The Geological Heritage of County Mayo

An audit of County Geological Sites in County Mayo

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2014 (Report revised 2019)

Cover image: Croagh Patrick and Clew Bay by Michael McLaughlin.

The County Mayo Geological Heritage Project was supported by

An Chomhairle Oidhreachta
The Heritage Council

Geological Survey
Suirbhéireacht Gheolaíochta
Ireland | Éireann

Comhairle Contae Mhaigh Eo
Mayo County Council

OÉ Gaillimh
NUI Galway

This report is an action of the
County Mayo Heritage Plan 2011 – 2016

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Contents

Section 1 – Main Report

Section 2 – Site Reports

Irish Geological Heritage Themes and County Geological Sites

IGH 1 Karst
Site Name
Aille River Cave - Pollatoomary [see IGH14]
Castle Lake (Lough Mask)
Curreighnabannow Spring

IGH 2 Precambrian to Devonian Palaeontology
Site Name
Bouris School
Burren Hill [see IGH10]
Doon Rock
Finny Bridlepath [see IGH4]
Finny Road Section [see IGH4]
Kilbride Farm Quarry [see IGH4]
Knock Airport Road
Knockmore Hill (Clare Island)
Old Head
Tourmakeady (Srah)
Uggool (Charlestown)
Uggool (Killary Harbour)

IGH 3 Carboniferous to Pliocene Palaeontology
Site name
Bolinglanna Trace Fossils [see IGH8 Bolinglanna Coast]
Downpatrick Head [see IGH8; IGH13]

IGH 4 Cambrian-Silurian
Site name
Bohaun South Volcanics (Partry Mountains)
Croagh Patrick Deer Park Complex (Serpentinite) [see IGH6; IGH11]
Emlagh Point
Finny and Kilbride
Glensaul (Tourmakeady)
Finny Bridlepath [see IGH2]
Finny Road Section [see IGH2]
Kilbride Farm Quarry [see IGH2]
Kilsallagh
Portruckagh (Clare Island)
Shanvallycahill (Lough Mask Shore)
Shivlagh Rocks

IGH 5 Precambrian
Site name
Annagh Head (Mullet Peninsula)
Belderg Harbour [see IGH11]
Belderg Pier and Harbour [see IGH7, IGH11]
Briska (North Mayo)
Callow Lakes
Cappagh

Cross Point (Mullet Peninsula)
Dooega - Atlantic Drive [see IGH6]
Doogort (Achill)
Doolough (Gneiss)
Inishkea Islands
Keem Bay to Rusheen Point
NW Erris [Stags of Broadhaven southwards]

IGH 6 Mineralogy
Site Name
Carrownisky River [see IGH15]
Clew Bay complex (Croagh Patrick)
Cregganbaun - Doolough [see IGH15]
Croagh Patrick Deer Park Complex (Serpentinite) [see IGH4; IGH11]
Dooega - Atlantic Drive [see IGH5]
Keem Bay (Achill Island)
Sheeffry Mine
Westport (Talc) [see IGH15]

IGH 7 Quaternary
Site Name
Acorrymore Cirque Moraines
Askillaun Spread
Belderg Pier and Harbour [see IGH5, IGH11]
Brookhill Delta
Burren [Interglacial]
Cappagh
Castlebar-Westport (Drumlins)
Cathedral Rocks (Paraglacial Spread)
Clare Island [Moraines]
Clew Bay
Corraun (North Slopes) [see IGH14]
Croagh Patrick Scree and Gullies [see IGH14]
Derrynadivva [Interglacial]
Doo Lough Valley [see IGH14]
Doo Lough Delta Terrace [see IGH14]
Dunmore-Ballyhaunis Esker System
Glenulra and Port Glenloss Point [see IGH14]
Kilkelly
Killala Area
Killary Harbour [see IGH13]
Knock-Ballyhaunis Area
Lough Furnace Moraines
Nephin Beg Range [see IGH14]
Pontoon Bridge [see IGH11]
Srahlea Bridge (Partry Mountains)

IGH 8 Lower Carboniferous
Site Name
Ballynew Outcrop
Bolinglanna Coast [see IGH3 Bolinglanna Trace Fossils]
Clare Island (Northeast Coast)
Crucknaree (King's Hill) [see IGH10]
Derrycraff, Erriff Valley
Downpatrick Head [see IGH3; IGH13]
Kilcummin Head
Lough Akeel
Moyne Abbey (Killala)
Ringarraun
Rockfleet Bay
Stella Maris
Tullaghmore

IGH 9 Upper Carboniferous and Permian
Not represented in Co. Mayo

IGH 10 Devonian
Site Name
Burren Hill [see IGH2]
Crucknaree (King's Hill) [see IGH8]
Derryharriff
Letter

IGH 11 Igneous intrusions
Site Name
Belderg Harbour [see IGH5]
Belderg Pier and Harbour [see IGH5, IGH7]
Corvock
Croagh Patrick Deer Park Complex (Serpentinite) [see IGH4; IGH6]
Dun na Mo (Oirreas)
Ocamhal (Killary Harbour)
Pontoon Bridge [see IGH7]
Ross Strand and Spinc

IGH 12 Mesozoic and Cenozoic
Not represented in Co. Mayo

IGH 13 Coastal Geomorphology
Site Name
Achill Island (North Coast)
Bartragh Island
Blacksod Bay
Broad Haven
Carrownisky
Clew Bay [see IGH7]
Downpatrick Head [see IGH3; IGH8]
Killary Harbour [see IGH7]

IGH 14 Fluvial and Lacustrine Geomorphology
Site Name
Aille River Cave - Pollatoomary [see IGH1]
Bellacorick
Corraun (North Slopes) [see IGH7]
Carrowteige
Croagh Patrick Scree and Gullies [see IGH7]
Doo Lough Valley [see IGH7]
Doo Lough Delta Terrace [see IGH7]
Erriff Valley
Glenulra and Port Glenloss Point [see IGH7]
Gubnastacky
Lough Mask
Maumtrasna
Nephin Beg Range [see IGH7]
Owenbrin River
River Moy

IGH 15 Economic Geology
Site Name
Belderg (Copper)
Carrownisky River [see IGH6]
Cregganbaun - Doolough [see IGH6]
Kilgeever
Lecanvey
Westport (Talc) [see IGH6]

IGH 16 Hydrogeology
Not represented in Co. Mayo

Executive Summary

County Mayo is a geologically diverse place with many landscapes, areas and sites treasured by both locals and visitors. The bedrock foundation formed and shaped over hundreds of millions of years, and the more recent history of geomorphological processes, such as coastal erosion, limestone solution and scouring by glaciers, has created this underlying geodiversity. Geological understanding and interpretation is best done on the ground at sites where the rocks and landforms occur.

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

County Geological Sites do not receive statutory protection like Natural Heritage Areas (NHAs) but receive an effective protection from their inclusion in the planning system. However, many of the sites described in this report are considered to be of national importance as best representative examples of particular geological formations or features. They have been provisionally notified to the National Parks and Wildlife Service (NPWS) by Geological Survey Ireland for designation as NHAs, after due survey and consultation with landowners. However, many of these sites fall within existing proposed Natural Heritage Areas (pNHAs) and Special Areas of Conservation (SACs) where the ecological interest is founded upon the underlying geodiversity.

The commission of this audit and adoption of the sites within the CDP ensure that County Mayo follows a now established and effective methodology (see Appendix 1 for more detail and the legal framework) for ensuring that geological heritage is not overlooked in the general absence of allocated resources for progress at national level. It ensures that Mayo remains at 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 department of Mayo County Council. It will also be made available via the County Council website for the people of Mayo. The report includes recommendations on how to best present and promote the geological heritage of Mayo 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.

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. The contents provide the essential ingredients for a booklet aimed at a general audience on the geological heritage of Mayo. The audit also contributes to the knowledge base and definition of geological heritage sites within the area of the aspiring Joyce Country and Western Lakes UNESCO Global Geopark in counties Mayo and Galway.

1. County Mayo in the context of Irish Geological Heritage

This audit brings County Mayo to the forefront of geological heritage within Ireland, as the majority of the counties have now commissioned a geological audit within the scope of the County Heritage Plan. It will hopefully encourage the remaining local authorities to follow what is now a tried and trusted methodology. County Geological Site audits are an important resource for geological conservation and promotion. Audits serve within an advisory capacity only in the context of County Development Plans, and do not attribute statutory protection to sites, although the County Development Plans provide 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 (as amended), Planning and Development Regulations 2001 (as amended), and the Wildlife (Amendment) Act, 2000 and the National Heritage Plan (2002). Geological Survey Ireland views partnerships with 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 Ireland complements 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 more recently on a national scale by the introduction of Natural Heritage Areas (NHA) as the national nature conservation method. As a targeted conservation measure to protect the very best of Irish geology and geomorphology, the IGH Programme fills a void which has been there since the abandonment of the Areas of Scientific Interest scheme, listed by An Fóras Forbartha in 1981.

The IGH Programme fulfils this by identifying and selecting the most important geological sites nationally for designation as NHAs. It looks at the whole of Irish geology and geomorphology under 16 different 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

Fundamental to the approach adopted is that only the minimum number of sites necessary to demonstrate the particular geological theme is selected. This means that our first criterion is to identify the best national representative example of each feature or major sequence, and secondly to identify any unique or exceptional sites. The third criterion, to identify any sites of International importance, is nearly always covered by the other two.

Geological NHAs are designated by Geological Survey Ireland's partners in the Programme, the National Parks and Wildlife Service (NPWS), currently operating within the Department of Culture, Heritage and the Gaeltacht. Once designated, any geological NHAs will be subject to normal statutory process within the Mayo 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 following section considers these issues**.

From a national perspective, as a result of extensive comparison of similar sites to establish the best among them, there is now a good knowledge of many other sites which are not the chosen best example, but may still be of national importance. Others may be of more local importance or of particular value as educational sites or as a public amenity. All these various important sites are proposed for County Geological Site (CGS) listing in the County Development Plan, along with any clear NHA selections.

In 2018, a Master List of candidate CGS and NHA sites has been established in Geological Survey Ireland with the help of Expert Panels for all 16 IGH themes. For several themes, the entire process has been largely completed and boundary surveys and detailed site reports have been prepared, along with a Theme Report. Due to various factors, they have not been formally designated yet, although many of the sites documented here (*e.g.* Aille River Cave, Annagh Head and the Finny/Kilbride sites) are considered to be of national and international importance and have been put forward as Natural Heritage Areas. Therefore, inclusion of all sites as County Geological Sites in Mayo'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. This 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 cases, but it is emphasised that 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 Mayo County Geological Sites

Site Name	Designation	IGH Primary	IGH Secondary	IGH Third	GIS Code
Achill Island (North Coast)	CGS, may be recommended for Geological NHA	IGH13			MO001
Acorrymore Cirque Moraines	CGS, recommended for Geological NHA	IGH7			MO002
Aille River Cave - Pollatoomary	CGS, recommended for Geological NHA	IGH1	IGH14		MO003
Annagh Head (Mullet Peninsula)	CGS, recommended for Geological NHA	IGH5			MO004
Askillaun Spread	CGS, may be recommended for Geological NHA	IGH7			MO005
Ballynew Outcrop	CGS	IGH8			MO006
Bartragh Island	CGS	IGH13			MO007
Belderg (Copper)	CGS	IGH15			MO008
Belderg Harbour	CGS, recommended for Geological NHA	IGH5	IGH11		MO009
Belderg Pier & Harbour	CGS, recommended for Geological NHA	IGH7			MO010
Bellacorick	CGS	IGH14			MO011
Blacksod Bay	CGS, recommended for Geological NHA	IGH13			MO012
Bohaun South Volcanics (Partry Mountains)	CGS	IGH4			MO013
Bolinglanna (Coast)	CGS, recommended for Geological NHA	IGH8			MO014
Bolinglanna Trace Fossils	CGS, recommended for Geological NHA	IGH3			MO015
Bouris School	CGS, recommended for Geological NHA	IGH2			MO016
Briska (North Mayo)	CGS	IGH5			MO017
Broad Haven	CGS	IGH13			MO018
Brookhill Delta	CGS, recommended for Geological NHA	IGH7			MO019
Burren Hill	CGS, may be recommended for Geological NHA	IGH2	IGH10		MO020
Burren (Interglacial)	CGS, recommended for Geological NHA	IGH7			MO021
Callow Lakes	CGS	IGH5			MO022
Cappagh	CGS	IGH7	IGH5		MO023
Carrownisky	CGS	IGH13			MO024
Carrownisky River	CGS	IGH15	IGH6		MO025
Carrowteige	CGS	IGH14			MO026
Castle Lake (Lough Mask)	CGS, recommended for Geological NHA	IGH1			MO027
Castlebar Westport Drumlins	CGS	IGH7			MO028
Cathedral Rocks Paraglacial Spread	CGS, recommended for Geological NHA	IGH7			MO029
Clare Island (Moraines)	CGS	IGH7			MO030
Clare Island (Northeast Coast)	CGS	IGH8			MO031
Clew Bay	CGS, recommended for Geological NHA	IGH7	IGH13		MO032
Corraun (North Slopes)	CGS, recommended for Geological NHA	IGH7	IGH14		MO033

Corvock	CGS	IGH11			MO034
Cregganbaun - Doolough	CGS, recommended for Geological NHA	IGH15	IGH6		MO035
Croagh Patrick Deer Park Complex (Serpentinite)	CGS, recommended for Geological NHA	IGH11	IGH6	IGH4	MO036
Croagh Patrick Scree and Gullies	CGS, recommended for Geological NHA	IGH7	IGH14		MO037
Cross Point (Mullet Peninsula)	CGS, recommended for Geological NHA	IGH5			MO038
Crucknaree (Kings Hill)	CGS, may be recommended for Geological NHA	IGH10	IGH8		MO039
Curreighnabannow Spring	CGS, recommended for Geological NHA	IGH1	IGH16		MO040
Derrycraff (Erriff Valley)	CGS	IGH8			MO041
Derryharriff	CGS	IGH10			MO042
Derrynadivva (Interglacial)	CGS, recommended for Geological NHA	IGH7			MO043
Doo Lough Delta Terrace	CGS	IGH7	IGH14		MO044
Doo Lough Valley	CGS, recommended for Geological NHA	IGH7	IGH14		MO045
Dooega – Atlantic Drive	CGS, recommended for Geological NHA	IGH5	IGH6		MO046
Doogort (Achill Island)	CGS	IGH5			MO047
Doolough Gneiss	CGS, recommended for Geological NHA	IGH5			MO048
Doon Rock	CGS, recommended for Geological NHA	IGH2	IGH4		MO049
Downpatrick Head	CGS, recommended for Geological NHA	IGH8	IGH13	IGH3	MO050
Dun na Mo (Oirreas)	CGS	IGH11			MO051
Dunmore - Ballyhaunis Esker System	CGS, recommended for Geological NHA	IGH7			MO052
Emlagh Point	CGS	IGH4			MO053
Erriff Valley	CGS	IGH14			MO054
Finny and Kilbride	CGS, recommended for Geological NHA	IGH4			MO055
Finny Bridlepath	CGS, recommended for Geological NHA	IGH2	IGH4		MO056
Finny Road Section	CGS, recommended for Geological NHA	IGH2	IGH4		MO057
Glensaul (Tourmakeady)	CGS	IGH4			MO058
Glenulra and Port Glenloss Point	CGS, recommended for Geological NHA	IGH14	IGH7		MO059
Gubnastacky	CGS	IGH14			MO060
Inishkea Islands	CGS	IGH5			MO061
Keem Bay (Achill Island)	CGS, recommended for Geological NHA	IGH6			MO062
Keem Bay to Rusheen Point	CGS, recommended for Geological NHA	IGH5			MO063
Kilbride Farm Quarry	CGS, recommended for Geological NHA	IGH2	IGH4		MO064
Kilcummin Head	CGS, recommended for Geological NHA	IGH8			MO065
Kilgeever	CGS, recommended for Geological NHA	IGH15			MO066
Kilkelly	CGS	IGH7			MO067
Killala Area	CGS	IGH7			MO068
Killary Harbour	CGS	IGH7	IGH13		MO069

Kilsallagh	CGS, may be recommended for Geological NHA	IGH4			MO070
Knock - Ballyhaunis area	CGS, may be recommended for Geological NHA	IGH7			MO072
Knock Airport Road	CGS	IGH2			MO071
Knockmore Hill (Clare Island)	CGS, recommended for Geological NHA	IGH2			MO073
Lecanvey	CGS, recommended for Geological NHA	IGH15			MO074
Letter	CGS	IGH10			MO075
Lough Akeel	CGS	IGH8			MO076
Lough Furnace Moraines	CGS, recommended for Geological NHA	IGH7			MO077
Lough Mask	CGS	IGH14			MO078
Maumtrasna	CGS, recommended for Geological NHA	IGH14			MO079
Moyne Abbey (Killala)	CGS	IGH8			MO080
Nephin Beg Range	CGS, recommended for Geological NHA	IGH7	IGH14		MO081
NW Erris (Stags of Broadhaven southwards)	CGS	IGH5			MO082
Ocamhal (Killary Harbour)	CGS	IGH11			MO083
Old Head	CGS, recommended for Geological NHA	IGH2			MO084
Owenbrin River	CGS	IGH14			MO085
Pontoon Bridge	CGS	IGH11	IGH7		MO086
Portruckagh (Clare Island)	CGS	IGH4			MO087
Ringarraun	CGS	IGH8			MO088
River Moy	CGS	IGH14			MO089
Rockfleet Bay	CGS	IGH8			MO090
Ross Strand and Spinc	CGS; recommended for Geological NHA	IGH11			MO091
Shanvallycahill (Lough Mask Shore)	CGS, recommended for Geological NHA	IGH4			MO092
Sheeffry Mine	CGS	IGH6			MO093
Shivlagh Rocks	CGS; recommended for Geological NHA	IGH4			MO094
Srahlea Bridge (Partry Mountains)	CGS; recommended for Geological NHA	IGH7			MO095
Stella Maris	CGS; recommended for Geological NHA	IGH8			MO096
Tourmakeady (Srah)	CGS; recommended for Geological NHA	IGH2			MO097
Tullaghmore	CGS	IGH8			MO098
Uggool (Charlestown)	CGS; recommended for Geological NHA	IGH2			MO099
Uggool (Killary Harbour)	CGS; recommended for Geological NHA	IGH2			MO100
Westport (Talc)	CGS; recommended for Geological NHA	IGH15	IGH6		MO101

1.2 Combined, Renamed and Rejected sites

A range of sites had been previously flagged for consideration in the IGH Master Sites 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 Mayo's geology. Other sites were visited on spec during fieldwork, based on knowledge of Mayo's geology gained from projects undertaken in the years since the original county site list was first supplied to County Mayo's Heritage Officer and/or planning department. The combined, renamed or rejected sites are listed below with brief notes as to why they were assessed as unsuitable for inclusion as County Geological Sites.

Ballymaglancy Cave
Situated on the Cong Isthmus, this site (IGH1 Karst) is located in Co. Galway and was not surveyed during the Co. Mayo survey.

Bohaun
Bohaun, listed as an IGH15 epithermal gold mineralisation site, is located in County Galway.

Clew Bay Complex and Croagh Patrick Deer Park Complex
The Clew Bay IGH6 Mineralogy serpentine site is the same site as the Croagh Patrick Deer Park Complex (Serpentinite) (MinLocs 1108), and has been included in the Croagh Patrick Deer Park Complex (Serpentinite) report.

Cregganbaun and Doolough
Doolough (Au) (IGH6 Mineralogy; IGH15 Economic Geology) has been combined with Cregganbaun (renamed Cregganbaun- Doolough) owing to the close proximity of the features and the shared IGH Themes. Both bedrock gold occurrences are linked to the Carrownisky River alluvial gold site.

Killala Esker
Listed under IGHP Theme 7 (Quaternary) as an esker with '*a herb-rich woodland with good birdlife*', the east-west trending elongate feature at this site is not an esker. Viewed on an airphoto, the feature resembles a woodland covered esker. Within this region, a series of discrete glaciotectonic ridges form a discrete body of tectonised proglacial features west of the Moy Estuary. The ridges occur over a 7km wide area (west-east) at its widest point, and along a coastal strip of around 5km (north-south). One of the highest ridges occurring to the south of Killala was erroneously interpreted as an esker.

The glaciotectonic ridge to the south of Killala

Nephin Beg Range and Nephin Beg Mountains
The IGH7 (Nephin Beg Mountains) site north of Lough Feeagh near Buckoogh and Mount Eagle is situated within the greater Nephin Beg Range site [IGH7 and IGH14] and the features are covered by the descriptions of the larger site.

Pigeon Hole - Cong Springs
Situated on the Cong Isthmus, this site (IGH1 Karst) is located in Co. Galway and was not visited during the Co. Mayo survey, even though it is listed in the Co. Mayo Master List.

Port Glenloss Point
Port Glenloss Point (IGH7 Quaternary) is combined with Glenulra (IGH7 Quaternary) owing to the close proximity of the features and the shared IGH Theme. The site could also be considered along with Belderg Pier and Harbour (IGH7 Quaternary).

Thick glaciomarine deposits at Glenglassera (Glenloss Point), looking south to road.

Sea cave at Glenloss Point.

Ross Strand and Spinc
Spinc (IGH11 Igneous Intrusions) is combined with Ross Strand (IGH11 Igneous Intrusions) and renamed Ross Strand and Spinc owing to the close proximity of the features and the shared IGH Theme.

Shanvallycahill (Lough Mask Shore) and Derry Bay
The Derry Bay, North Shore site, showing the IGH4 Ordovician-Silurian succession, has been renamed as Shanvallycahill (Lough Mask Shore).

Toomore
Drumlins occur in the townlands of Toomore, Ballinillaun and Unmoon, situated to the north and northeast of Ballylahan Bridge (where the N58 Foxford to Bellavary road crosses the River Moy). Whilst the site exhibits several small drumlins, the site does not merit inclusion as a County Geological Site. More extensive drumlins swarms occur within the Newport-Westport-Castlebar area and to the NW in the Pontoon Bridge site.

View of drumlins at Unmoon, looking north of the N58 junction to Toomore.

Looking south over the drumlins at Ballillaun near Toomore.

Westport (Sulphur)

This site was listed under IGH Theme 6 (Mineralogy). A lack of original definition or information from the IGH Master site list meant this site was difficult to locate. The site area in Carrowkennedy was visited during the County survey, but no mineral occurrences were identified in the field. The site does not have a Mineral Location (MinLocs) identifier number.

2. Mayo County Council Policies regarding geological heritage

The clear and significant inclusion of geological heritage in the County Mayo Heritage Plan 2011-2016 and the Mayo County Development Plan 2014 - 2020, is a welcome and positive step, for an aspect of our heritage that is often undervalued and not well known in the wider community. This section examines the existing actions in the Heritage Plan relating to geological heritage and provides some suggestions as to how these may be implemented, supported or enhanced by the audit of geological heritage sites in the county. The policies of Mayo County Council, detailed in the County Development Plan 2014-2020 (page 41–51) are quite robust and comprehensive, which is very positive for geological heritage.

County Heritage Plan 2011-2016

Objective 1: Promotion of Awareness and Appreciation of our heritage

Action 1.4 Work in partnership with Ireland West Tourism to produce and disseminate in various formats, promotional material on the heritage of Mayo and on selected heritage sites. Investigate the possibility of erection of interpretive signage at selected sites.
Audit Action: This audit will provide information on aspects of geological interest that can be adapted for public promotion in the form of publications, website content, and public information panels.

Action 1.2 Develop a Mayo Summer Field School
Audit Action: The inclusion of a geological heritage and landscape component(s) in a field school would be greatly assisted by the content of the audit reports. The authors of this audit report could contribute training in geological topics by arrangement with the Heritage Officer.

Action 1.20 Raise awareness of the importance of Clew Bay to protect its ecosystem.
Audit Action: The content of this audit report will provide detailed information and an insight into the significance of the physical (geological and geomorphological) landscape and the processes (glacial, coastal) that have been central to the development of the Clew Bay landscape.

Action 1.22 Develop a cultural/heritage trail of the county encompassing sites of cultural/heritage importance and the promotion of these to the economic benefit of the county.
Audit Action: The content of this audit report will provide the content for leaflets on appropriate sites or themes according to resources available for publishing. Such content is also adaptable to modern digital media such as smartphone apps.

Action 1.23 Identify heritage initiatives aimed at primary and secondary schools to foster active participation
Audit Action: The content of this audit report will provide the background content for education packs on appropriate themes according to curricular needs. Further work would be needed to adapt the format of the audit content to this action.

Action 1.24 Develop heritage trails for Westport to Achill railway line and other areas of the county as appropriate.
Audit Action: Understanding the importance of relevant stone materials in built heritage such as on the railway 'Greenway' is important, along with geological knowledge behind

route selection. The audit site reports will provide relevant geological heritage input along the route.

Action 1.25 Produce publications on various aspects of Mayo's heritage, to highlight and promote the wealth and importance of heritage in the county.
Audit Action: The authors would expect to contribute articles about the audit to publications, and to other publications relating to the geological heritage of the county. The content of this audit report will provide the information on appropriate sites or themes according to resources available for publishing.

Action 1.27 Raise awareness of the importance and value of Mayo's peatlands, including their economic value
Audit Action: The relatively recent (<12,000 years) development of peatlands in Mayo is significant aspect of the county's landscape heritage. The association of peatlands with the underlying bedrock geology is highlighted in the report.

Objective 2 - Collection and Dissemination of Heritage

Action 2.6 Record non-structural elements such as curtilage features, stone walls, historic ironwork, historic elements (gates, mausolea, etc.) which contribute to our built heritage.
Audit Action: Understanding the importance of relevant stone materials in walls and historic buildings is important, and the need for geological heritage input is highlighted here.

Action 2.6 Undertake a study of the lakes in the county which will include an assessment of their economic, natural and cultural heritage and tourism potential.
Audit Action: The audit will contribute to this objective, particularly in respect of karst lakes (e.g. Lough Mask) and corrie lakes (e.g. Acorrymore, Achill Island). The physical development of the lakes should be considered.

Action 2.8 Continue Habitat Mapping of the county and identify important local biodiversity areas.
Audit Action: The audit will contribute to part of this objective, particularly in respect of features such as islands, eskers, coastal cliffs, beaches, machair and uplands, many of which are richly represented in the county. Geological foundations of the habitats and their host species should be overlooked.

Action 2.9 Carry out an audit of geological sites in county with view to developing geological trails. Support development of a UNESCO Geopark.
Audit Action: This audit helps fulfil this action and will serve as a significant information resource toward the development of geological trails, and in particular toward furthering the development of a county-based or trans-country UNESCO Geopark.

Action 2.11 Work with relevant educational institutions and individuals to carry out research and disseminate information on all aspects of heritage.
Audit Action: The reports and reference lists in this audit will serve as a resource for educational institutions and individuals wishing to conduct research into aspects of the county's geological heritage.

Action 2.12 Compile all heritage information into a comprehensive database.
Audit Action: The reports and reference lists provided in this audit will significantly contribute to the database as regards geoscience in the broadest way possible.

Objective 3 - Promotion of Best Practice in Heritage

Action 3.3 Promote traditional skills in County Mayo and provide opportunities for showcasing various traditional skills (e.g. use of lime mortar, thatching, dry-stone walling etc.), including hosting Irish Georgian Society's Traditional Building Skills Weekend.
Audit Action: The importance of relevant stone materials in built heritage and the exploitation of industrial resources in mining and quarrying is important, and an understanding of geological heritage is available in these reports. Partnership with the Mining Heritage Trust of Ireland would be very beneficial in realising this action.

Action 3.13 Develop a policy in relation to directional and interpretative heritage signage in Mayo to achieve a consistent approach and easy recognition
Audit Action: This audit will provide information on aspects of geological interest that can be adapted for public promotion in the form of public information signs and panels (such as have been developed and erected at geosite locations in the Burren and Cliffs of Moher Geopark)

Action 3.14 Promote and provide training opportunities on various aspects of heritage, including countryside guiding courses, development of heritage trails, hedge-laying and development of organic gardens and community orchards.
Audit Action: This audit will serve as an important information resource for the delivery of training workshops and courses and in the development of heritage trails.

Other audit benefits:

1. *The audit could serve as a basis for developing a publication on selected sites of geological interest that would be aimed at local communities and visitors.*

2. *The audit could serve as the basis for a television documentary of the landscape heritage of County Mayo*

County Development Plan 2014-2020

Environment, Heritage and Amenity Strategy 4:

Natural Heritage

NH01 It is an objective of the Council to protect, enhance, conserve and, where appropriate restore:

a) Candidate Special Areas of Conservation, Special Areas of Conservation, Special Protection Areas, Natural Heritage Areas and proposed National Heritage Areas, Statutory Nature Reserves, Ramsar Sites and Biogenetic Reserves, including those listed in the Environmental Report documenting the Strategic Environmental Assessment of this plan and any modifications or additional areas that may be so designated during the lifetime of the plan.

d) Bogs, fens and turloughs listed in the Environmental Report documenting the Strategic Environmental Assessment of this plan

e) Features of geological interest as listed in the Audit of County Geological Sites (Mayo County Council).

g) Surface waters, aquatic and wetland habitats and freshwater and water-dependent species through the implementation of all appropriate and relevant Directives and transposed legislation

NH05 It is an objective of the Council to increase awareness of the importance of the natural he ritage of the County and to promote education, knowledge and pride in our natural heritage.

Access to Heritage and Amenities

AC01 It is an objective of the Council, within the lifetime of this plan, to:

a. Identify, preserve and enhance existing accesses and public rights of way to recreational areas including the coast, upland areas, lakeshores, river bank areas and heritage sites

b. Where necessary, establish new accesses and public rights of way to recreational areas including the coast, upland areas, lakeshores, river bank areas and heritage sites in cooperation with landowners and the local community. When public rights of way are identified, the owners of the public rights of way shall be notified in accordance with the Planning & Development Acts 2000 2010

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. In these areas, the geological case enhances and cements the value of these sites for nature conservation, and requires no additional designation of actual land areas, other than citation of the geological interest.

Broadly speaking, there are two broad 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 Aille River Cave and its rising at Pollatoomary, Kilbride Farm Quarry, Uggool (near Charlestown), Annagh Head, Keem Bay on Achill Island and Knockmore Hill on Clare Island. They typically have a feature or features of specific interest such as fossils, minerals or 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 illustrate the processes that formed it. The Coastal Geomorphology theme, the Quaternary theme and the Karst theme include such sites. In Mayo, the Clew Bay area with its superb drumlin islands is characteristic of the larger sites considered under the IGH 7 Quaternary Theme, although many of such landscapes are just too extensive to be considered as a 'site'. Long stretches of the coast of Mayo are likewise characteristic of the Coastal Geomorphology theme sites, aside from their other interesting features making them important under IGH Themes such as Precambrian (e.g. Doeega/Claggan Bay, Achill Island) or Carboniferous to Pliocene Palaeontology (e.g. Downpatrick Head). In the Karst theme, the entire isthmus between Lough Mask and Lough Corrib should really be considered as one large site, with the wealth of karstic landforms and ongoing processes, but only the highlights are actually specified as sites in this audit process.

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 Mayo. A lack of awareness in the past, has led to the loss of important geological sites and local character, throughout the country. In Mayo, a full Landscape Characterisation Assessment has been completed and is included in its entirety as a supporting document to the Mayo County Development Plan 2008-2014, with landscape policies included in the main CDP. This provides a tool to help future planning decisions maintain the landscape character of the County. 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.

There are large differences in the management requirements for geological sites in contrast to ecological 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 better served 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 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 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 entire 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. 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 in 2008 (Gatley and Parkes 2008).

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 or open cast mine that has finished working may become more relevant as a geological heritage site at that stage in its life. It may need regular 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.

Nationally, specific sites may require restrictions and a typical case might be at an important fossil locality or a rare mineral locality, where a permit system may be required for genuine research, but the opportunity for general collecting may need to be controlled. Although Mayo's palaeontological and mineralogical sites are not considered likely to require such an approach, visitors should be reminded to take home photos, not specimens.

Waste dumping
A lesser problem, but one which does still occur, is the dumping of rubbish in the countryside. This often happens in enclosed depressions (dolines), collapsed caves or in active sinkholes in karstic areas. The dumping of waste is not only unsightly and messy, but when waste materials are dumped in areas where rock is exposed, such as quarries or karstic depressions, they may leach into the groundwater table as they degrade. This can cause groundwater pollution and can affect nearby drinking water supplies in wells. 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. Such a scheme has largely been completed for Mayo County Council by Geological Survey Ireland, thus ranking the county land surface into vulnerability categories of 'Extreme', 'High', 'Moderate' and 'Low', and this helps planners in assessing which developments are suitable or not in certain areas of Mayo.

The Groundwater Vulnerability Map of County Mayo and the Groundwater Protection Scheme for the county can be seen on the Geological Survey Ireland website.
See https://www.gsi.ie/en-ie/data-and-maps/Pages/Groundwater.aspx

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 construction of new roads. **Wherever major new carriageways are built**, it should be a policy within the Planning Department that **where new rock exposures are created, they are left open and exposed** unless geotechnical safety issues occur (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 hard to change.

However, it leads to sterile and uninteresting roads that look the same throughout the country. By leaving rock exposures along the routeway, where they are intersected, it provides an improvement in character and interest, 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. Mayo County Council has been successful over recent years in implementing this approach in the construction of new road sections, for example on the N17 cutting at Lurga Upper, bypassing Knock Airport, and the N17 cutting (Carrowmore) bypassing Knock.

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). Geoparks were elevated to full United Nations Educational, Scientific and Cultural Organisation (UNESCO) status 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.

There are three UNESCO Global Geoparks on the island of Ireland; the cross-border Marble Arch Caves UNESCO Global Geopark in Counties Fermanagh and Cavan www.marblearchcavesgeopark.com; the Copper Coast UNESCO Global Geopark in County Waterford www.coppercoastgeopark.com; and the Burren and Cliffs of Moher UNESCO Global Geopark in County Clare www.burrengeopark.ie. An application from Mourne Gullion Strangford in Counties Down and Armagh was submitted to UNESCO in late 2019 and the Joyce Country & Western Lakes project in north Galway and south Mayo is progressing.

Joyce Country and Western Lakes Geopark Project

Joyce Country geopark has been a concept since 2008 and it made good progress through the work of volunteers. With Geological Survey Ireland as lead partner, and in collaboration with Údarás na Gealtachta, Galway County Council, Mayo County Council and Coillte, funds of €1.19 million were secured, mainly from the Rural Regeneration and Development Fund in the Department of Rural and Community Development under Project Ireland 2040 for the development of a geopark and to apply for UNESCO status in the future. The aspiring Geopark is being managed by Joyce Country and Western Lakes Geo Enterprise in Tourmakeady, Co Mayo. Four full-time staff will be employed until December 2021 for the development of the geopark and it is anticipated that a robust management and financial plan is in place by the end of 2021 for the long-term future.

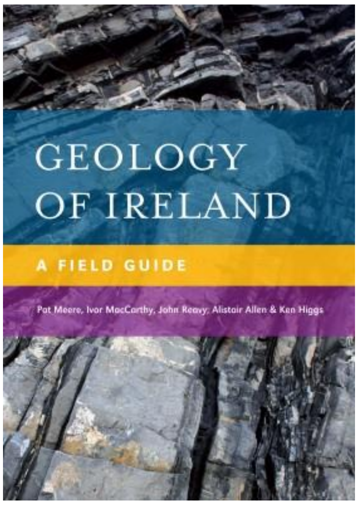
Geological Survey Ireland and Mayo County Council are already committed to the geopark project and this audit should contribute to ongoing promotion of the area's outstanding geological heritage and to local commitment to the geopark. The production of county geological publications based on this audit or geological map for tourists would help further enhance the geopark.

4. Recommendations

4.1 Proposals and ideas for promotion of geological heritage in Mayo

Guides

There are only a few existing guides to the geology of parts of County Mayo, and even less aimed at a general audience. There is scope for many others, and 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 content of this report would comprise a good general guide to the geological heritage of County Mayo, in similar style to that produced as a follow-on from the county audits completed for Sligo (2004), Fingal (2011); Clare (2014); Waterford (2014); and Roscommon (2014). Aspects of County Mayo's geology are covered in the 2013 book *Geology Ireland: A Field Guide (Meere et al. 2013).*



The 1:100,000 Geological Survey Ireland map reports for Sheets 6, 7, 10 and 11 cover County Mayo and surrounding regions, and are an essential resource.

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 such as the aspirant **Joyce Country and Western Lakes Geo-enterprise** in the planning stage so that maximum benefits can be achieved and local input is included.

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

The extensive promotion of the Wild Atlantic Way by Fáilte Ireland has recently led to a proliferation of information panels at positions of interest and viewpoints etc. Whilst these can be well designed and attractive, it seems that little Earth Science content has been included. This is a missed opportunity when the very scenic features that prompt people to stop, are not explained, in favour of historical or cultural asides.

Museum exhibitions

Using the information obtained and compiled of the Mayo audit, the material for a panel based exhibition could be relatively easily prepared. With appropriate captions, and with some extra research covering human dependence on geology and resources, an interesting exhibition could be put together for display in one of the museums in the county, Council offices or County Library branches. The model could follow that produced for Carlow and for Dun Laoghaire-Rathdown. Images of these can be seen on the Geological Survey Ireland website www.gsi.ie.

New media

There are increasing numbers of examples of new methods of promoting earth sciences, via mobile phones 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 recently launched app for tourists in the Burren and Cliffs of Moher UNESCO Geopark.

Earth Science Ireland Group and magazine

The group Earth Science Ireland is an all-Ireland group promoting awareness of earth sciences and supporting educational provision in the subject. A main vehicle for the efforts is the twice yearly magazine *Earth Science Ireland* which is distributed free to thousands of individuals, schools, museums, centres and organisations. The editors would welcome more material from the Republic of Ireland and Mayo's geological heritage is of such variety and potential interest that it would make excellent content. Audits of Waterford and Roscommon have provided 2-part articles in recent *ESI* issues.

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 Mayo is already part of the available material (see Appendix 9). If no material is available to add, then at least working links to the county council website (when the results of this audit are available) 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 Mayo geology and geomorphology will assist many users and researchers into the future. However, the literature is so extensive, and much is very specialist in nature, that a geological heritage section with a select bibliography PDF on the Heritage web pages for Mayo might suffice for most users with general interest in 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 of Wicklow, Mayo etc. which include such data from Geological Survey Ireland).

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 offshore. This viewer allows users to look at a wide range of built and natural heritage data sets in map form. The outlines of and data on each County Geological Site in Mayo will be visible on the HeritageMaps.ie viewer.

https://heritagemaps.ie/WebApps/HeritageMaps/index.html

Geological Survey Ireland Geoheritage Viewer

Geological Survey Ireland Geological Heritage Online Viewer displays County Geological Sites (CGS) audit data. Individual county geological site boundary and attribute data can be downloaded in ESRI Shapefile format.
https://www.gsi.ie/en-ie/programmes-and-projects/geoheritage/Pages/default.aspx

Biodiversity Management Plans

The County Heritage Office prepares and implements Biodiversity Management Plans for County Mayo's towns and villages. It is recommended that geological heritage considerations and County Geological Sites be integrated into these plans as appropriate.

5. A Summary of the Geology of County Mayo

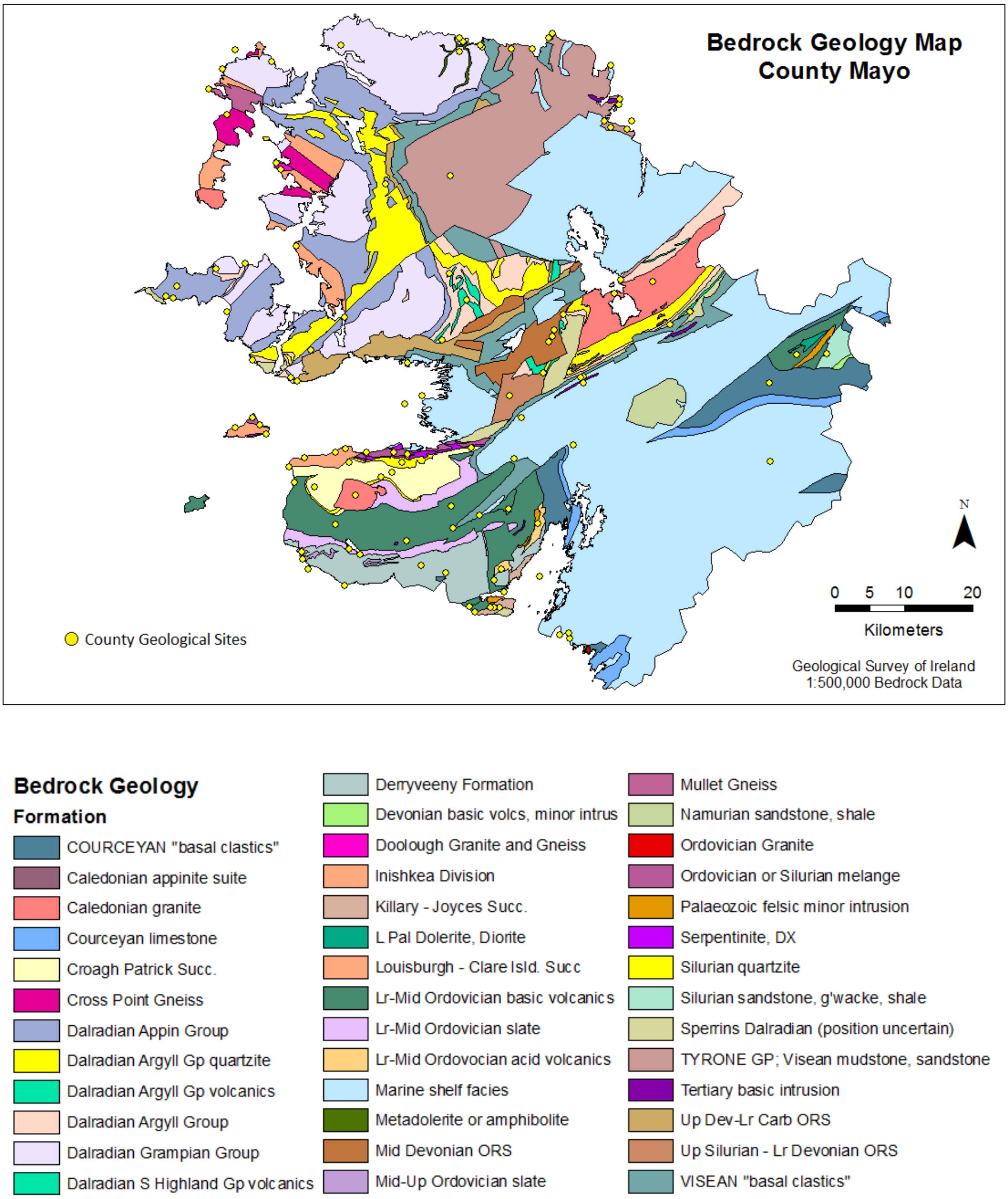
5.1 Concise summary of the geology of County Mayo

County Mayo is approximately 5,586km^2 in area and has a diverse landscape reflecting a long and eventful geological history. The geology of County Mayo comprises the three major types of rock: metamorphic, igneous and sedimentary. Mayo's geological heritage boasts some remarkable features ranging from rare views of the "young" Earth some 2 billion years ago to unique Irish landscapes formed around 15,000 years ago at the close of the last Ice Age. The bedrock of Mayo's Mullet Peninsula for example, comprises some of the oldest rocks (1.75 billion years old) exposed in Ireland. The Mullet Peninsula's Annagh gneisses therefore, provide us with very rare records of the Earth's early history. The county's geological foundations can be described as being in two regions – the western and eastern regions. The eastern region is predominantly of Devonian-Carboniferous age, whilst the western part is varied, dating from 1.75 billion years ago to around 419 million years ago. Killary Harbour, on Mayo's southern coastal county boundary is one of just three glacial fjords in Ireland, the others being Lough Swilly and Carlingford Lough.

County Mayo's mountainous landscape reflects the sculpting by ice during the most recent glaciation, which ended around 13,000 years ago. In the lowlands, a veneer of recent (less than 15,000 years old) unconsolidated glacial deposits of sand and gravel and younger peat and soil (5,000-7,000 years old) covers large tracts of the bedrock. These sands and gravels reflect repeated glaciations that occurred during the Quaternary period. With each advance and retreat of the ice from the poles, glacial landscape elements were formed in Ireland e.g. U-shaped valleys, corries, drumlins, moraines and eskers. The last glacial maximum occurred around 18,000 years ago. Most notable is Clew Bay's drowned drumlin field which extends onshore. Geological processes continue to change the landscape such as through coastal erosion of the Atlantic cliffs and coastlines, and continuing dissolution of karst limestone areas.

AGE (millions of years	*ERA*	*PERIOD*	*EVENTS IN MAYO*	*IF THIS TIMESCALE WERE A DAY LONG*
2.6	**Cenozoic**	**Quaternary**	Modern humans. Recent Ice Ages.	The ice ages begin ~ 38 seconds before midnight
23 / **66**		**Neogene & Paleogene**	Igneous dykes form as a result of the opening of the North Atlantic Ocean.	The Paleogene period begins at 11.40 pm
145	**Mesozoic**	*Cretaceous*	*Erosion. No record of rocks of this age in Mayo.*	11.15 pm
201		*Jurassic*	*Uplift and erosion. No record of rocks of this age in Mayo.*	The age of the dinosaurs, starting at 10.55 pm
252		*Triassic*	*Desert conditions on land.*	10.42 pm
299	**Palaeozoic**	*Permian*	*No record of rocks of this age in Mayo.*	10.30 pm
359		**Carboniferous**	Land became flooded by sea. Limestones with some shale and sandstone deposited in tropical seas across much of NE, SE and central Mayo.	Limestones of eastern Mayo deposited around 10.10 pm
419		**Devonian**	Caledonian mountain building. Granites (e.g. Ox Mountains; Corvock) intruded. Old Red Sandstone rocks deposited.	Granites form and 'Old Red' Sandstone deposited at 9.52 pm.
443		**Silurian**	Marine and terrestrial sedimentary rocks form (mostly south of Clew Bay).	Begins at 9.42 pm
485		**Ordovician**	Submarine volcanic lavas and thick accumulations of sedimentary rocks in South Mayo Trough (mostly south of Clew Bay).	Begins at 9.28 pm
541		**Cambrian**	Opening of the Iapetus Ocean.	Begins at 9.11 pm
2500	**Proterozoic (Palaeo-,Meso- ,Neo-)**	**Precambrian**	Dalradian rocks deposited in marine environment. Oldest rocks in Mayo (and on island of Ireland) formed 1750 Ma.	Begins at 11.00 am
4000	**Archaean & Priscoan**		*Oldest known rocks on Earth.*	Begins at 3.00 am
4600			*Age of the Earth.*	Begins 1 second after midnight

The Geological Timescale and County Mayo



5.2 Detailed summary of the geology of County Mayo

Mayo's geological heritage spans nearly two billion years of Earth's history. Igneous, metamorphic and sedimentary rocks make up the bedrock of the county.

There is a fundamental geological divide between the major rock types found in the western coastal regions and eastern plains of County Mayo. The eastern region is predominantly of Devonian-Carboniferous age (*c.*419 to 299 Ma), whilst the western part is varied, dating from *c.*1.75 billion years ago to *c.*419 Ma. Within the western region, the metamorphic rocks of the Mullet Peninsula, northwest Mayo are the oldest rocks in the county and among the oldest in

Ireland. The Annagh Gneisses have been dated at *c.*1.75 billion years old, and the nearby Cross Point Gneisses have been dated at *c.*1.25 billion years old. The entire northwest Mayo region is underlain by a suite of metamorphic rocks that include gneisses, schists and quartzites. Most of these rocks are younger than the Mullet gneisses and form part of a belt of metamorphic rocks that extends from Connemara, through northwest Mayo, Donegal and Tyrone into the Scottish Highlands. These metamorphic rocks belong to a group of rocks geologists call the Dalradian Supergroup. This supergroup was named by the renowned Scottish geologist Archibald Geikie in 1891, after an ancient tribe's territory called Dál Riada which extended from Ulster across to Scotland. The Dalradian rocks range in age from *c.*800 to 550 Ma and represent marine sedimentary and volcanic rocks that were subsequently metamorphosed *c.*485 to 465 Ma.

A northeast trending corridor that extends from Clew Bay to the County boundary, is comprised of older Dalradian metamorphic rocks and the *c.*419 million year old Ox Mountains Granite, known as the Ox Mountains inlier (Zone 2 in Figure. 1). An inlier is defined as an area of older rocks surrounded by younger rocks. The contacts between the central core of older rocks and the marginal younger rocks are commonly marked by faults. The older rocks typically form the topographic highs due to their relative resistance to erosion. The Ox Mountains inlier consists of hard crystalline metamorphic and igneous rocks and is surrounded by the less resistant Carboniferous limestones (see Figure 1).

Cambrian to Ordovician (or Silurian) age igneous and metamorphic rocks of the Deer Park Complex and the Clew Bay Complex occur in an east-west elongate belt along the southern and eastern shore area of Clew Bay and extend offshore to Clare Island (Zone 3 in Figure 1). The majority of the Clew Bay Complex comprises deep marine metasediments (metamorphosed sedimentary rocks). The Clew Bay Complex is faulted against the Dalradian of northwest Mayo on Achill Beg Island. The Deer Park Complex is an ophiolitic melange located within a major regional fault zone called the Fair Head-Clew Bay Lineament. Most notable are the green serpentinites and talc schists of the Deer Park Complex that outcrop along the northern flanks of Croagh Patrick.

The region of South Mayo (Zone 3 in Figure 1) is underlain by Ordovician and Silurian rocks and by the *c.*400 million year old Corvock Granite. The Ordovician rocks (*c.*485 to 443 Ma) predominate and record submarine volcanic activity and sedimentation that accumulated in an ocean basin, referred to by geologists as the South Mayo Trough. The Silurian rocks (*c.*443 to 419 Ma) of Mayo occur to the south of Clew Bay. The iconic conical peak of Croagh Patrick (764m high) and its flanking ridge are underlain by Silurian quartzites. To the southeast, Silurian rocks are encountered on the Kilbride peninsula close to Lough Mask, and form part of a more expansive occurrence that extends westwards along the south shore of Killary Harbour (essentially along the Mayo - Galway boundary). These Silurian rocks cradle the older Ordovician rocks of the South Mayo Trough. The Charlestown inlier (Zone 4 in Figure 1) forms the Curlew Mountains and marks a core of Ordovician and Silurian volcanic and sedimentary rocks. They are flanked by Devonian sandstones and Carboniferous limestones.

Devonian (Old Red Sandstone) sandstones (*c.*419 to 359 Ma) occur in two inliers (the Curlew Mountains and Southwest Ox Mountains) to the north and east of Clew Bay (Zone 6[1] in Figure 1). They reflect the development of arid desert conditions, very different to the depositional environments that preceded this period.

Carboniferous shales, sandstones and limestones (*c*.359 to 299 Ma) form the bedrock in most of the eastern half of Mayo (Zones 6^1, 6^2 and 6^3 in Figure 1). The Carboniferous period marks the inundation of the Devonian desert landscapes by shallow subtropical seas that triggered the formation and accumulation of the characteristic Carboniferous limestones which contain an abundance of fossils –the remains of marine life that thrived in these ancient seas.

There is a gap of around 230 million years between the Carboniferous rocks and those of the younger Paleogene period (*c*.66 Ma). Several NE trending Paleogene dyke swarms extend from Killary Harbour to the Clew Bay area. These dykes range in thickness from 1 to 10 metres and have been traced discontinuously over distances of tens of kilometres. They are made of basaltic rock (dolerite) and their steep to vertical orientation reflects the stretching and thinning of the Earth's crust during the early formation of the Atlantic Ocean.

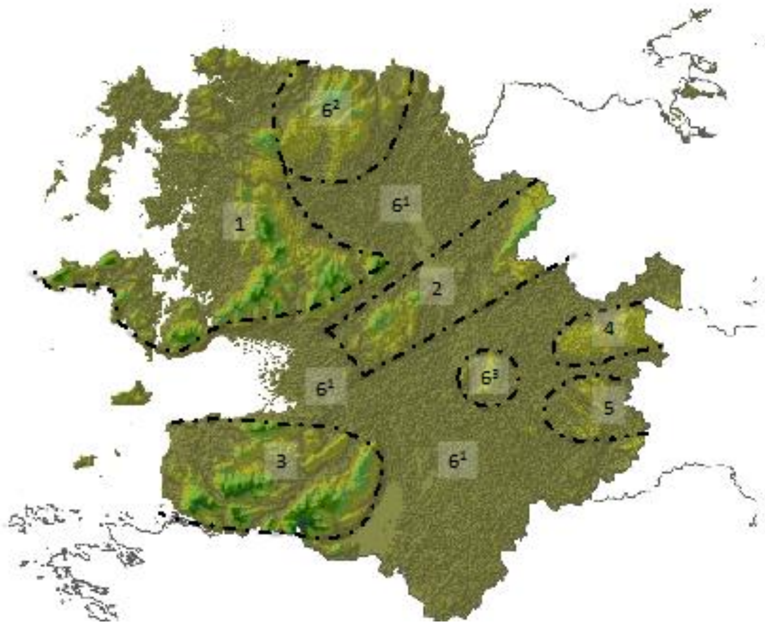


Figure 1. Topographic map of County Mayo showing geo-topographic zones.

The zones outlined by dashed lines highlight mountainous regions that generally comprise the older metamorphic and igneous rocks. The Carboniferous limestone plains of Mayo occur principally in the eastern part of the County and around Clew Bay and are designated by the numeral 6^1. The numbered geo-topographic zones are: 1. NW Mayo region comprising the oldest metamorphic rocks e.g. gneisses (*c*.1.75 billion years old Annagh gneisses) and Dalradian schists and quartzites; 2. The Ox Mountains inlier comprising Dalradian schists and quartzites, and younger *c*.419 million year old granite; 3. Clew Bay and Deer Park Complexes (Cambrian to Ordovician/Silurian) along the southern shore of Clew Bay; and the South Mayo Trough to the south, comprising Ordovician (*c*.485 to 443 Ma) and Silurian (*c*.443 to 419 Ma) sedimentary and volcanic rocks, and the *c*.400 Ma Corvock Granite; 4. The Charlestown inlier comprising Ordovician and Silurian sedimentary and volcanic rocks and granite; 5. Devonian sandstones (*c*.419 to 359 Ma); 6^1 Carboniferous limestones (*c*.359 to 326 Ma) with subordinate Devonian sandstones in the Clew Bay area; 6^2 Carboniferous sandstones and slates (*c*.359 to 326 Ma); and 6^3 Carboniferous shales and sandstones (*c*.326 to 299 Ma).

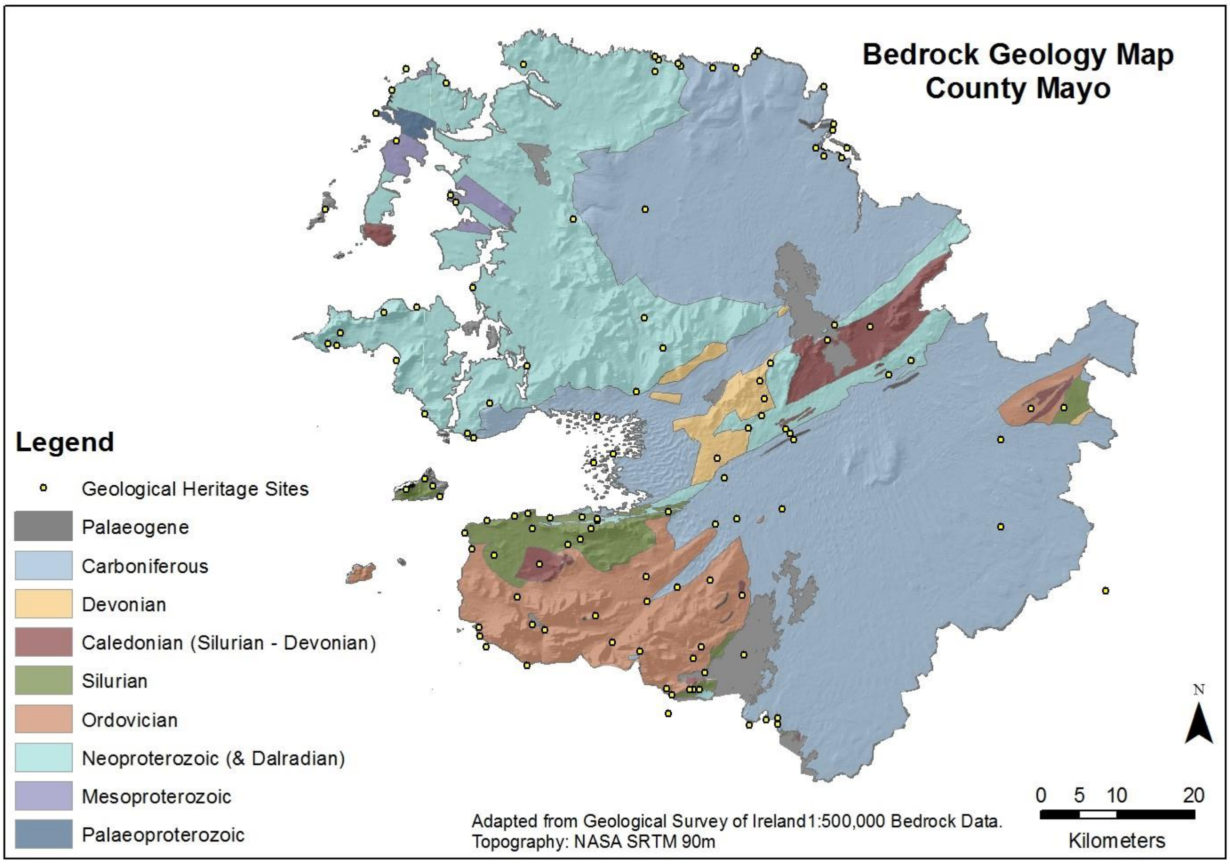


Figure 2. Simplified bedrock geology map of County Mayo, showing distribution of geological heritage sites. The west of the county is dominated by igneous and metamorphic rocks while to the east the bedrock geology is predominantly composed of Devonian and Carboniferous age bedrock. The latter is marked by the NE trending inlier of Dalradian metamorphic rocks and the Ox Mountains Granite.

Summary of Quaternary Geology of Mayo

The veneer of unconsolidated sands and gravels overlying the bedrock geology reflect repeated glaciations during the Quaternary period which extends from around 2.6 Ma to the present. With each advance and retreat of the ice, from the poles, glacial landscape elements were formed in Ireland e.g. U-shaped valleys, bowl-shaped corries, mega-scale glacial lineations, drumlins, moraines and eskers. Four major periods of glaciation lasting for millions of years are recorded in the geologic record. Ice ages are made up of individual stages or cycles of glacial advance following a fall in climatic temperature, and glacial retreat when temperatures rise. For example, over the last two million years, some sixty glacial advance and retreat phases have occurred, some only minor, but others lasting for thousands of years. The shorter time periods (tens of thousands of years) during which glaciers reach their maximum development are known as glaciations. Our climate today represents an interglacial period, or a warm period between glacial advances so we are still in an ice age

The last glacial maximum occurred around 18,000 years ago. Glacial landforms such as eskers and drumlins were formed as the ice retreated. Most notable is Clew Bay’s drowned drumlin field which extends onshore. These elongate hills range in length from *c.*100 to 300m, are 30m to 105m wide and reach heights of *c.*15m. In the west, rock debris within the moving ice sheets left linear markings on bedrock surfaces - many exposures of Mayo’s granites and quartzites display these markings called striae.

Karst features are well displayed near Lough Mask and Carra. Solution by slightly acidic water of Carboniferous limestone has developed a range of landforms such as sinks, caves, risings, dolines and limestone pavements, mostly formed since the ice sheets finally disappeared.

6. Acknowledgements

The authors would like to gratefully acknowledge the assistance of Deirdre Cunningham, Heritage Officer from Mayo County Council in the development of this project. Funding from the Heritage Council and Mayo 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. Dr Markus Pracht is gratefully acknowledged for additional site data for this audit.

Appendices

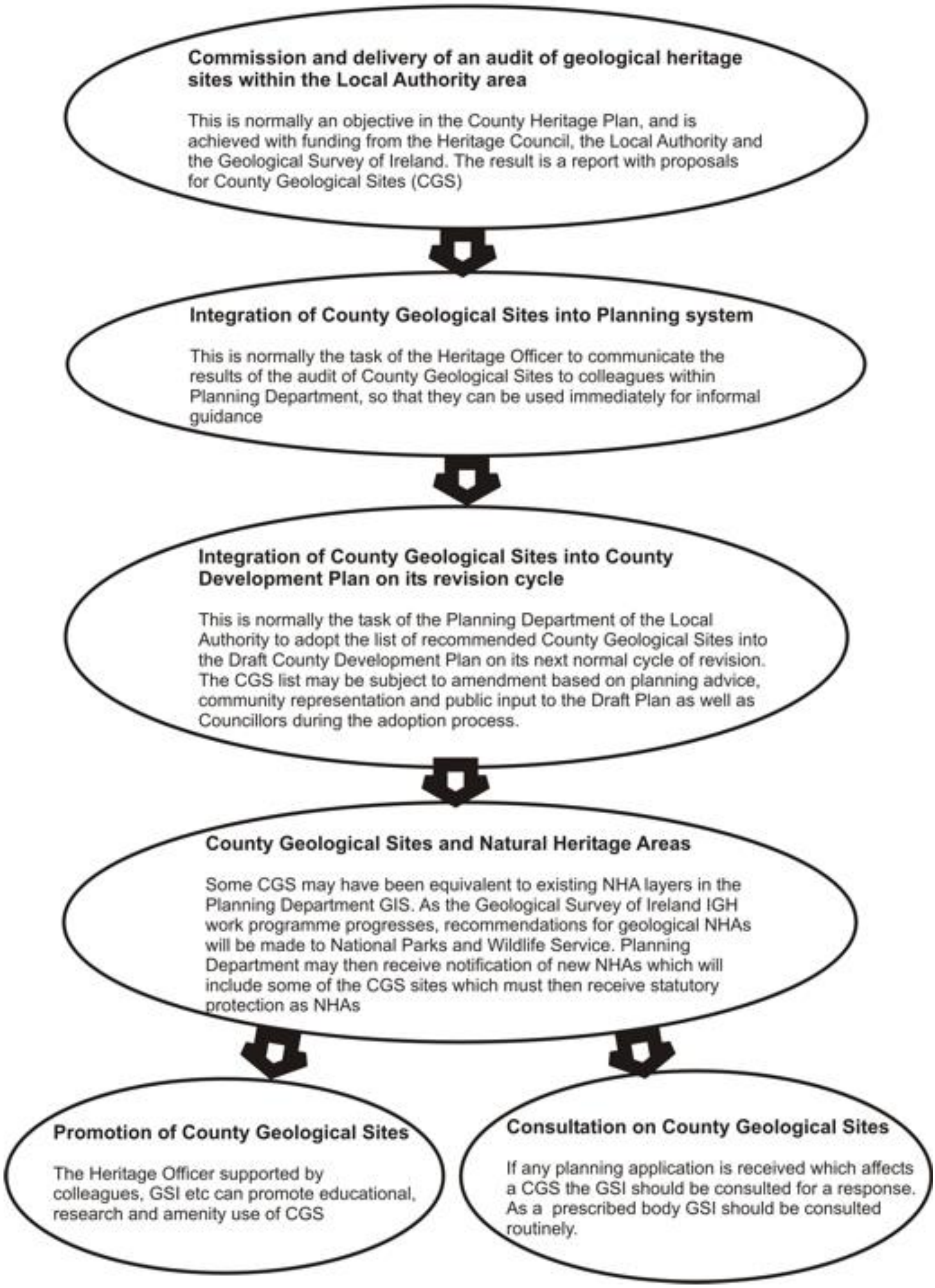
Appendix 1: Geological heritage audits and the planning process

This appendix contains more detail on the legal framework behind geological heritage audits conducted by County Councils, and the process which operates as a partnership between the Geological Heritage and Planning Section 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: Planning and Development Act 2000 (as amended) [e.g. Sections 212 (1)f; Part IV, 6; First Schedule Condition 21], Planning and Development Regulations 2001, Wildlife (Amendment) Act 2000 (enabling Natural Heritage Areas) and the Heritage Act 1995. The Planning and Development Act 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 twenty-five other county audits since 2004.

County Geological Sites - a step by step guide



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Appendix 4: Bibliography – Caves and Karst of County Mayo

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Appendix 5: Bibliography – County Mayo Quaternary References

There are many important sites in terms of large-scale Quaternary subglacial geomorphology that complement the abundant and excellent variety of glacial geomorphology landforms in County Mayo. The overall areas occupied by drumlins, moraines, mega-scale glaciation lineaments etc. are extensive with many good examples of individual features. Such individual examples should be protected, with a presumption of maintaining the integrity of the landscape. Development affecting them should only be permitted based on strong arguments.

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Appendix 6: Geological heritage versus geological hazards

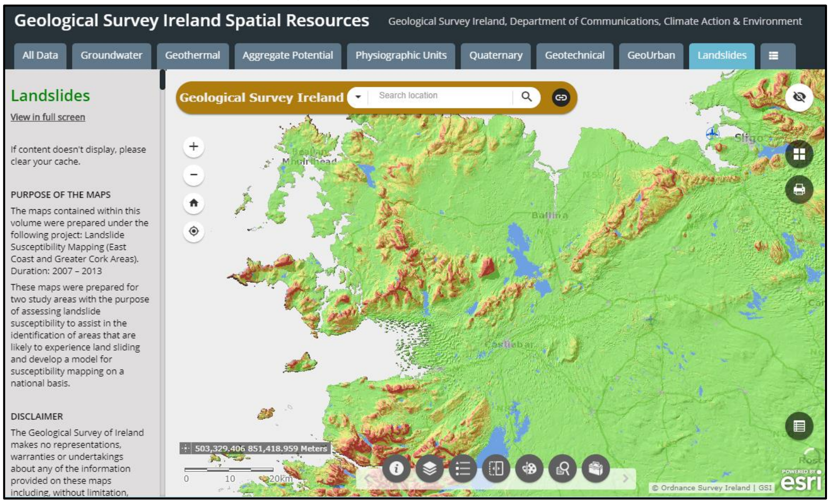
Ireland is generally considered a country with very low risk of major geological hazards: there are no active volcanoes, stable tectonic plates mean earthquakes are relatively rare and our human history is not peppered with disastrous landslides, mudflows or other geological hazards. There are of course risks of one-off events such as tsunamis from collapse of volcanos in the Canary Islands, and this section briefly looks at the specific record and nature of geological hazards in Mayo 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 they can be suddenly active with major events, and quiet periods in between. Many of the sites in this audit represent evidence of past environments and geological processes, such as volcanic activity, tropical coral seas, glacial erosion of mountains and so on. However, some sites represent the active geomorphological or land-forming processes of today. These sites, generally coastal, are dynamic environments and are subject to constant or intermittent, and sometimes sudden, change.

Landslides and bog flows
Geological Survey Ireland has been compiling national data on landslides since 2004 (see https://www.gsi.ie/en-ie/data-and-maps/Pages/Geohazards.aspx#landslides). The event that primarily initiated this project was a serious landslide on Pollatomish in County Mayo in 2003, which caused serious damage and disruption for some local residents.



In 2013, Geological Survey Ireland completed a landslide susceptibility mapping project as part of the Geoscience Initiative 2007-2013. This project was one of the main recommendations made in the 2006 publication "Landslides in Ireland" published by Geological Survey Ireland and the Irish Landslides Working Group.

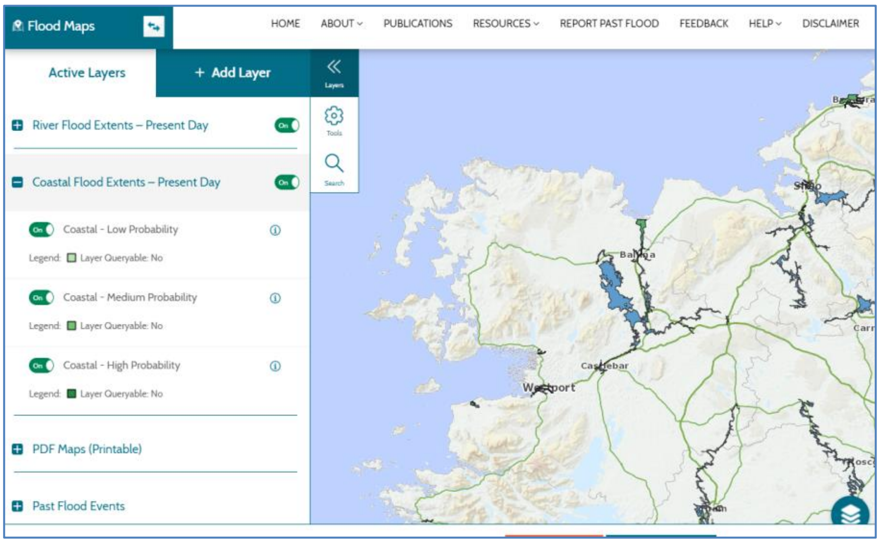


https://www.gsi.ie/en-ie/programmes-and-projects/geohazards/projects/Pages/Landslide-Susceptibility-Mapping.aspx

Flooding
There are three types of flooding which need consideration.

Coastal flooding is potentially only a problem in low-lying areas when a combination of high-tides and weather conditions may cause the sea to overtop barriers or coastal defences, whether man-made or natural. Where natural systems exist, different habitats adapt to and absorb occasional inundations, but when people build in vulnerable areas or channelise rivers (remembering that geological time is far greater than human lifespans) problems can occur.

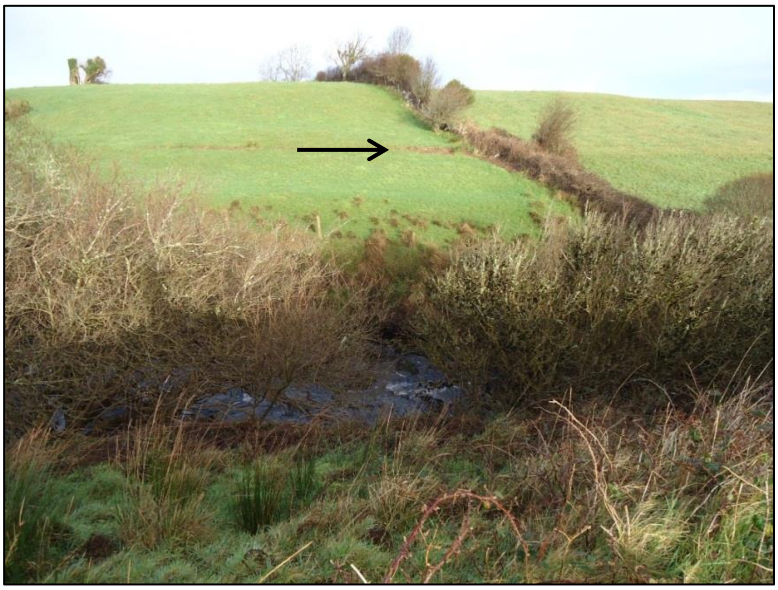
River flooding occurs inland when the rainfall exceeds the capacity of the ground to absorb moisture, and the river channels cannot adequately discharge it to the sea. This has not been a widespread issue in the county. The OPW website (http://www.floodinfo.ie/) can be consulted for details of flood plans and flood maps developed by the OPW and information on flood risk management.



OPW Flood Maps Web Map

Karstic flooding can occur when underground passages are unable to discharge high rainfall events. The karst in the limestone lowlands has many active caves, and in some places the phreatic zone (the water table) does rise significantly.

There are also numerous turloughs in Mayo, which are seasonal lakes where the water table intersects the land surface. The Ordnance Survey of Ireland six inch to the mile (1:10,560) mapping record any such areas as 'liable to flooding' in the karstic landscapes. Historical knowledge provided against people building in marginal parts of these landscapes. However, poor planning decisions have allowed dwellings in some areas of the country that have subsequently flooded during high rainfall events. If such buildings have been permitted in Mayo, it may only be known when a combination of weather conditions occur.



Arrow indicates flood level above Aille River (the river sinks into Aille River Cave and gets backed-up after heavy rainfall).

Coastal erosion

Whilst much of the Mayo coastline is composed of hard rocks such as Precambrian gneisses or Ordovician sandstones, erosion is generally slow and not a significant hazard. However, in some areas there are relatively unconsolidated glacial tills and head deposits. These are much more prone to erosion by the sea and can constitute a hazard. The cliffs at sites such as around Clew Bay retreat by slumping of the cliff faces. The slumped material is removed by the sea, further undermining the stability of the till, and causing renewed slumps. This only normally becomes a hazard to landowners or property on the cliff-top when assets are threatened.

Coastal protection techniques can include placing of large boulders at the toe of slumping areas, which are a significant modification of local landscapes. One effect of these interventions may be to prevent regular slumping and therefore the accessible geological interest can become degraded. In addition, the loss of sediment input at one point may affect the accumulation of sediment along the coast.

Coastal erosion of unconsolidated sediments in cliffs at Askillaun, south Clew Bay coast

Wasting on Bartragh Island

Karstic collapse

This is a localised hazard in parts of Mayo. In the flat limestone land in the south east of the county there is limestone only a few metres beneath the surface. Whilst the number of known caves in the limestone is limited, the hydrogeological data and recent research suggest that there are cavities and indicate that there are risks. These can actually occur quite frequently, but collapses are often filled in quickly by farmers and not recorded.

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/. 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. County Mayo is a county quite dependent on groundwater supplies, and therefore the risk is more serious than for most other counties. As the groundwater is largely 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 7: Data sources on the geology of County Mayo

This section is a brief summary of relevant Geological Survey Ireland 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 (DMS), into which about half a million documents and maps have been scanned, is freely available to any person at Geological Survey Ireland Customer Centre. This means that any user can visit Geological Survey Ireland Customer Centre themselves and search on screen for data of relevance to them. High quality colour and black and white print-outs can be made or data supplied on CD, or via USB keys etc. **Data is available free of charge**. It is planned to make this resource available online but no date is yet set for when this may be achieved, although many subsets are already available within online data.

Key datasets include:

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. Parts of Sheets 6, 10 and 11 cover County Mayo.

19th century 6 inch to the mile field sheets
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 (1:63 360) maps, of which all or parts of Sheets 39, 40, 41, 51, 52, 53, 62, 63, 64, 65, 73, 74, 75, 76, 83, 84, 85, 86, 94, 95, 96 cover County Mayo. 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 in the Customer Centre library and scanned on the DMS. Historical geological mapping is 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 of the Department of Communications, Energy and Natural Resources (currently) carries an obligation on the exploration company to lodge records of the work undertaken, for the common good. These records are held by Geological Survey Ireland 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.

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

Historic Mine Records
Limited information of abandonment plans and varied other material may exist for the various mining ventures in the county, at places such as Sheeffry Mine, but few mines of any significance are known in Mayo. The Mining Heritage Trust of Ireland has published detailed research papers on sites, including Belderg (Belderrig) in 2011.

Subsoils Mapping
Since a Groundwater Protection Scheme has been completed for County Mayo by Geological Survey Ireland, a recently completed map of the geometry of subsoils across Mayo exists, as well as the previously completed bedrock mapping. The groundwater vulnerability ranking for the county has therefore been completed, as well as the derivation of groundwater resource protection zones, the results of which will be available for inclusion in the final County Mayo audit report. This provides a significant resource in general terms as well as for groundwater protection, and customised output by the Groundwater Section of Geological Survey Ireland is possible.

Detailed mapping of karstic features
Geological Survey Ireland, in conjunction with Teagasc, have completed detailed field-scale mapping of karst features in the Cregduff Springs Catchment, which covers just under fifty square kilometres, just east of Ballinrobe. This is the most detailed study of a karst catchment ever completed in Ireland, and the results can be summarised as follows:

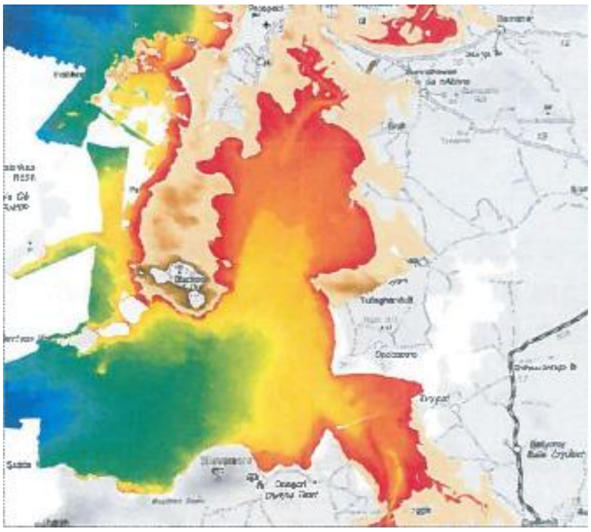
- Much limestone at surface was mapped, and the extent of limestone subcrop was also mapped in detail. Just over a fifth of the mapped area comprised limestone within 1 metre of the surface (9.95 km^2);
- Much of this limestone was considered to be epikarst, as all rock exposures displayed this;
- At the time of mapping, during a dry winter (2010), turlough extents were very low; this allowed a high quality map of outcrop and subcrop, as well as associated swallow holes and springs, in or around the turloughs to be produced;
- The total area of water area within the catchment covers just under two kilometres when turloughs were flooded;
- Thirty six springs were mapped; only ten of these were previously known;
- Seventeen swallow holes were mapped; eleven of these were previously unknown;
- One sluggera was mapped, previously unrecorded;
- Eighteen hundred and fifty five enclosed depressions(dolines) were mapped, with none of these recorded previously in the Geological Survey Ireland Karst Database;
- Eighteen lengths of ephemeral stream were mapped, with these all sinking into swallow holes for all or part of the year;
- Forty one areas of karst pavement were mapped in their entirety, with none of these previously in the Geological Survey Ireland Karst Database;
- Two epikarst windows were mapped, which are depressions which have a spring at one side and a swallow holes at the other.

Digital mapping of very many different datasets is now available via Geological Survey Ireland website: www.gsi.ie. This resource is being added to on a regular basis.

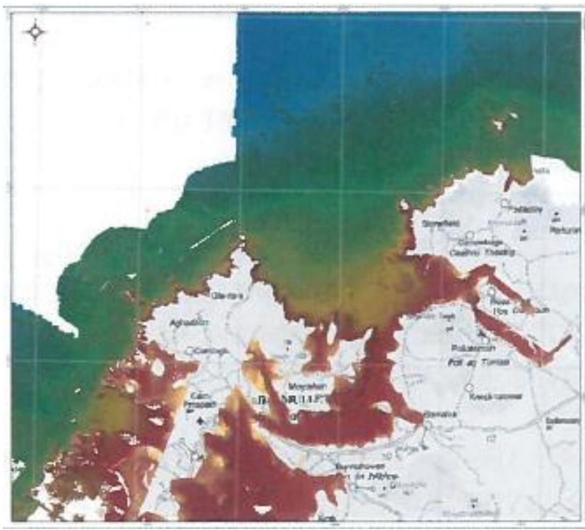
INFOMAR data
The original Irish National Seabed Survey, carried out by Geological Survey Ireland and the Marine Institute (1999-2005), focused on deep-water mapping at the outer margins of Ireland's territorial seabed, moving closer shoreward over time. Its successor programme, INFOMAR (INtegrated mapping FOr the sustainable development of Ireland's MArine Resource) is in the process of mapping inshore areas, having identified 26 priority bays, including Clew Bay and Killala Bay.

INFOMAR survey operations for Mayo include Broadhaven, Killala and Blacksod bays, Clew Bay & Achill Sound and Killary Harbour.

Areas such as Clew Bay, that have been surveyed in detail, provide new insights into the geomorphological evolution of the landscape in Quaternary times and since the Ice Age in the Holocene period (over the last 10,000 years).



Bathymetry of Blacksod Bay (2014)



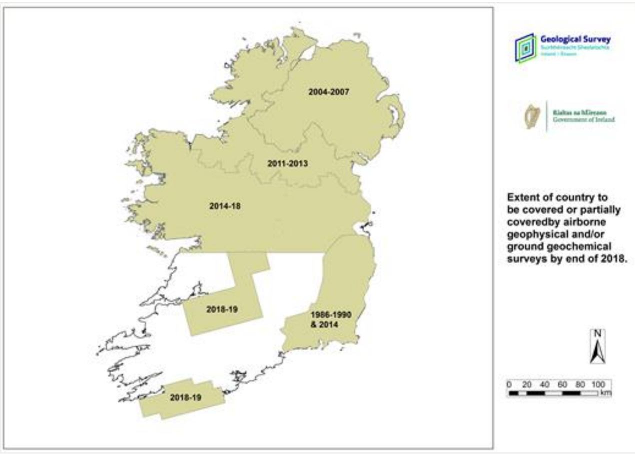
Broadhaven Bay (Shaded Relief Illumination NW), 2014

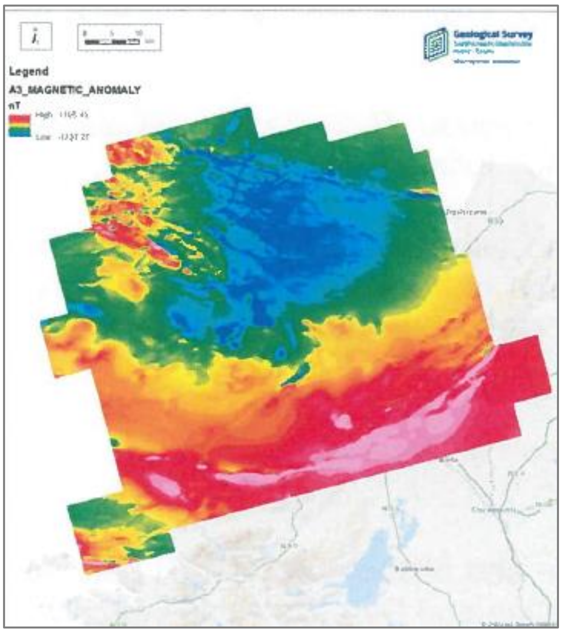
Further information about INFOMAR data can be obtained on www.infomar.ie.

There may be scope for integrating 3D on- and offshore/INFOMAR data (see the EMODnet - European Marine Observation and Data Network - website at http://www.emodnet.eu), as in the Copper Coast Geopark, County Waterford where it has been successfully used to develop various 3D films and video flythroughs as tourism tools (in partnership with Geological Survey Ireland under the Interreg IVB ATLANTERRA project).

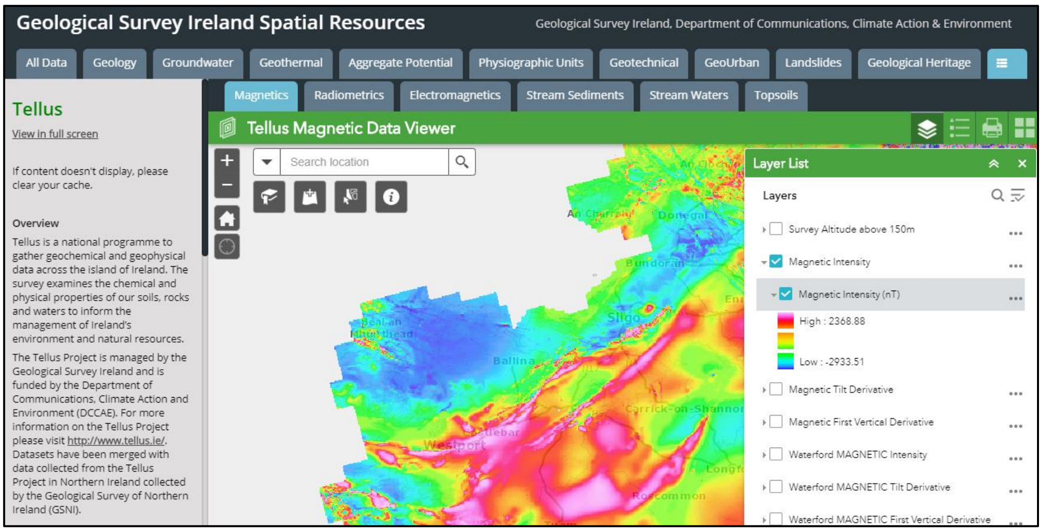
TELLUS Mapping
Tellus is a regional mapping project, combining airborne geophysical and geochemical surveys to provide geoscientific information for the island of Ireland. Since 2004, more than 50,000 km^2 of the island of Ireland has been surveyed or partially surveyed through the **Tellus** surveys, which support mineral exploration, environmental management, agriculture and research activity. Tellus involves two types of surveying – airborne geophysical surveying using a low-flying aircraft and ground-based geochemical surveying of soil, stream water and stream sediment.

Data is freely available from www.tellus.ie. County Mayo was surveyed during 2017 (A3 block) and data was released in early 2018. All data from Tellus is freely available online at www.gsi.ie/en-ie/data-and-maps/Pages/Geophysics.aspx#Tellus2018Mayo





Residual magnetic anomaly for Block County Mayo (2017)



Tellus Magnetic Data Viewer (2018)

Appendix 8: Further sources of information and contacts

The Head of the Geological Heritage and Planning Programme, Geological Survey Ireland, can be contacted in relation to any aspect of this report. Deirdre Cunningham, the Heritage Officer of Mayo County Council, or the Senior Executive Planner in the County Council are the primary local contacts 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 Arts, Heritage and the Gaeltacht. The names and phone numbers of current staff may be found in the phone book, or at www.npws.ie. Information on Joyce Country and Western Lakes aspiring UNESCO Geopark project is available from the project office in Tourmakeady or via info@jcwlgeopark.ie.

Websites of interest

- www.gsi.ie - for general geological resources
- https://secure.dccae.gov.ie/goldmine/index.html Geological Survey Ireland online digital data archive
- www.geology.ie – the website of the Irish Geological Association who run fieldtrips and lectures for members, including many amateur enthusiasts
- http://www.iqua.ie - for information, fieldtrips, lectures etc in relation to Ireland's Ice Age history
- http://www.cavingireland.org/ - for information on caves and safe caving
- http://www.progeo.ngo/ - for information about ProGEO the European Association for the Conservation of Geological Heritage
- http://www.ballycroynationalpark.ie/ - Ballycroy National Park NPWS
- www.joycecountrygeoparkproject.ie – Joyce County and Western Lakes Geopark project
- http://www.galwaygeology.net/ - Galway Geological Association
- http://www.mhti.com/ - Mining Heritage Trust of Ireland

Appendix 9 - Geoschol leaflet on the geology of County Mayo

MAYO

AREA OF COUNTY: 5,585 square kilometres or 2,156 square miles

COUNTY TOWN: Castlebar

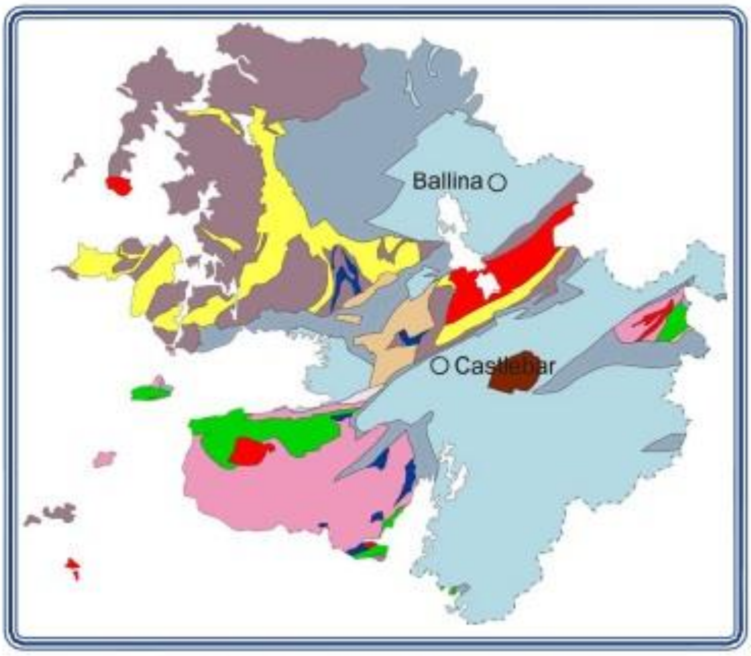
OTHER TOWNS: Ballina, Newport, Westport

GEOLOGY HIGHLIGHTS: Silurian fossils, Ordovician conglomerates, Clew Bay drumlins, Lough Mask karst features

AGE OF ROCKS: Precambrian; Ordovician to Carboniferous

Croghaun, Achill Island

These are the highest cliffs in Ireland, at 2192 feet.



Geological Map of County Mayo

Pale purple: Precambrian Dalradian rocks; **Pale yellow:** Precambrian quartzites; **Dark blue:** Precambrian Gneiss and Schists; **Pink:** Ordovician; **Green:** Silurian; **Red:** Granite; **Beige:** Devonian sandstones and conglomerates; **Blue gray:** Lower Carboniferous sandstones; **Light blue:** Lower Carboniferous limestone; **Brown:** Upper Carboniferous shales.

Geological history

Mayo has a very long and complex geological history which geologists are still trying to understand. Many large areas are defined as terranes. These are sequences of rocks that were formed in one place and are now alongside other sequences that were originally formed a long way apart. Major faults in the Earth's crust (perhaps like the San Andreas Fault in California) have brought them together over millions of years.

North Mayo has the oldest rocks in the county, and among the oldest in the country, with ancient metamorphic schists, gneisses and other rocks. On the Belmullet Peninsula the Annagh Gneiss is around 1750 million years old. Other metamorphic rocks are younger, with most of north Mayo composed of Dalradian metamorphic rocks, similar to those found in Connemara, Donegal and in the Highlands of Scotland.

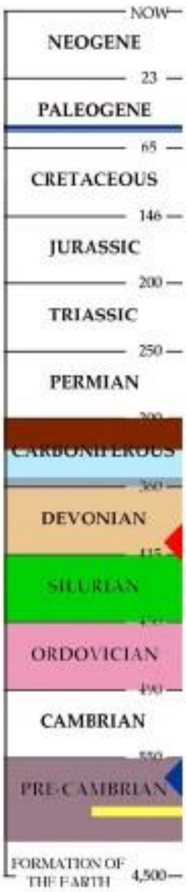
South Mayo has sedimentary rocks, including some spectacular boulder conglomerates of Ordovician age preserved in an enormous fold called the South Mayo Trough. Terrane faults separate it from rocks either side. Silurian rocks are faulted alongside too, in three distinct sequences. Croagh Patrick is made of quartzite rock as one sequence. Louisburgh and Old Head have another different sequence and the southern rocks of Joyces Country are distinct again.

During the Carboniferous the sea lapped against the shores of mountains and hills from the lowlands to the east of the county. Around Lough Mask and in the Clew Bay area there are some sandstones and other rocks that were deposited on a land surface by rivers and then in a coastal plain. Above them limestone bedrock is found. Around Corraun to Newport, and on the north coast at Downpatrick Head are good places to see these rocks.

The youngest solid rocks in the county are around 60Ma (Paleogene) and are volcanic in origin (they are not shown on map). Stretching of the Earth's crust as the north Atlantic Ocean was opening allowed molten magma to move up through fractures in the rock. It cooled and solidified to form dykes of a dark crystalline rock called gabbro. A few of these have been found the Mayo hills but the largest by far, almost 400 metres wide, can be seen on the shore on the west side of Killala Bay.

The lakeshore of Lough Mask and Lough Carra have a range of superb karst features caused by slightly acid lake water dissolving the rock. One very strange feature is the cylindrical tubes which are dissolved *upwards* on the bottom of limestone

Drumlins in Clew Bay viewed from the summit of Croagh Patrick



Geological timescale showing age of rocks in Mayo.

beds and boulders. There are also massive sinks where the lake goes underground to reappear at Cong in Lough Corrib.

The Clew Bay drumlin field shows how powerful ice is in shaping the landscape. Drumlins (named from the Irish) are humps of debris left behind by ice sheets. In Clew bay the sea rose and drowned the low ground making a hundred or so islands.

Mayo fossils

There are Ordovician fossils in many of South Mayo's rocks but they are small and very hard to find. By the Silurian period, animal life had diversified such that South Mayo is a fine place to find fossils. In the Kilbride Peninsula, generations of geology students have mapped sedimentary sequences from terrestrial rocks with no fossils through to deep water rocks with only planktonic animal remains such as graptolites. In between a range of trace fossils, brachiopod shells (pictured right), trilobites, corals and other animals are preserved in their communities showing how the depth of water changed through time. In some places coral colonies can be seen that have been swamped and killed by a fall of volcanic ash.

Carrownagower Bridge, Cong Canal

The Cong Canal

Understanding geology can be very important for engineers. In the 19th century they tried to make a canal between Lough Mask and Lough Corrib. The rock is so karstified (dissolved away) that all the water sinks away and it is dry most of the year!

Map adapted with permission from Geological Survey of Ireland 1:1,000,000 map 2003. Image credits: Mike Simms 1, 4 (bottom); Matthew Parkes 3, 4 (top).

GEOSCHOL www.geoschol.com

Text by Matthew Parkes & Mike Simms

Appendix 10: Glossary of geological terms

Geological term	Definition
Adit	A horizontal or only gently inclined mine tunnel dug to access ore, or to drain, ventilate or further develop a mine
Agglomerate	large, coarse, rock fragments associated with lava flow that are ejected during explosive volcanic eruptions.
Aeolian	wind-blown or deposited; associated with wind processes.
Alluvial Deposit	unconsolidated clay, silt, sand and gravel, deposited by a body of running water.
Amphibolite	dark-coloured, coarse grained/crystal non-foliated mafic metamorphic rock.
Analcime	a common feldspathoid mineral, a hydrated sodium aluminosilicate.
Andesite	a volcanic rock of intermediate composition (between rhyolite and basalt).
Anticline	a structural geological term meaning an upfold of sedimentary strata in a linear arch shape.
Arthropod	an invertebrate animal of the large phylum Arthropoda, (such as an insect, spider, or crustacean)
Barrovian zones	metamorphic zones that describe the changes in metamorphic mineral assemblages that occur in regionally metamorphosed pelitic rocks. Associated with orogenic belts.
Bedding Plane	the contact between individual beds of rock.
Bedrock	a general term for the rock, usually solid, that underlies soil or other unconsolidated, superficial material.
Biotite	black mica, a silicate mineral in the common mica group.
Bioturbation	the disturbance of sediment by organisms.
Biostratigraphy	using fossils to define the succession of rocks/sedminent layers.
Bivalve	molluscs (e.g., clams, oysters, mussels, scallops) that have an external covering that is a two-part hinged shell and contains a soft-bodied invertebrate.
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.
Blueschist facies	a low to medium-grade metamorphic facies, typical of low temperature and high pressure, and associated with subduction.
Boulder Clay	unconsolidated, unsorted glacial deposits consisting of boulders and cobbles mixed with very finely ground-up rock or silt. Also known as till.
Brachiopods	a marine invertebrate of the phylum Brachiopoda - a type of shellfish. Ranging from Lower Cambrian to present.
Braided River	a river that consists of a network of small channels separated by small and often temporary islands.
Breccia	a clastic sedimentary rock composed of angular clasts (gravel to boulder size) cemented together in a consolidated matrix.
Bryozoa	invertebrates belonging to the phylum Bryozoa, ranging from Ordovician to present, often found as frond-like, net-like or stick-like fossils.
Calcareous	containing significant calcium carbonate.
Calcite	a pale mineral composed of calcium carbonate, which reacts with dilute acid.
Carbonate	a rock (or mineral), most commonly limestone (calcite) and dolomite.
Cave	a natural underground space large enough for a human to enter, which is usually formed in either soluble limestone by karstic processes, or in exposed rock along the coastline, where the sea erodes natural rock fractures.
Chert	a very fine-grained (microcrystalline) rock, composed of quartz (silica mineral) with minor impurities.
Charophyte	a type of (mostly) freshwater green algae related to modern land plants.
Chattermarks	crescent-shaped gauges chipped out of the bedrock as a glacier drags rock fragments underneath it.
Chlorite	green-grey coloured basic iron magnesium aluminium silicate mineral.
Chromite	brownish black cubic mineral belonging to the spinel group.
Cirque	a horseshoe-shaped, steep-walled valley formed by glacial erosion.
Clast	an individual constituent, grain or fragment of a sediment or rock, usually produced by mechanical weathering (disintegration) of a larger rock mass.
Cleavage	a finely spaced, flat plane of breakage caused by compressive deformation of rocks. e.g. the splitting of slate.
Conglomerate	a sedimentary rock comprising of large rounded fragments in a finer matrix.

Corrie	a horseshoe-shaped, steep-walled valley formed by glacial erosion.
Cosmogenic dating	a chronological dating technique that uses the interactions between cosmic rays and nuclides to provide age estimates for rocks on the earth's surface. An excellent way of directly dating glacial sediments.
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).
Cross-bedding	layering in sedimentary rocks at an inclined angle to bedding formed by current-ripples.
Crust	the outermost, solid, layer of the Earth.
Dalradian	the Dalradian Supergroup in northwest Ireland and Scotland represents a variably deformed and metamorphosed late Neoproterozoic (~750–600 Ma) succession of marine shelf sediments, tillites, volcanics and turbidites.
Diamict	poorly sorted sediment deposits.
Dolerite	a medium-grained sub-volcanic rock, similar to basalt.
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.
Drumlin	a streamlined mound of glacial drift, rounded or elongated in the direction. of the original flow of ice.
Dune slacks	the hollow between dunes, sometime long and linear like a valley, sometimes a round trough.
Dyke	vertical or near-vertical sheet-like body of magma that cuts across pre-existing rock.
Epidosite	metamorphic rock consisting of epidote and quartz; a product of hydrothermal metamorphism; parent rock was a mafic igneous rock.
Epikarst	the shallow layer, near surface, of highly karstified rock, with many voids included.
Erratic	a rock fragment, often large, 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	a long, narrow ridge of coarse gravel and sand deposited by a stream. flowing in or under a decaying glacial ice sheet.
Facies	the character of the rock derived from its original sedimentary environment and process of deposition.
Fan	a usually triangular deposit of sand and gravel deposited by a glacial
Fault	planar fracture in rocks across which there has been some displacement or movement.
Fault Zone	a tabular volume containing many faults and fault rocks (rocks broken up by fault movement).
Fauna	collective term used to group all animal life.
Feldspar	a group of silicate minerals, and the most common mineral group in the Earth's crust.
Floodplain	a flat or nearly flat land area adjacent to a stream or river that experiences occasional or periodic flooding.
Fluvial/Fluviatile	pertaining to a river or stream.
Fjord	a drowned glaciated U-shaped valley.
Fold(ing)	flexure in layered rocks caused by compression.
Formation	a formal term for a sequence of related rock types differing significantly from adjacent sequences.
Fossiliferous	rich in fossils.
Fossils	any remains, trace or imprint of a plant or animal that has been preserved in the Earth's crust since some past geological or prehistorical time.
Fuchsite	greenish variety of muscovite, high in chromium.
Glacial	of or relating to the presence and activities of ice or glaciers.
Glaciation	an interval of time within an ice age marked by colder climate temperatures and ice sheet advances
Glaciofluvial	relating to processes or deposits associated with glacial streams flowing from glacial ice.
Glaciogenic/glacigenic	in the context of sediments, those which are derived from glaciers.
Glaciolacustrine	relating to processes or deposits associated with a lake which received meltwater from glacial ice.
Glacioisostatic depression	the sinking (subsidence) of the Earth's crust due to the overlaying mass of thick ice sheets.
Gilbert-type delta	a type of delta that consists of gently inclined fine-grained bottomsets, covered by steep sandy and/or gravelly foresets.
Gneiss	a medium- to coarse-grained metamorphic rock, characterized by alternating light and dark

	bands differing in mineral composition.
Granite	a coarsely crystalline intrusive igneous rock composed mostly of quartz and feldspar.
Granodiorite	a medium-coarse crystalline intrusive igneous rock composed of quartz, plagioclase, orthoclase, biotite, amphibole.
Graptolite	extinct organism of the phylum Hemichordata with colonies consisting of one or more fine branches with cups. Ranging from Middle Cambrian to Devonian, but particularly important in dating Ordovician and Silurian rocks.
Greywacke	an impure sandstone, characterised by poorly-sorted, angular grains in a muddy matrix, that was deposited rapidly by turbidity currents (submarine avalanches).
Grike	solutionally widened vertical fracture separating clints on a limestone pavement.
Group	a geological unit, or succession, consisting of two or more formations.
Gully	a deep valley created by running water eroding sharply into bedrock or subsoil.
Head	weathered rock fragments accumulated on lower slopes from periglacial freezing and thawing action acting with gravity.
Heterolithic strata/bedding	bedding features indicative of deposition in a subaqueous environment (tidal currents. fluvial channel, tidally influenced channel, tidal channels).
Holocene	geological epoch dating from 11,600 years ago to the present day.
Hornblende	dark-green to black coloured, calcium-rich amphibole mineral.
Hornfels	metamorphic rock formed by the contact between mudstone / shale, and a hot igneous body, and represents a heat-altered equivalent of the original rock – a process termed contact metamorphism.
Hummock	a small hill or knoll in the landscape, which may be formed by many different processes.
Hydrogeology	the study of the interrelationships of groundwater and surface water processes, water properties and geologic materials
Iapetus Ocean	ancient ocean that separated NW Ireland (Laurentia) from SE Ireland (Avalonia). Ocean closed 480-430 Ma, and closure zone in Ireland is marked by the Iapetus Suture).
Ice margin	edge of an ice sheet or glacier.
Ice-berg rafting	a near-continuous rain-out of sediment from the melting of icebergs drifting offshore in a marine environment.
Igneous	a rock or mineral that solidified from molten or partially molten material i.e. from a magma.
Ignimbrite	deposits of a pyroclastic density current, or pyroclastic flow.
Imbricated fault zone	thrust faults that have *en echelon* arrangement in cross-section are described as imbricate.
Inclined heterolithic strata	strata possessing original depositional dips occur within lithologically heterogeneous units of subaqueous sedimentary sequences.
Inlier	an area of older rocks surrounded by younger rocks.
Interglacial	the time interval between glacial stages or pertaining to this time.
Isthmus	narrow strip of land adjoining two larger masses of land with water on each side.
Jasper	an impure variety of microcrystalline silica (chalcedony), often blood red coloured, but other colours occur.
Joint	a fracture in a rock, which shows no evidence of displacement.
Karst	general term used for landscapes formed by weathering of soluble rocks, usually limestone, by surface water and/or groundwater.
Kame	a mound or hill composed of sand and gravel deposited by meltwater derived from melting glaciers.
Kamenitza	solution pans/hollows on the surface (cm to metre diameter).
Kame-kettle	irregularly shaped hill or mound composed of sand, gravel and till that accumulates in a depression on a retreating glacier, is then deposited on land surface with further melting of glacier. Kames are often associated with kettles and referred to as *kame and kettle* topography.
Karren	water-worn features (e.g. kamenitza, flutes, runnels, clints, grikes) on `bedrock surface formed by dissolution.
Karst	landscape formed by dissolution of rock (typified by limestone landscapes).
Knoll	a small hill or hillock sticking up from generally flat terrain.
Lacustrine	associated with a lake(s).
Laminated	the finest example of stratification or bedding, typically exhibited by shales and fine-grained sandstones.
Lamprophyres	group of basic igneous rocks consisting of feldspathoids and ferromagnesian minerals (e.g. biotite) occurring as dykes and minor intrusions
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. Mostly formed by the accumulation of calcareous shells, cemented by calcium carbonate precipitated from solution.

Lithification — the process of rock formation from unconsolidated sediment.

Lithology — the description of rocks on the basis of such characteristics as colour, composition and grain size.

Machair — a sandy grassland habitat, characteristic of the exposed coasts of the western seaboard of Ireland and Scotland.

Mafic — igneous rock that is dominated by the silicates pyroxene, amphibole, olivine, and mica.

Marble — a non-foliated metamorphic rock composed of recrystallized carbonate minerals, most commonly limestone or dolomite.

Marl — lime-mud.

Marram — a keystone plant species of sand dunes, with many other species dependent on its presence to stabilise the dune ecosystem.

Mélange — a body of rock characterized by a lack of continuous bedding and the inclusion of fragments of rock of all sizes, contained in a fine-grained deformed matrix.

Melt-out — process by which glacial debris is very slowly released from ice that is not sliding or deforming internally; also describes tills emplaced by this process (i.e. melt-out till).

Mesoproterozoic — geological era that occurred from 1,600 to 1,000 Ma.

Metadolerite — dark-coloured fine-medium grained intrusive igneous rock, the equivalent of basalt, usually found in dykes or sills that has been metamorphosed (meta-igneous).

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.

Metasedimentary — sedimentary rocks that have been subjected to alteration by metamorphism.

Metasomatic/ metasomatism — a process of alteration of rocks by which their chemical composition is modified, new substances being introduced while those originally present are partly or wholly removed in solution.

Micaceous — rich in mica (shiny, flaky silicate minerals).

Migmatite — a heterogeneous silicate rock with properties of both igneous and metamorphic rocks.

Mollusc — an invertebrate of a large phylum including snails, slugs, mussels, and octopuses. Have a soft unsegmented body and live in aquatic or damp habitats, and most kinds have an external calcareous shell.

Moraine — any glacially formed accumulation of unconsolidated debris, in glaciated regions, such as during an ice age.

Mudstone — a very fine grained sedimentary rock, containing quartz and clay minerals. Similar to shale, but not as easily split along the plane of bedding.

Mushroom Stone — water-worn stones/boulders that have been undercut by water to form a narrow foot capped by a wider crown; shaped like a mushroom.

Mylonite — a metamorphic rock formed by ductile deformation during intense shearing encountered during folding and faulting.

Nautiloid — a mollusc of a group of mainly extinct marine molluscs which includes the pearly nautilus.

Neoproterozoic — a geological era dating from 1,000 to 541 Ma.

Olivine — a common mineral, olive-green, grey-green, or brown mineral occurring widely in basalt, peridotite, and other basic igneous rocks.

Ophiolitic — ophiolites are pieces of oceanic crust and lithosphere that have been thrust (obducted) onto continental crust.

Ore — a mineral which is concentrated enough to be exploited by mining.

Orogeny — the creation of a mountain belt as a result of tectonic activity.

Orthogneiss — a metamorphic rock that was originally an igneous rock (the protolith)

Ostracod — a class of the Crustacea, sometimes called seed shrimp.

Outcrop — part of a geologic formation or structure that appears at the surface of the Earth.

Palaeomagnetic analysis — the study of the record of the Earth's magnetic field in rocks.

Palaeoproterozoic — a geological era dating from 2,500 to 1,600 Ma.

Palaeocurrent — geological feature indicating the direction of flow of water when sediments were deposited.

Palaeosol — a layer of fossilised soil.

Paraglacial — landforms formed during and after the deglaciation in the course of the readjustment toward an environmental equilibrium stage.

Pegmatite — an intrusive igneous rock with very large (coarse) crystals.

Pelite — a metamorphosed fine-grained sedimentary rock.

Periglacial very cold but non-glacial climatic conditions.

Phreatic when a cave passage or void space in limestone rocks is filled with water it is said to be phreatic or in the phreas. When later found without water in them such passages have a characteristic cylindrical shape from solution in all directions and are called phreatic tubes.

Plate Tectonics a paradigm that states that the crust is divided up into a number of plates, whose pattern of horizontal movement is controlled by the interaction of these plates at their boundaries with one another.

Pleistocene geological epoch dating from 2.588 Ma to 11,700 years ago.

Phyllite fine-grained metamorphic rock formed by the reconstitution of fine-grained, parent sedimentary rocks, such as mudstones or shales.

Porphyry igneous rock containing feldspar crystals embedded in a fine-grained groundmass.

Psammite a term applied to metamorphic rocks derived from a sandstone (an arenaceous sedimentary) protolith. A quartzite, for example, is a quartz-dominated psammite.

Quartzite a hard, metamorphosed sandstone composed mostly of recrystallised quartz grains that are tightly interlocking. Quartzite is formed through heat and pressure usually related to tectonic compression.

Red-beds continental sedimentary rocks displaying a red-purple colour due to the presence of ferric oxides, such as the Old Red Sandstone

Rhyolite an igneous, volcanic (extrusive) rock of acidic composition. The mineral assemblage is usually quartz and alkali and plagioclase feldspars.

Roche moutonnées *"sheep's back"* – a term of French origin used for glacially erosional features and outcrops that were shaped by the passage of ice to give a smooth up-ice side and a rough, plucked and steeper surface on the down-ice side.

Sand spit a linear coastal sedimentation feature where sand accumulates in a spit across a bay or along a coast.

Sandur a plain formed of glacial sediments deposited by meltwater outwash at the terminus of a glacier.

Sandstone a fine to coarse sedimentary rock, deposited by water or wind, and composed of fragments of sand (quartz grains), cemented together by quartz or other minerals.

Schist a medium to coarse grained rock, formed by the metamorphism of a sedimentary mudstone by heat and pressure. The minerals are aligned in parallel layers.

Sea-stack an erosional landform occurring on the coast; a vertical column of rock becomes isolated from the adjacent coastline.

Sedimentary a rock formed by the deposition of sediment or pertaining to the process of sedimentation.

Serpentinite metamorphic rocks composed of one or more serpentine group minerals; formed by hydrothermal metamorphism; common in ophiolite sequences, representing oceanic crust and lithosphere obducted during orogeny.

Shaft a vertical hole dug in a mine for access, ventilation, for hauling ore out or for pumping water out.

Shale a very fine-grained mudstone, containing quartz and clay minerals, that splits easily along the plane of bedding.

Sillimanite an aluminium silicate, (Al_2SiO_5) occurring in high temperature, aluminium-rich metamorphic rocks. Colourless, white, yellow, brown, green, grey.

Siltstone is similar to mudstone but with a predominance of silt-sized (slightly coarser) particles.

Sink another name for a swallow hole, the point where a stream passes underground.

Slate is a fine-grained metamorphic rock produced from a sedimentary mudstone by pressure, imposing a cleavage along which the slate easily splits.

Slickenslide a polished, striated rock surface caused by one rock mass sliding over another, usually along a fault plane.

Slumping the movement of a mass of unconsolidated sediment or rock layers down a slope, or pertaining to contorted sedimentary bedding features.

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.

Striae/Striations scratches on the surface of rock caused by abrasion due to the movement of glaciers passed/over the rock

Strike direction of the line formed by the intersection of a rock surface with a horizontal plane.

Stromatoporoid reef building organisms, related to sponges

Sub-aerial refers to processes occurring above ground level, such as the weathering of rocks.

Subduction (zone) the sinking of one crustal plate beneath the edge of another through the process of plate tectonics.

Sub-glacial bedform	term used for a range of longitudinal and transverse landforms formed at the base of an ice sheet as a result of ice movement across a sediment base.
Subsidence (zone)	the sudden sinking or gradual downward settling of the Earth's surface with little or no horizontal movement.
Supergroup	a geological unit comprising two or more groups (a group comprises two or more formations).
Supratidal	above high tide.
Swallow hole	the point where a stream passes underground, sinking below the ground surface.
Syncline	a structural geological term meaning a downfold of sedimentary strata in a linear trough shape.
Tarn	corrie lake.
Terrestrial	pertaining to the Earth's dry land.
Till	unconsolidated, unsorted glacial deposits consisting of boulders and cobbles mixed with very finely ground-up rock as sand, silt or clay also known as boulder clay.
Tillite	a sedimentary rock composed of consolidated glacial till.
Tonalite	a granular intermediate igneous rock consisting of quartz, plagioclase feldspar, mafic minerals, and small amounts of orthoclase
Trace fossil	non-body remains indicating the activity or behaviour of an organism; *Ichnofossil.*
Transgression	an incursion of the sea over land area.
Transpression	the occurrence of strike-slip shearing (faulting) and simultaneous compression in the Earth's crust.
Trilobites	extinct arthropods.
Tuff	rock formed from pyroclastic volcanic ash material usually composed of silt-sized to sand-sized particles.
Tuff(aceous)	consolidated rock formed from the ash ejected from a volcano.
Turbidite	deposit of a turbidity current.
Turbidity Current	underwater density current carrying suspended sediment at high speed down a subaqueous slope. The resulting deposit is called a turbidite.
Ultramafic	igneous rock with a very low silica content and rich in minerals such as hypersthene, augite, and olivine.
Unconformable	a sedimentary rock that is not following in sequence from the one below but has a significant time gap present between them.
Unconformity	a buried erosion surface separating two rock masses or strata of different ages, indicating that sediment deposition was not continuous.
Vauclusian spring	a spring where water ascends up a steeply inclined, water-filled passage into a small surface pool.
Vein quartz	white thin veins of quartz injected in rock fractures during episodes of stress. Also found as durable beach pebbles, once it has been eroded.
Viséan	the second oldest stage in the Carboniferous, after the Tournaisian.
Volcanic Arc	a linear belt of volcanoes formed on the overlying plate at a subduction zone, resulting from subduction of the underlying plate.
Volcanic Ash	very fine rock and mineral particles ejected from an erupting volcano.
Volcanic Rock	any rock produced from volcanic material, e.g. ash, lava.
Volcanism	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.
Volcano	a vent in the surface of the Earth through which magma and associated gasses and ash erupt.
Volcanogenic	created by a volcano; of volcanic origin.

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 Mayo. 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 Section in Geological Survey 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 a few low-resolution photographs exemplifying the site. Grid references are given for a central point in the site generated from the GIS mapping (Shapefile) of the site boundary. They are only indicative of the location, but the site extent is best shown on the included maps.

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 coordinate 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/

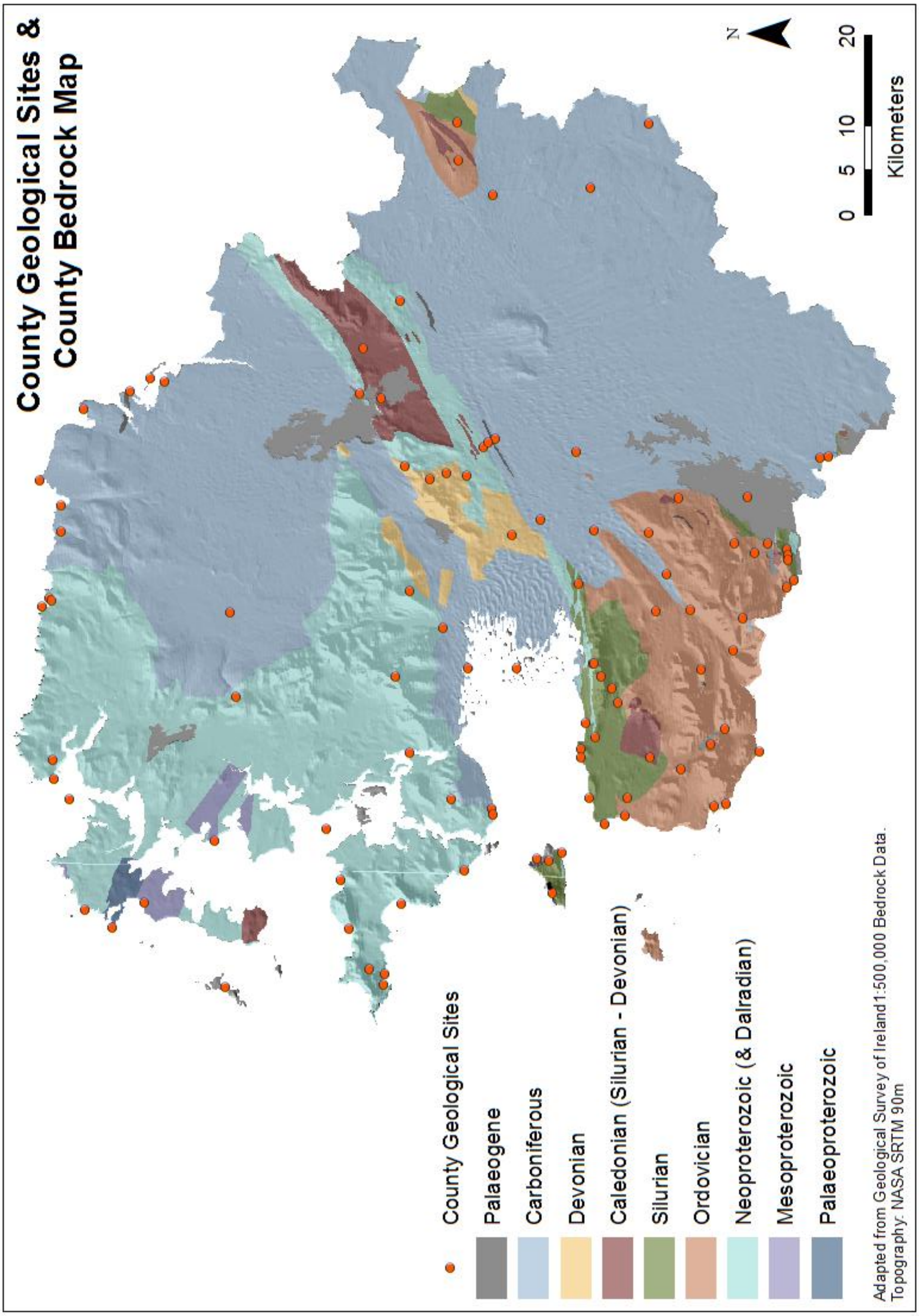
A series of maps are provided with an outline of the site boundary. It is important to note that these boundaries have no legal or definitive basis. They are indicative only of the limits of exposure or of geological interest, and not based on detailed field and boundary surveys, which were outside the scope of this contract. Boundaries are drawn to include the geological or geomorphological interest of the site, but are 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 assessed for NHA status in the future, such a boundary may require small revisions.

For sites that have been proposed or will be proposed for NHA designation detailed site boundary maps will become available to the Local Authority, through NPWS as 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 the wider area of nature conservation.

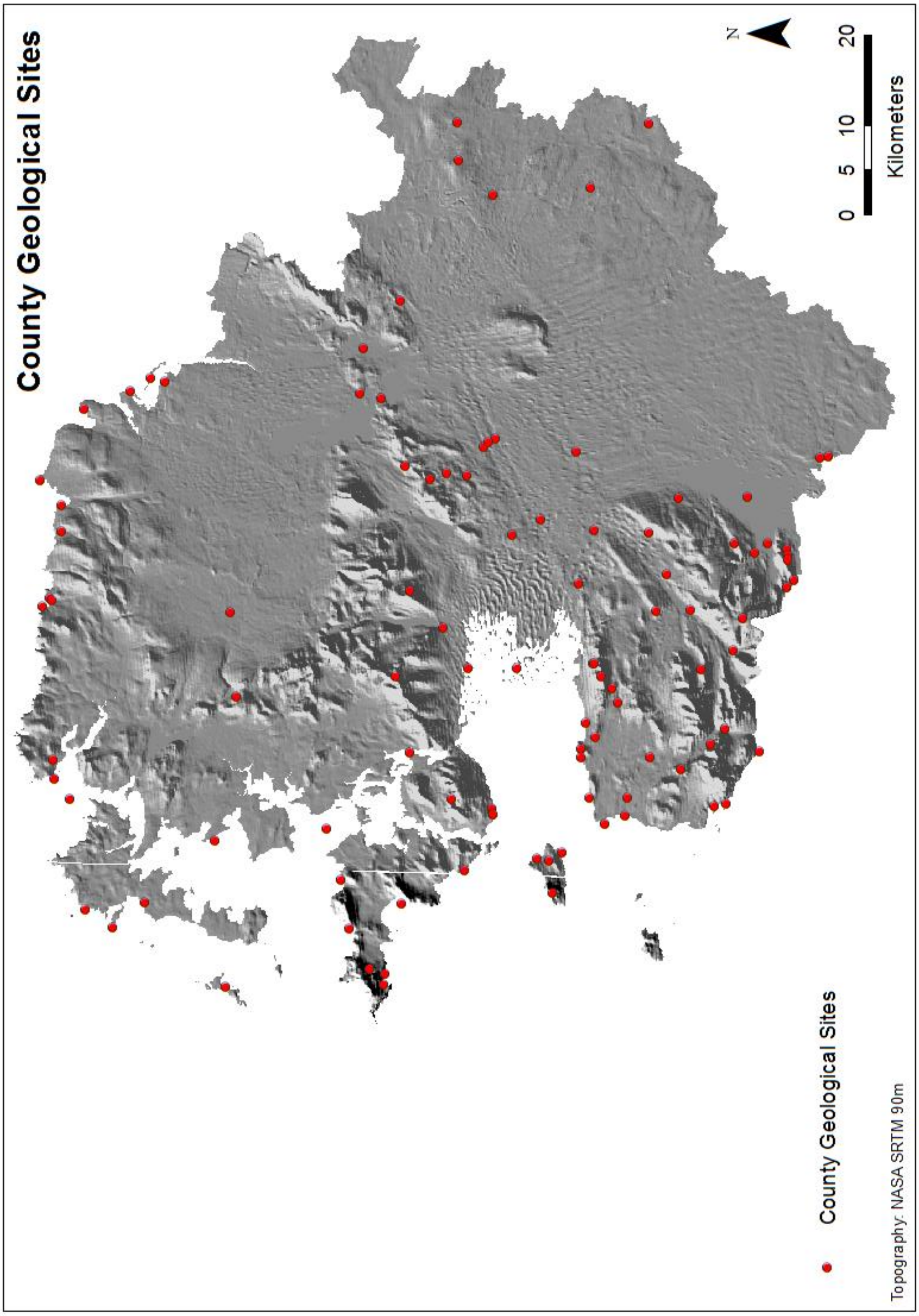
In terms of any geological heritage site designation as NHA, due process of site reporting, boundary survey and very importantly, consultation with landowners where they can be readily identified, will take place before Geological Survey Ireland finalises recommendations to NPWS on the most important 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 the Geoheritage Programme in Geological Survey Ireland, Beggars Bush, Haddington Road, Dublin D04 K7X4.

Telephone: 01-6782837
Web Contact: Geological Survey Ireland Geoheritage Programme

Site Reports – Geological Map and Site Locations



Simplified Geological Map of County Mayo with site locations indicated.



County Geological Sites in County Mayo