.
TUBRIDY, M. and MEEHAN, R.T, 2005. Study to establish the extent, location of eskers and associated habitats in Co. Westmeath: Phase 1. Westmeath County Council. Unpublished report for Westmeath County Council, 104pp.
TUBRIDY, M. and MEEHAN, R.T, 2006. Study to establish the extent, location of eskers and associated habitats in Co. Westmeath: Phase 2. Westmeath County Council. Unpublished report for Westmeath County Council, 96pp.
VAN DER MEER, J.J.M. and WARREN, W.P., 1997. Sedimentology of late glacial clays in
WARREN, W.P. 1979. The stratigraphy and age of the Gortian Interglacial deposits. *Geological Survey IrelandBulletin* **2**, 315-332.
WARREN, W.P., 1991. *Ireland 1991: INQUA Commission on formation and properties of glacial deposits. Field Guide for excursion*, Geological Survey of Ireland, Dublin, 65pp.
WARREN, W.P., 1992. Drumlin orientation and the pattern of glaciation in Ireland. *Sveriges Geologiska Undersokning, Research Papers*, Series Ca **81**, 359-366.
WARREN, W.P. and ASHLEY, G., 1994. Origins of the ice contact stratified ridges (eskers) of Ireland. *Journal of Sedimentary Research*, **64A**, 433-449.

QUATERNARY REFERENCES ON A NATIONAL OR REGIONAL TOPIC WITH INFORMATION CITED ON SITES OR AREAS IN WESTMEATH

AALEN, F.H.A., WHELAN, K. and STOUT, M., 1997. *Atlas of the Irish Rural Landscape*. Cork University Press, 352pp.
ASHLEY, G.M. AND WARREN, W.P., 1995. Irish Eskers; Origin of ice contact stratified deposits. INQUA Commission on Formation and properties of Glacial Deposits Symposium and field excursion handbook. Geological Survey of Ireland, Dublin. 59pp.
BELLAMY, D., 1986. *The Wild Boglands: Bellamy's Ireland*. Country House Publishers, Dublin, 178pp.
CARVILLE LEWIS, H., 1894. *Papers and notes on the glacial geology of Great Britain and Ireland*. Longman, Green and Company, London, 649pp.
CHARLESWORTH, J.K., 1963. Some observations on the Irish Pleistocene. *Proceedings of the Royal Irish Academy* **62B**, 295-322.
COLE, G.A.J., 1901. The topography and geology of Ireland. In: Coyne, W.P. (Editor) *Ireland Industrial and Agricultural*. Department of Agriculture, Dublin, 450 pp.
COLEMAN, J.C., 1965. *The caves of Ireland*. Anvil Books, Tralee.
COXON, C.E., 1987a. The spatial distribution of turloughs. *Irish Geography* **20**, 11-23.
COXON, C.E., 1987b. Irish lake Marls. *Appendix 1 in 'Offaly and West Kildare' Irish Quaternary Association Field Guide,* No. 10, pp. 69-72.
COXON, P., 1993. Irish Pleistocence biostratigraphy. *Irish Journal of Earth Sciences* **12**, 83-105.
DAVIES, G.L., 1970. The Enigma of the Irish Tertiary. *In* Stephens, N. and Glasscock, R.E., *Irish Geographical Studies*. Queens University of Ireland, Belfast, pp. 1-16.
DREW, D., 2002. Landforms and hydrology of the County Westmeath 'Lakeland' area. In Hickey, C., Lee, M., Drew, D., Meehan, R. and Daly, D., '*Lowland Karst of North Roscommon and Westmeath*', International Association of Hydrogeologists (Irish Group) Field Guide. Geological Survey of Ireland, 20-28.
DUNLOP, P., 2004. The characteristics of ribbed moraine and assessment of theories for their genesis. Unpublished PhD Thesis, Department of Geography, Sheffield.
EDWARDS, K.J. and WARREN, W.P. (Editors), *The Quaternary history of Ireland*. Academic Press, London.

EHLERS, J., GIBBARD, P. and ROSE, J. (Editors.) *Glacial Deposits in Great Britain and Ireland*. Balkema, Rotterdam.
FARRINGTON, A. AND SYNGE, F.M., 1970. Three local studies of the Irish Pleistocene. In Stephens, N. and Glasscock, R. (Editors) 'Irish Geographical Studies in honour if E. Estyn Evans'. Queens University of Belfast, 49-52.
FEALY, R.M., GREEN, S., LOFTUS, M., MEEHAN, R.T., RADFORD, T., CRONIN, C. AND BULFIN, M., 2009. *Teagasc EPA Soil and Subsoil Mapping Project –Final Report. Volumes I and II*. Teagasc, Kinsealy, Dublin.
FLINT, R.F., 1930. The origin of the Irish 'eskers'. *Geographical Review* **20**, 615-620.
GALLAGHER, P.H. and WALSH, T., 1943. Characteristics of Irish Soil Types – I. *Proceedings of the Royal Irish Academy* **42**, 205-250.
GARDINER, M. and RADFORD, T., 1980. Soil Associations of Ireland and their land-use potential. *Soil Survey Bulletin* **No. 36**, An Foras Taluintais, Dublin, 142 pp.
GLANVILLE, C. and WARREN, W.P., 1995. Eskers and associated gravels map of Ireland (Draft), 1:120,000 scale. Quaternary Section, Geological Survey of Ireland, Dublin.
GOODWILLIE, R., 1992. *Information on Areas of Scientific Interest in An Foras Forbartha Files*. A catalogue prepared for National Parks and Wildlife Service of the Office of Public Works. 232 pp.
GREENWOOD, S.L. and CLARK, C.D., 2008. Subglacial bedforms of the Irish ice sheet. *Journal of Maps* 2008, 332-357.
GREENWOOD, S.L. and CLARK, C.D., 2009a. Reconstructing the last Irish Ice Sheet 1: changing flow geometries and ice flow dynamics deciphered from the glacial landform record. *Quaternary Science Reviews* **28**, 3085-3100.
GREENWOOD, S.L. and CLARK, C.D., 2009b. Reconstructing the last Irish Ice Sheet 2: a geomorphologically-driven model of ice sheet growth, retreat and dynamics. *Quaternary Science Reviews* **28**, 3101-3123.
GREGORY, J.W., 1920. The Irish Eskers: Royal Society (London), *Philosophical transactions* Ser. B, v. 210, 115-151.
HAMMOND, R.F., 1981. The Peatlands of Ireland. *Soil Survey Bulletin* **No. 35** (to accompany the Peatland Map of Ireland, 1978). An Foras Taluintais, Dublin, 60pp.
HICKEY, C., 2009. An understanding of the workings of lowland karst hydrogeology in Ireland, using Roscommon as an example. *Unpublished PhD Thesis, Trinity College Dublin.*
HOLLAND, C.H., 2001. *The Geology of Ireland* (Second Edition). Edinburgh, Dunedin Academic Press, 532 pp.
HULL, E., 1891. *The physical geology and geography of Ireland*. London, 328pp.
KINAHAN, G. H., 1878. *Manual of the Geology of Ireland*. Dublin. 444pp.
KINAHAN, G.H, 1887a. Irish arenaceous rocks – sands, sandstones, grits, conglomerates, quartz rocks and quartzytes. *Scientific Proceedings of the Royal Dublin Society*, **5**, 507-620.
KINAHAN, G.H, 1887b. Irish marbles and limestones. *Scientific Proceedings of the Royal Dublin Society*, **5**, 372-444.
KINAHAN, G.H, 1888. Slates and clays of Ireland. *Scientific Proceedings of the Royal Dublin Society*, **6**, 143-166.
LEWIS, C.A., 1978. Periglacial features in Ireland: an assessment. *Journal of Earth Science, Royal Dublin Society* **1**, 135-142.
LEWIS, C.A., 1985. Periglacial features. *In* Edwards, K.J. and Warren, W.P. (Eds.) *The Quaternary History of Ireland.* Academic Press, London, pp. 95-113.
MITCHELL, G.F., 1980. The search for Tertiary Ireland. *Journal of Earth Sciences of the Royal Dublin Society*, **3**, 13-33.
PRAEGER, R.L., 1937. *The Way that I Went*. Collins Press, Dublin. 394pp.
SMITH, M.J. and KNIGHT, J., 2011. Palaeoglaciology of the last Irish Ice Sheet reconstructed from striae. *Quaternary Science Reviews* **30** (1-2), 147-160.
SYNGE, F.M., 1970. The Irish Quaternary: current views 1969. In: Stephens, N. and Glasscock, R.E. (Editors) *Irish Geographical Studies in honour of E. Estyn Evans*. Geographical Society of Ireland, Dublin.
WARREN, W.P., 1985. Stratigraphy. *In* Edwards, K.J. and Warren, W.P. (Editors), *The Quaternary history of Ireland*. Academic Press, London, pp. 39-65.

WARREN, W.P. 1979. The stratigraphy and age of the Gortian Interglacial deposits. *Geological Survey IrelandBulletin* **2**, 315-332.
WARREN, W.P. 1991. Fenitian (Midlandian) glacial deposits and glaciations in Ireland and the adjacent offshore regions. In: Ehlers, J., Gibbard, P. and Rose, J. (Eds.), *Glacial Deposits in Great Britain and Ireland*, Balkema, Rotterdam, 79-88.
WATTS, W. A., 1970. Tertiary and interglacial floras in Ireland. *In* Stephens, N. and Glasscock, R.E. (Editors), *Irish Geographical Studies*, Queens University Belfast, pp. 17-33.
WATTS, W.A., 1985. Quaternary vegetation cycles. *In* Edwards, K. And Warren, W.P. (Eds.), *The Quaternary History of Ireland*, Academic Press, London, 155-185.
WHITTOW, J.B., 1974. *Geology and scenery in Ireland*. Dublin, Penguin Books, 304 pp.
WILLIAMS, P.W., 1970. Limestone morphology in Ireland. *In* Stephens, N. and Glasscock, R.E. (Editors), Irish Geographical Studies in honour of E. Estyn Evans', Geographical Society of Ireland, Dublin. 105-124.
WOODMAN, P. C., McCARTHY, M. and MONAGHAN, N. T. 1997. The Irish Quaternary fauna project. *Quaternary Science Reviews* **16**, 129-15.

Appendix 4 – Geological heritage versus geological hazards

Ireland is generally considered to be a country with very low risk of major geological hazards: there are no active volcanoes, Ireland's location on stable tectonic plates mean earthquakes are relatively rare and its recorded human history is not peppered with disastrous landslides, mudflows or other geological catastrophes. There are of course risks of one-off events, and this section briefly looks at the specific record and nature of geological hazards in County Westmeath and the relationship of the County Geological Sites to those hazards.

The difference between human timescales and geological timescales can be difficult to comprehend but, for many geological processes, there are periods of sudden activity encompassing major events, and then quiet periods in between. The sites in this audit represent evidence of past geological environments and processes, such as the building of high mountain chains, ice sheets covering the land surface and so on. However, in County Westmeath there are relatively few sites representing the active geomorphological or land-forming processes of today.

Landslides and bog flows
The Geological Survey Irelandhas been compiling national data on landslides in the past decade, although there were no events recorded in Westmeath. See https://www.gsi.ie/en-ie/programmes-and-projects/geohazards/Pages/default.aspx

Flooding
There are two types of flooding which need consideration. River flooding occurs inland when the rainfall exceeds the capacity of the ground to absorb moisture, and the river channels cannot adequately discharge it to the sea. The OPW website, www.floods.ie, can be consulted for details of individual flood events in County Westmeath. Karstic flooding can occur when underground passages are unable to absorb high rainfall events. The Carboniferous limestone bedrock in County Westmeath is karstified but hydrogeological regimes are heavily modified by glacial tills and sand and gravel deposits.

Radon
Radioactive minerals and gases at higher concentrations can be carcinogenic. Radon can seep into homes and workplaces and can be carried in water supplies. A map showing the areas predicted to be at particular risk from radon in Ireland, called High Radon Areas, can be seen on the EPA website at http://www.epa.ie/radiation/#.VRu9OVROPcs. The Radiological Protection Institute of Ireland was formerly responsible for this but has been merged with the EPA.

Groundwater pollution
Whilst not such an obvious hazard as physical collapses, flooding and landslides, the pollution of groundwater supplies carries a serious risk to human health. Westmeath is a county quite dependent on groundwater supplies, and therefore the risk is more serious than for most other counties. As the groundwater is often contained within limestone, it should be noted that karstic springs are especially vulnerable to pollution since the flow is mainly within fissure conduits allowing rapid transmission of pollution from source to water supply. The opportunity for microbial attenuation of pollutants is far less in limestone fissures (as there are no natural barriers to stop pollutants) than it would be in granular deposits, which act as natural filters.

Appendix 5 – Data sources on the geology of County Westmeath

This section is a brief summary of relevant GSI datasets, to assist any enquiry concerning geology and to target possible information easily. Geological Survey Ireland has very many datasets, accumulated since it began mapping Ireland's geology in 1845. A Document Management System (called GOLDMINE) is freely available online, into which about half a million documents and maps have been scanned. This means that any user can search on screen for data of relevance to them. **Data is available free of charge**.

Digital mapping of many different datasets is now available via an easy to use public viewer on Geological Survey Ireland website: www.gsi.ie

Key GSI datasets available in the public domain include:

GOLDMINE (**G**SI **O**n**L**ine **D**ocument, **M**aps and **I**nformatio**N** **E**xplorer).

The GSI online digital archive enables visitors to search the Geological Survey Irelandonline data archive database and download full-size resampled pdfs and/or original high resolution TIFF image files. The data consists of: Scanned Capture of 450,000 pages and maps, including all of GSI principal datasets, (Mineral Exploration Reports-Open File, Geotechnical Reports, boreholes & tests, Historic 6":1 mile and 1":1 mile Geological Maps, GSI Publications, Bulletins, Published and Unpublished Reports, Groundwater Well Hydrographs, Marine Maps, Airborne Geophysical Maps, Mineral Locality Reports and Mine Record Reports and Maps). The database runs on Oracle© and the stored imagery is currently 1.4TB in size. https://secure.dccae.gov.ie/goldmine/index.html

1:100,000 Map Report Series
All historical, modern and other mapping has been compiled into very useful maps and reports that describe the geology of the entire country. Sheets 12, 13, 15 and 16 cover all of Westmeath.

19th century 6 inch to the mile fieldsheets
These provide an important historical and current resource, with very detailed observations of the geology of the entire country.

19th century one inch maps and Memoirs
Information from the detailed 19th century mapping was distilled into one inch to the mile maps, of which parts of Sheets 89, 90, 98, 99, 100, 108, 109, 110 cover County Westmeath. Each sheet or several sheets were accompanied by a Memoir which described the geology of that area in some detail. These still provide valuable records of observations even though interpretations may have changed with better geological understanding. Memoirs are scanned and uploaded on GOLDMINE. Historical geological mapping is also now available via a website: http://www.geologicalmaps.net/irishhistmaps/history.cfm

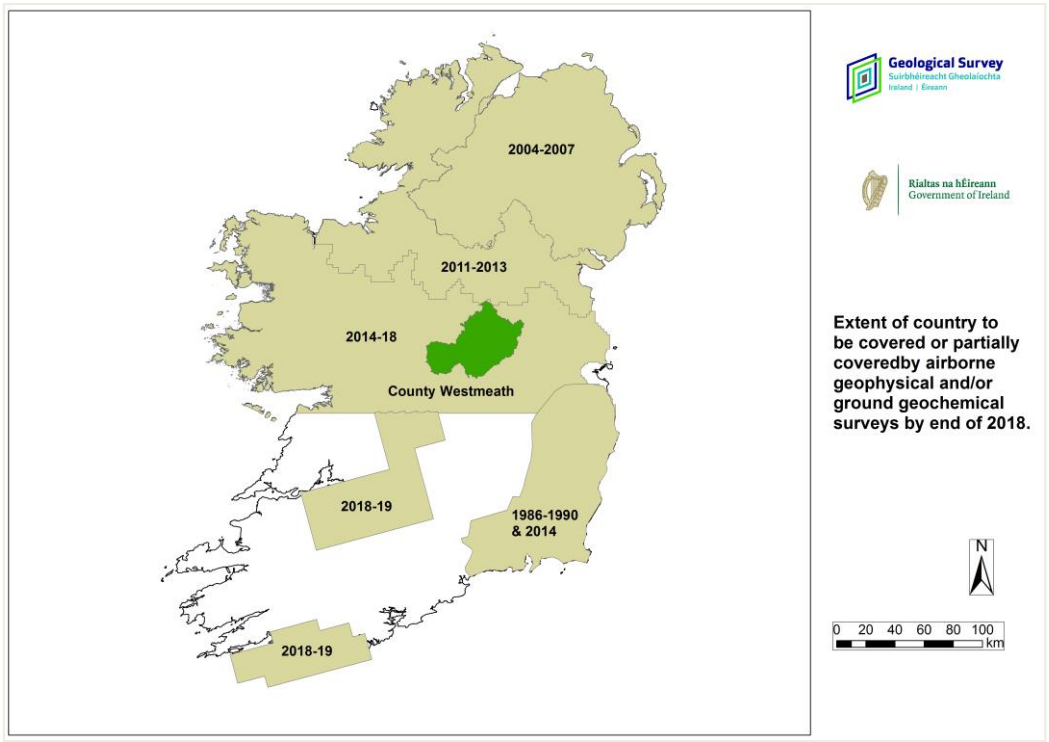
Open File Data
Each Mineral Prospecting Licence issued by the Exploration and Mining Division (EMD), currently of the Department of Communications, Climate Action and Environment, carries an obligation on the exploration company to lodge records of the work undertaken, for the common good. These records are held by the Geological Survey and are available as Open File Data, once a period of time has expired. They may include geological interpretations,

borehole logs, geophysical and geochemical surveys and so on. Licences relate to numbered prospecting areas, and these are available on a map from EMD. See also www.mineralsireland.ie

MinLocs Data
The MinLocs Database records all known mineral occurrences, however small, from GSI records, such as 19th century field sheets and Open File data.

Subsoils Mapping
Since a Groundwater Protection Scheme has been completed by GSI (2012) for the whole country, a modern map of the subsoil types and depths across County Westmeath exists, as well as the previously completed bedrock mapping. This provides a significant resource in general terms as well as for groundwater protection. Customised output is possible. Furthermore, detailed compilation of glacial geology datasets, including a revision published by GSI in late 2014, now provides more data. Specific groundwater group scheme supply sources such as Multyfarnham have had more detailed studies completed for them.

Tellus Mapping
Tellus is a regional mapping project, combining airborne geophysical and geochemical surveys to provide geoscientific information for the island of Ireland.
Since 2004, more than 50,000 km^2 of the island of Ireland has been surveyed or partially surveyed through the **Tellus** surveys, which support mineral exploration, environmental management, agriculture and research activity. Airborne surveying has been completed and ground surveying partly completed in the northern half of the country, which includes County Westmeath. Data will be freely available from. https://www.gsi.ie/en-ie/programmes-and-projects/tellus/Pages/Data-and-Maps.aspx



Historic Mine Records

Abandonment plans and varied other material exists for the sparse mining ventures in the country. The range of data varies from single items for some historical mine sites to immensely detailed series of plans for more modern mine sites. Virtually all of these are scanned and available on GOLDMINE (see above) but there is occasionally additional material in the paper records, such as photographs, that did not get scanned. Additionally, the scanned material did not include some very historic or rare plans and documents that were stored in a separate archive.

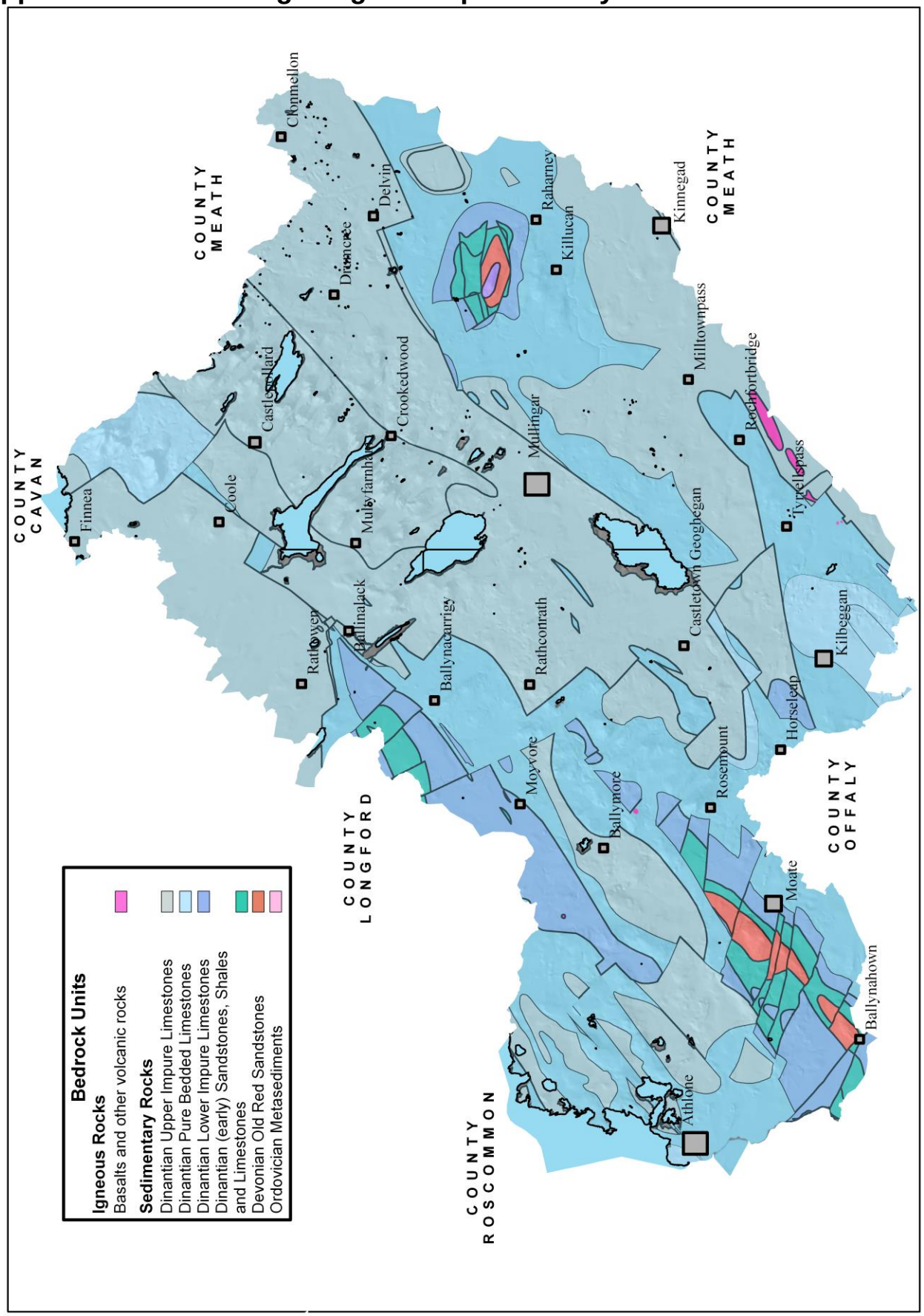
Appendix 6 – Further sources of information and contacts

Sarah Gatley of the Geological Survey of Ireland, who is the Head of the Geological Heritage and Planning Programme, can be contacted in relation to any aspect of this report. Melanie McQuade, the Heritage Officer of Westmeath County Council is the primary local contact for further information in relation to this report. Other contacts include the Conservation Rangers of the National Parks and Wildlife Service, currently in the Department of Culture, Heritage and the Gaeltacht. The names and phone numbers of current staff may be found in the phone directory, or at www.npws.ie.

Web sites of interest

www.gsi.ie - for general geological resources
www.geologicalmaps.net/ - for historical geological maps
www.geology.ie – the website of the Irish Geological Association who run fieldtrips and lectures for members, including many amateur enthusiasts
www.earthscienceireland.org - for general geological information of wide interest
http://www.iqua.ie - for information, fieldtrips, lectures etc in relation to Ireland's Ice Age history
http://www.progeo.se/ - for information about ProGEO the European Association for the Conservation of Geological Heritage

Appendix 7 – Detailed geological map of County Westmeath



Appendix 8 – Geoschol leaflet on the geology of County Westmeath

WESTMEATH

AREA OF COUNTY: 1,838 square kilometres or 709 square miles

COUNTY TOWN: Mullingar

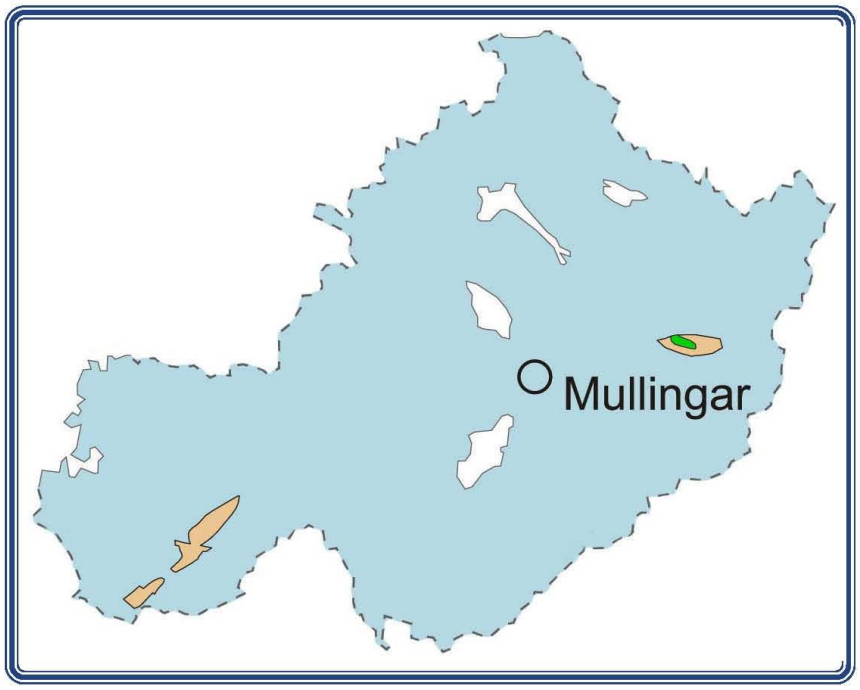
OTHER TOWNS: Athlone, Castlepollard, Devlin, Fore, Kilbeggan, Kinnegad, Moate, Tyrrellspass.

GEOLOGY HIGHLIGHTS: Fore springs, eskers, Carboniferous limestone

AGE OF ROCKS: Silurian to Carboniferous

Mullingar bypass

The trees have now been removed so that the full anticline fold in the Lower Carboniferous limestones is visible.



Geological Map of County Westmeath

Green: Silurian; **Beige:** Silurian & Devonian sandstones and conglomerates; **Light blue:** Lower Carboniferous limestone.

Geological history

The very oldest rocks in the county are marine sandstones of Silurian age, about 425 Ma, found around the summit of Sion Hill, north of Killucan. Younger rocks, of Devonian age around 400 Ma, are also found on Sion Hill and further west in low hills near Moate. These sandstones and conglomerates, with some volcanic ash layers, were deposited on a low flood plain.

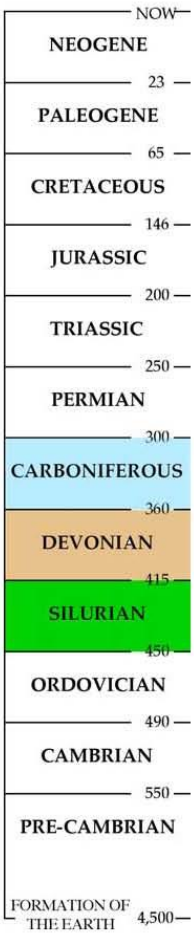
The dominant rock types in Westmeath belong to the early part of the Carboniferous, between about 360 and 330 Ma. At that time the region was covered by a shallow tropical sea (Ireland was just south of the Equator then). The sea teemed with life, with animal communities changing as sea levels changed. Also different marine environments formed different types of limestone. Carbonate mud banks or "reefs" (Waulsortian Limestones) developed as upstanding mounds on the sea floor across parts of Westmeath (and much of the Midlands of Ireland). Growth of these mounds was probably due to the rapid accumulation of fine carbonate mud produced by unknown

Panorama of Lough Derravaragh

organisms. A rich fauna and varying micro-organisms lived on the mounds. In other parts deeper water basins had what is known as Calp limestone. This developed from occasional flows of limey sediments from shallow water into the basins, with quiet periods of mud sedimentation in between each flow event. This leads to beds of regular limestone separated by thin black shale layers.

Carboniferous limestones are often easily dissolved by surface water or groundwater. This has resulted in the development of many karst features involving underground drainage especially in the Fore area (Seven Springs). Isolated hills like the Rock of Curry and Hill of Uisneach are thought to be residual tower karst landscapes (like that seen today in parts of China and SE Asia). Lough Funshinagh although not a turlough, has been known to drain away completely several times!

The last development occurred during the last 1.6 million years when ice ages came and went. The last one ended about 10,000 years ago, giving Westmeath some of the finest glacial deposits of sand and gravel across the lowlands. Eskers (the international name for these features comes from the Irish name: eiscir) formed throughout the county, from rivers flowing beneath the ice, leaving a long narrow ridge of sand and gravel. Around 10% of the county is covered by eskers, and even more by associated outwash deposits of sand and gravel where the rivers came out from under the ice.



Geological timescale showing age of rocks in Westmeath

A bog near Derravaragh

The final stage of landscape evolution has been the growth in the last 10,000 years of raised bogs in wet depressions in the landscape. Groundwater in Westmeath is also an important part of its geology. Water from Lough Lene flows to the River Deel and hence to the Boyne and the Irish Sea. Underground drainage goes to the springs at Fore and onto the River Shannon and the Atlantic.

Folds in Rocks

Sedimentary rocks are normally laid down in flat layers called beds. Sometimes they get squeezed and folded later on. One such fold is visible in the N4 road between Mullingar and Lough Owel. When the road was improved the fold was very clear, then trees were planted which obscured a lot of it, but now they have been cleared and it can be seen properly again. As you drive up and over the hill, you can see the beds dipping one way and then gradually flatten out and start dipping the other way. This fold is called an anticline.

Quarrying & Building Stones

Prehistoric (Mesolithic) chert quarrying for stone tools has been recognised around Lough Derravaragh. The Calp limestone is good for local building stone supplies as it comes out in regular shaped blocks. One or two small quarries extract limestone for aggregate for the construction industry, with agregate also obtained from small quarries exploiting the glacial sand and gravel of the eskers.

Map adapted with permission from Geological Survey of Ireland 1:1,000,000 map 2003.
Image credits: Matthew Parkes (all).

www.geoschol.com

Text by Matthew Parkes & Mike Simms

Appendix 9 – Glossary of geological terms

Geological term	Definition
Alluvial Deposit	unconsolidated clay, silt, sand and gravel, deposited by a body of running water.
Alluvium	a term for unconsolidated clay, silt, sand and gravel, deposited by a body of running water.
Basin	low areas in the Earth's crust, of tectonic origin, in which sediments have accumulated.
Bedrock	a general term for the rock, usually solid, that underlies soil or other unconsolidated, superficial material.
Bioclast	fragment of a shell or fossil forming part of a sedimentary rock.
Blanket Bogs	bog covering a large, fairly horizontal area, which depends on high rainfall or high humidity, rather than local water sources for its supply of moisture.
Boulder Clay	unconsolidated, unsorted glacial deposits consisting of boulders and cobbles mixed with very finely ground-up rock or silt. Also known as till.
Breccia	igneous or sedimentary rock comprising of large angular fragments within finer grained material.
Bryozoa	invertebrates belonging to the phylum Bryozoa, ranging from Ordovician to present, often found as frond-like fossils.
Calcite	a pale mineral composed of calcium carbonate, which reacts with dilute hydrochloric acid.
Calp	dark grey, fine-grained, muddy limestone.
Channel	a landform consisting of the outline of a path of relatively shallow and narrow body of fluid, most commonly the confine of a river, river delta or strait.
Chert	a sedimentary rock comprising of very fine-grained quartz.
Chironomid	a family of flies, similar in size and form to mosquitoes.
Coleopteran	a family of moths which are sensitive indicators of climatic changes during the last ice age.
Crag and tail	a steep resistant rock mass (crag), with sloping softer sediments (tail) protected from glacial erosion or deposited as glacial debris on the crag's 'downstream' side.
Crinoid	a variety of sea-urchin, with a long flexible stem, usually anchored to the sea-floor and a body cup with arms which may be branching (a sea lily).
Diatom	a major group of algae, among the most common types of phytoplankton.
Dip/dipping	when sedimentary strata are not horizontal they are dipping in a direction and the angle between horizontal and the inclined plane is measured as the dip of the strata or beds.
Doline	circular/oval closed depression found in karst terrain.
Dolomite	calcium- and magnesium-bearing carbonate mineral; also a rock composed of the mineral.
Drumlin	a streamlined mound of glacial drift, rounded or elongated in the direction of the original flow of ice.
Echinoderm	marine organisms with interlocking plates (skeletal) covered by spines.
Erratic	a large rock fragment that has been transported, usually by ice, and deposited some distance from its source. It therefore generally differs from the underlying bedrock, the name "erratic" referring to the errant location of such boulders. Tracing their source can yield important information about glacial movements.
Esker	an elongated ridge of stratified sand and gravel which was deposited in a subglacial channel by meltwaters. Eskers are frequently several kilometers in length.

Fan	a usually triangular deposit of sand and gravel deposited by a glacial stream, either under a lake or under air.
Fault	planar fracture in rocks across which there has been some displacement or movement.
Floodplain	a flat or nearly flat land area adjacent to a stream or river that experiences occasional or periodic flooding.
Flute (glacial)	smooth gutter-like channels or furrows made by the abrasive underside of a glacier moving across a rock face.
Fluvial	pertaining to a river or stream.
Glacial	of or relating to the presence and activities of ice or glaciers.
Glacial striae	markings left on the surface of pebbles / boulders / bedrock by moving ice sheets.
Glaciofluvial	pertaining to the meltwater streams flowing from wasting glacier ice and especially to the deposits and landforms produced by such streams.
Grading	a sorting effect with the coarsest material at the base of the bed and finest grained material at the top.
Greywacke	an impure sandstone, characterised by poorly-sorted, angular grains in a muddy matrix, that was deposited rapidly by turbidity currents (submarine avalanches).
Haematite (Hematite)	a mineral form of iron oxide, which is the main ore mined as iron.
Hummock	a small hill or knoll in the landscape, which may be formed by many different processes.
Ice margin	the edge of an ice sheet or glacier.
Igneous	a rock or mineral that solidified from molten or partially molten material i.e. from a magma.
Inlier	area of older bedrock completely surrounded by younger bedrock.
Interglacial	the time interval between glacial stages, or pertaining to this time.
Irish Sea Till	clay-rich till found along the eastern seaboard of Ireland, and occurring as much as 12km inland, which was deposited by an ice stream which occupied the Irish Sea Basin during the last glaciation.
Joint	a fracture in a rock, which shows no evidence of displacement.
Lava	magma extruded onto the Earth's surface, or the rock solidified from it.
Limestone	a sedimentary rock consisting chiefly of calcium carbonate ($CaCO_3$), primarily in the form of the mineral calcite.
Lithology	the description of rocks on the basis of such characteristics as colour, composition and grain size.
Meander	a bend in a sinuous watercourse or river which forms when moving water in a stream erodes the outer banks and widens its valley, and the inner part of the river has less energy and deposits fine sediment.
Meltwater	water from melted snow or ice.
Meltwater channel	a channel cut by glacial meltwater, either under, along or in front of an ice margin.
Metamorphic	referring to the process of metamorphism or to the resulting metamorphic rock, transformed by heat and pressure from an originally igneous or sedimentary rock.
Metasediments	metamorphosed sediments.
Moraine	any glacially formed accumulation of unconsolidated debris, in glaciated regions, such as during an ice age.
Mudmound	Waulsortian limestone of Carboniferous age is characterised by forming as massive mounds or ridges or sheets of carbonate mud on the seafloor of the time. Mudmound is a general term to describe the varieties of forms.

Nautiloid	marine cephalopods (molluscs) with an external shell – and are still alive today.
Ore	a mineral which is concentrated enough to be exploited by mining.
Outcrop	part of a geologic formation or structure that appears at the surface of the Earth.
Raised Bogs	an area of acid, peaty soil, in which the centre is relatively higher than the margins.
Sandur	an outwash plain formed by meltwater from a glacier or an ice sheet.
Shaft	a vertical or inclined hole dug in a mine for access, ventilation, for hauling ore out or for pumping water out.
Shale	A fine-grained sedimentary rock, formed by the compaction and lithification of clay, silt, or mud. It has a finely laminated (composed of layers) structure that gives it a fissility, or tendency to split along bedding planes.
Spring	the point where an underground stream reaches the surface.
Stratigraphy	the study of stratified (layered) sedimentary and volcanic rocks, especially their sequence in time and correlation between localities.
Stromatactis	a sedimentary structure characterized by a nearly flat bottom, and a convex-upward upper surface, consisting of sparry-calcite cement, usually in the central part of a reef
Testate amoebae	microscopic, unicellular, shelled animals which are sensitive indicators of hydrological conditions in peatlands, primarily the depth of the water table.
Terrace	terraces are remnants of the former floodplain of a stream of river, formed by the downcutting of a river or stream channel into and the abandonment and lateral erosion of its former floodplain.
Till	unconsolidated, unsorted glacial deposits consisting of boulders and cobbles mixed with very finely ground-up rock as sand, silt or clay.
Volcaniclastic	the process by which magma and its associated gasses rise into the crust and are extruded onto the Earth's surface and into the atmosphere.
Volcanic Rock	any rock produced from volcanic material, e.g. ash, lava.
Waulsortian	Lower Carboniferous age limestones consisting of skeletal debris and carbonate mud. The sediments commonly form individual and coalesced mounds with depositional dips of 20-40 degrees. Named after rocks in Belgium.

Section 2 - Site Reports

Site reports – general points
The following site reports are brief non-technical summaries of the proposed County Geological Sites for County Westmeath. These have been specially prepared for this Report in order to make the information accessible to planners and others without geological training. For most sites more detailed reports and information files are held in the IGH Programme in the Geological Survey of Ireland. These are available for consultation if required. Further sites may become relevant as IGH Programme work develops.

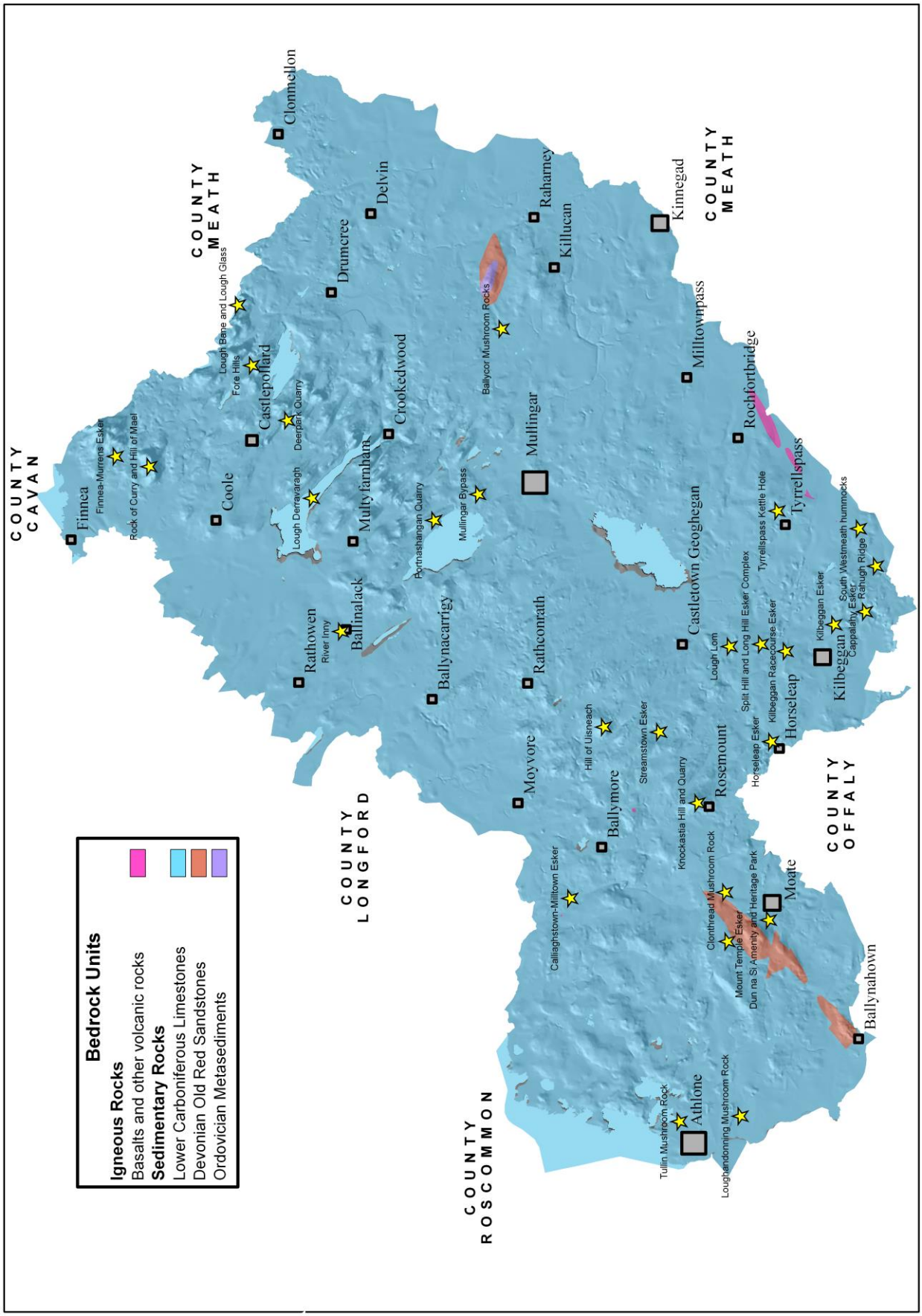
Each site report has primary location information, a mention of the main rock types and their age, and a short description of the key aspects of scientific interest. A section outlining any particular management or other issues specific to the site is included, along with several low resolution photographs exemplifying the site. **A CD/memory drive accompanying this report will include further pictures of most sites at higher resolution, should they be required for a glossy booklet or leaflet for the general public**. Grid references are given for a central point in the site generated from the GIS mapping (a shapefile) of the site boundary. They are only indicative of the location, but the site extent is best shown on the included maps.

Coordinate Projection System – IRENET95 ITM
Irish Transverse Mercator (ITM) is the geographic projection co-ordinate system now in use for Ireland, and has been applied to all site localities in the site reports. It is the standard co-ordinate system for OSi maps, including the new Discovery map series, but a coordinate conversion tool is available on the OSi website at: https://www.osi.ie/services/geodetic-services/coordinate-converter/
http://www.osi.ie/calculators/converter_index.asp?alias=/services/gps-services/co-ordinate-converter#results

A series of maps are provided with an outline of the site boundary. It is important to note that these boundaries have no legal or definitive basis. They are indicative only of the limits of exposure or of geological interest, and not based on detailed field and boundary surveys, which were outside the scope of this contract. Boundaries are drawn to include the geological or geomorphological interest of the site, but are often extended to the nearest mappable boundary, such as a field boundary, stream, road or edge of forestry. On a few sites, such as in open mountain terrain, it is impractical to find a boundary within a reasonable distance and an arbitrary line may be defined. County Geological Sites are non-statutory and so this is not problematic. If any such site is fully assessed for NHA status in the future, such a boundary may require small revisions.

For sites that have been recommended or which will be recommended for NHA designation, detailed site boundary maps will become available to the Local Authority through NPWS if and when the designation process is undertaken. Some areas may already be available if they are proposed NHAs (pNHA), under the Wildlife (Amendment) Act 2000. Areas which have been designated as Special Areas of Conservation (SAC) under European Habitats Directives will also have statutory boundaries already determined. The geological interest may be included within these wider areas of nature conservation.

In terms of any geological heritage site designation as NHA, due process of site reporting, boundary survey and very importantly, consultation with landowners where they can be readily identified, will take place before Geological Survey Ireland finalises recommendations with NPWS on the most important sites to be designated. Any landowner within areas or sites identified in this report with concerns over any aspect of this project is encouraged to contact Siobhán Power , Geological Survey Ireland, Beggars Bush, Haddington Road, Dublin D04 K7X4. Phone 01-6782760. Email: Siobhan.Power@gsi.ie



Simplified Geological Map of County Westmeath with site locations indicated.