Rialtas na hÉireann
Government of Ireland

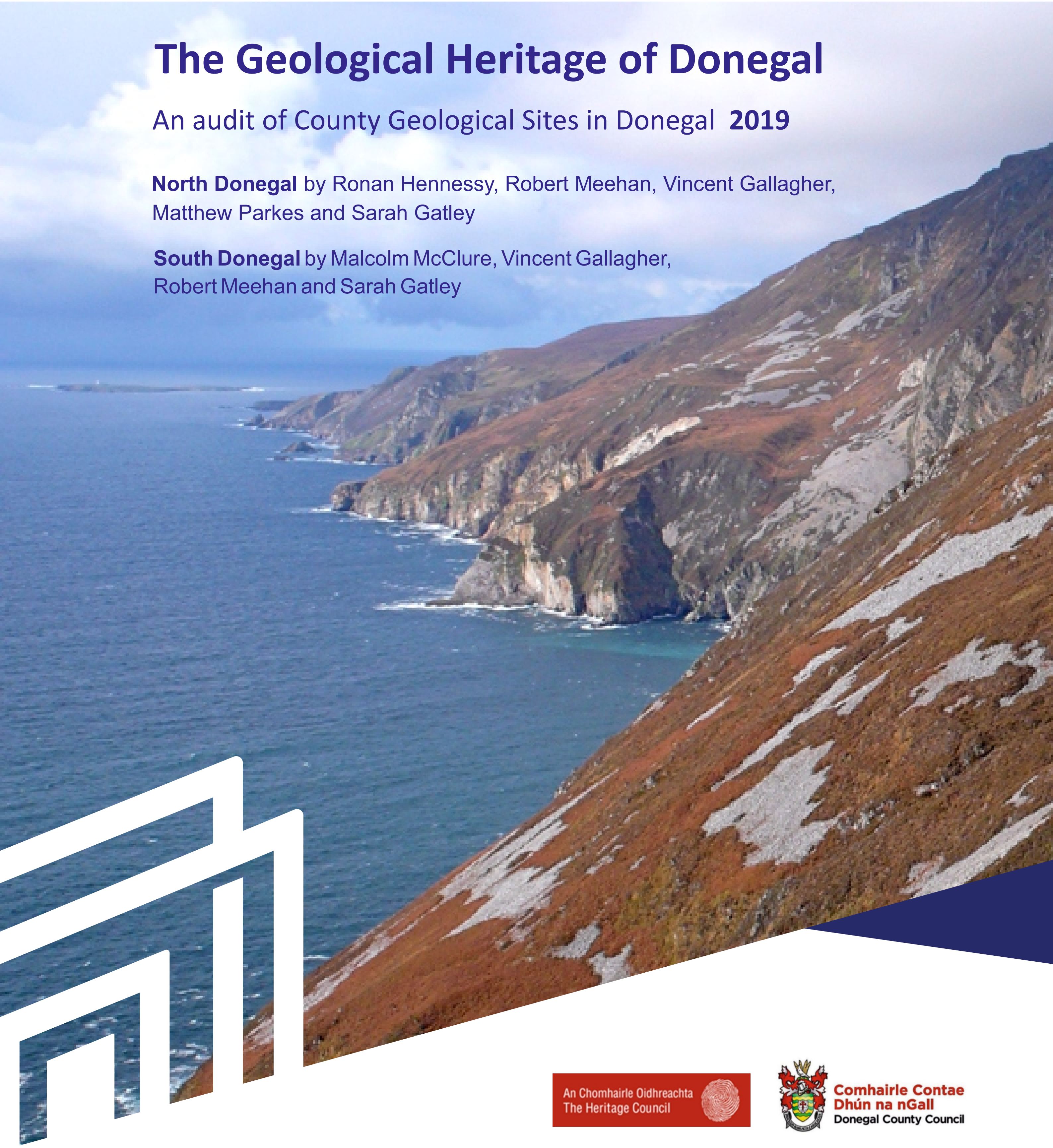
Geological Survey
Suirbhéireacht Gheolaíochta
Ireland | Éireann

The Geological Heritage of Donegal

An audit of County Geological Sites in Donegal **2019**

North Donegal by Ronan Hennessy, Robert Meehan, Vincent Gallagher, Matthew Parkes and Sarah Gatley

South Donegal by Malcolm McClure, Vincent Gallagher, Robert Meehan and Sarah Gatley



An Chomhairle Oidhreachta
The Heritage Council

Comhairle Contae
Dhún na nGall
Donegal County Council

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

The Geological Heritage of County Donegal

An audit of County Geological and Geomorphological Sites in north Donegal

by Ronan Hennessy, Robert Meehan, Vincent Gallagher, Matthew Parkes and Sarah Gatley

2019

and

A compilation of

An audit of County Geological Sites in south Donegal

By Malcolm McClure, Vincent Gallagher, Robert Meehan and Sarah Gatley

2019

DRAFT

The north and south Donegal Geological Heritage Projects were supported by

An Chomhairle Oidhreachta
The Heritage Council

Geological Survey
Suirbhéireacht Gheolaíochta
Ireland | Éireann

Comhairle Contae
Dhún na nGall
Donegal County Council

This report is an action of the
County Donegal Heritage Plan 2007 – 2013

For the:
Geoheritage Programme
Geological Survey Ireland
Beggars Bush
Haddington Road
Dublin
D04 K7X4
01-6782837

And the:
County Donegal Heritage Office
Heritage Officer
Donegal County Council
Station Island
Lifford
County Donegal

DRAFT

Contents

Section 1 – Main Report

Contents 3
Report Summary 9
Donegal in the context of Irish Geological Heritage 10
North Donegal County Geological Sites 12
South Donegal County Geological Sites 14
Geological conservation issues and site management 16
Proposals and ideas for promotion of geological heritage in Donegal 21
A Summary of the Geology of Donegal 29
Quaternary Geology County Donegal 36
Geological heritage versus geological hazards 41
Glossary of geological terms 43
Data sources on the geology of Donegal 50
Shortlist of Key Geological References 57
Further sources of information and contacts 59
Acknowledgements 59
Appendix 1. Geological heritage audits and the planning process 60
Appendix 2. Bibliography – Bedrock Geology 63
Appendix 3. Bibliography – Quaternary Geology and Geomorphology 85
Appendix 4. Rejected sites and Renamed Sites 97
Appendix 5. History of Geological and Geomorphological research in Donegal 104
Appendix 6. Geoschol leaflet on the geology of Donegal 108
Site Reports – general points 112
Site Reports – Location Map North Donegal 114
Site Reports – Location Map South Donegal Audit 115

Section 2 – Site Reports

North Donegal Audit

IGH 1 Karst

Site Name

Not represented in north Donegal

IGH 2 Precambrian to Devonian Palaeontology

Site Name

Not represented in north Donegal

IGH 3 Carboniferous to Pliocene Palaeontology

Site name

Not represented in north Donegal

IGH 4 Cambrian-Silurian

Site name

Not represented in north Donegal

IGH 5 Precambrian
Site name
Ardsbeg (An Ardaidh Bheag)
Ards Friary
Ballyness Bay (Bá Bhaile an Easa) [see IGH13]
Croaghan Hill
Doagh Isle
Dunfanaghy
Dunlewy Quarry (Cairéal Dhún Lúiche)
Fahan Pier, Inishowen
Glinsk
Horn Head Slide
Inishtrahull
Lackagh Bridge
Lagh Hill
Moville to Greencastle
Muckish Mountain (An Mhucais) [see IGH7; IGH15]
Pollnalong (Poll na Long)
Rosepenna (Machaire Loiscthe)
Tremone Bay

IGH 7 Quaternary
Site Name
Altawinny Bay (Ailt an Bhuinne)
Altnapeaste (Ailt na Péiste)
Ballycramsey
Burnfoot Spread
Carndonagh Fan
Corvish
Errigal (An Earagail)
Gweedore Moraines (Moiréin Ghaoth Dobhair)
Malin Flat
Muckish Mountain (An Mhucais) [see IGH5; IGH15]
The Poisoned Glen (Cró Nimhe) [see IGH11]
The Rosses (Na Rosa) [see IGH14]
Tory Island (Toraigh) [see IGH13]

IGH 8 Lower Carboniferous
Site Name
Not represented in north Donegal

IGH 9 Upper Carboniferous and Permian
Site Name
Not represented in north Donegal

DRAFT

IGH 10 Devonian

Site Name

Ballymastocker
Knockalla

IGH 11 Igneous intrusions

Site Name

Barnes Beg Gap (An Bearnas Beag)
Malin Head
Melmore Migmatite (Miogmaitít an Mhill Mhóir)
Mullaghderg (Mullach Dearg)
Rough Point Sill
The Poisoned Glen (Cró Nimhe) [see IGH7]

IGH 13 Coastal Geomorphology

Site Name

Ballymastocker Bay
Ballyness Bay (Bá Bhaile an Easa) [see IGH5]
Dunagree Point
Five Finger Strand
Inishfree Bay (Trá Inis Fraoigh)
Inishowen Head
Kinnagoe Bay
Lough Swilly (Loch Súilí)
Mulroy Bay (An Mhaoil Rua)
Pollet Great Arch (Stua Mór Phollaide)
Quigley's Point (Lough Foyle)
Sheep Haven (Cuan na gCaorach)
Tory Island (Toraigh) (see IGH7]
Trawbreaga Bay

IGH 14 Fluvial and lacustrine geomorphology

Site Name

Lough Keel
Owenator River (Abhainn an Toir)
The Rosses (Na Rosa) [see IGH7]

IGH 15 Economic Geology

Site Name

Carrowtrasna
Glentogher Mine
Muckish Mountain (An Mhucais)[see IGH5; IGH7]
Quigley's Point (Cabry River)

IGH 16 Hydrogeology

DRAFT

Site Name
Carndonagh Well Field

South Donegal Audit

IGH 1 Karst
Site Name
Pollnapaste Caves
The Pullauns
St. John's Peninsula

IGH 2 Precambrian to Devonian Palaeontology
Site Name
Not represented in south Donegal

IGH 3 Carboniferous to Pliocene Palaeontology
Site name
Bundoran Bay
Largymore Syncline (Cuaschlaonas na Leargadh Móire)
St. John's Point

IGH 4 Cambrian-Silurian *Not represented in south Donegal*
IGH 5 Precambrian
Site name
Breesy Hill
Kiltyfanned Lough (Loch Choillte Feannaid)
Lough Boyle
Lough Lareen
Malin Bay (Bá Mhálanna)
Oughtarnid
Skelpoonagh Bay (Sceilp Úna)
Stralinchy (Srath Loingsigh)

IGH 6 Mineralogy
Site Name
Columbkille Lough
Crohy Head
Sheskinarone Site 2 (Seascann an Róin - Suíomh 2)
Skelpoonagh Bay (Sceilp Úna) [see IGH5]

IGH 7 Quaternary
Site Name
Barnesmore Gap
Donegal and Inver Bays (Bánna Dhún na nGall agus Inbhir)
Lough Finn (Loch Finne)

DRAFT

Trabane (An Trá Bhán)
St. John's Peninsula [see IGH1, IGH8, IGH13]
Slieve League Cliffs (Aillte Shliabh Liag)

IGH 8 Lower Carboniferous
Site Name
Ballyshannon
Bundoran Bay [see IGH3, IGH13]
Clady River
Edergole
Kildoney Point
Laghy Quarries
Largymore Syncline (Cuaschlaonas na Leargadh Móire) [see IGH3]
Mountcharles Sandstone Mine
Muckros Head (Cionn Mhucrois)
Slieve League Carboniferous (Sliabh Liag Carbónmhar)
St. John's Peninsula [see IGH1, IGH7, IGH13]
St. John's Point [see IGH3, IGH12]

IGH 9 Upper Carboniferous and Permian *Not represented in south Donegal*

IGH 10 Devonian *Not represented in south Donegal*

IGH 11 Igneous intrusions
Site Name
Barnesmore Granite
Brockagh (Na Brocacha)
Clooney
Doorin Point
Dunmore Head Breccia Pipe
Kilkenny Breccia Pipe
Kilrean Appinite
Naran Hill
Parkmore Dyke

IGH 12 Mesozoic and Cenozoic
Site Name
St. John's Point [see IGH3, IGH8]

IGH 13 Coastal Geomorphology
Site Name
Bundoran Bay [see IGH3, IGH8]
Doorin Point [see IGH11]
Fairies Bridge
Loughros More Bay

DRAFT

Maghera Strand (Trá an Mhachaire)
Rathlin O'Birne Island (Reachlainn Uí Bhirn)
Slieve League Cliffs (Aillte Shliabh Liag) [see IGH 7]
Slieve Tooey Coast (Cósta Shliabh Tuaidh)
Trabane (An Trá Bhán) [see IGH7]
St John's Peninsula [see IGH1, IGH7, IGH8]

IGH 14 Fluvial and lacustrine geomorphology
Site Name
River Finn Meanders (Lúba na Finne)

IGH 15 Economic Geology
Site Name
Crohy Head (Ceann na Cruaiche) [see IGH6]
Glenaboghil (Gleann na mBuachaill)
Mountcharles Sandstone Mine [see IGH8]
Sheskinarone Site 2 (Seascann an Róin - Suíomh 2) [see IGH6]

IGH 16 Hydrogeology *Not represented in south Donegal*

DRAFT

Report Summary

This document is the combination of two independent county geological audits carried out within County Donegal. Due to the size of County Donegal and the number of sites to be audited it was decided to split the county geographically in to north and south for logistical reasons. The first audit was undertaken in south Donegal and was largely concluded in 2014. The second audit was undertaken in north Donegal and was largely concluded in 2018. The two audits were completed by different audit teams and authors. This document tries to be honest to both audit teams and sets of authors and for that reasons retains the structure of north and south to allow the individual audits to be presented with transparency under this single cover.

Donegal has some of the most dramatic landscape in Ireland. The coastal and mountainous landscape of the Donegal region owes its scenic diversity to the region's bedrock geology, its coastal and glacial geomorphology, and the surface cover of peat and soil. The bedrock foundation has undergone a long history of mountain-building, igneous intrusion and sediment deposition that, together with the more recent geomorphological processes such as glacial scouring and coastal erosion, has created wonderful geological diversity or geodiversity. North Donegal bedrock hosts the oldest rocks in Ireland (almost 1.8 billion years old), while in south Donegal, some of it dates back more than 700 million years. Geological understanding and interpretation is best carried out on the ground at sites where the rocks and landforms are displayed. Donegal has a wealth of such natural and man-made sites, from spectacular coastal scenery, to remarkable glacial valleys, to historical mining locations.

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 Donegal. It proposes them as County Geological Sites (CGS), for inclusion within the Donegal 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 (NHA) but receive an effective protection from their inclusion in the planning system. However, some 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 the Geological Survey Ireland for designation as NHAs (Natural Heritage Areas), after due survey and consultation with landowners. However, many of these sites fall within existing pNHAs and SACs where the ecological interest is founded upon the underlying geodiversity. The commission of these audits and adoption of the sites within the County Development Plan ensure that County Donegal follows a now established and effective methodology for ensuring that geological heritage is not overlooked in the general absence of allocated resources for progress at national level. It ensures that Donegal 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 Donegal County Council. It will also be made available via the County Council website for the people of Donegal. A chapter of the report includes recommendations on how to best present and promote the geological

DRAFT

heritage of Donegal to the people of the county. It will also inform the work of the IGH Programme and be made available through Geological Survey Ireland's 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 also provide the essential ingredients for a public-oriented book on the geological heritage of Donegal, if funding can be sourced to produce it.

Donegal in the context of Irish Geological Heritage

This report ensures Donegal remains active at the forefront of geological heritage within Ireland, as it is one of around half of the counties to date to commission such an audit within the scope of the county-based Heritage Plan. It will hopefully encourage the remaining local authorities to follow what is now a tried and trusted methodology. In the absence of significant political and economic resources available at a national level to the relevant bodies for conservation of geological heritage as Natural Heritage Areas (NHA), it represents a significant level of progress in defining and safeguarding Ireland's geological heritage.

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

The Irish Geological Heritage Programme (IGH) in Geological Survey 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 NHAs 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 existed since the abandonment of the Areas of Scientific Interest scheme, listed by An Foras 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 entire spectrum within Irish geology and geomorphology under 16 different themes:

DRAFT

IGH Themes	
1	Karst
2	Precambrian to Devonian Palaeontology
3	Carboniferous to Pliocene Palaeontology
4	Cambrian-Silurian
5	Precambrian
6	Mineralogy
7	Quaternary
8	Lower Carboniferous
9	Upper Carboniferous and Permian
10	Devonian
11	Igneous intrusions
12	Mesozoic and Cenozoic
13	Coastal geomorphology
14	Fluvial and lacustrine geomorphology
15	Economic geology
16	Hydrogeology

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

Designation of geological NHAs will be by the Geological Survey Ireland's partners in the Programme, the National Parks and Wildlife Service (NPWS). Once designated, any geological NHAs will be subject to normal statutory process within the Donegal Planning Department and other relevant divisions. **However, compared to many ecological sites, management issues for geological sites are generally fewer and somewhat different in nature. The subsequent section considers these issues**.

From a national perspective, 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.

Currently, a Master List of candidate CGS and NHA sites has been established in Geological Survey Ireland with the help of Expert Panels for all the 16 IGH themes. For several themes, the entire process has been largely completed and detailed site reports and boundary surveys have been done along with a Theme Report. Due to various factors, they have not been formally designated yet, but a number of sites (*e.g*. Pollnapaste and Stralinchy) are considered to be of national or even international importance and have been put forward as Natural Heritage Areas (NHA). Therefore, inclusion of all sites as County Geological Sites (CGS) in Donegal'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.

DRAFT

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

It was not possible within the scope of this study to identify landowners except in a few sites but it is emphasised that 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.

North Donegal County Geological Sites

Site Name	Designation	IGH Primary	IGH Secondary	IGH Third	IGH Fourth	GIS Code
Altawinny Bay (Ailt an Bhuinne)	CGS	IGH7				ND001
Altnapeaste (Ailt na Péiste)	CGS	IGH7				ND002
Ards Friary	CGS	IGH5				ND003
Ardsbeg (An Ardaidh Bheag)	CGS	IGH5				ND004
Ballycramsey	CGS, may be recommended for NHA	IGH7				ND005
Ballymastocker	CGS	IGH10				ND006
Ballymastocker Bay	CGS, recommended for NHA	IGH13	IGH10			ND007
Ballyness Bay (Bá Bhaile an Easa)	CGS, recommended for NHA	IGH5	IGH13			ND008
Barnes Beg Gap (An Bearnas Beag)	CGS, may be recommended for NHA	IGH11				ND009
Burnfoot Spread	CGS	IGH7				ND010
Carndonagh (Well Field)	CGS	IGH7				ND011
Carndonagh Fan	CGS	IGH7				ND012
Carrowtrasna	CGS	IGH15				ND013
Corvish	CGS, recommended for NHA	IGH7				ND014
Croaghan Hill	CGS, recommended for NHA	IGH5				ND015
Doagh Isle	CGS, recommended for NHA	IGH5				ND016
Dunagree Point	CGS	IGH13				ND017
Dunfanaghy	CGS	IGH5				ND018
Dunlewy Quarry (Cairéal Dhún Lúiche)	CGS	IGH5	IGH11			ND019
Errigal (An Earagail)	CGS, recommended for NHA	IGH14				ND020

DRAFT

Fahan Pier	CGS	IGH5				ND021
Five Finger Strand	CGS, recommended for NHA	IGH13				ND022
Glentogher Mine	CGS	IGH15				ND023
Glinsk	CGS, may be recommended for NHA	IGH5				ND024
Gweedore Moraines (Moiréin Ghaoth Dobhair)	CGS	IGH7				ND025
Horn Head Slide	CGS, may be recommended for NHA	IGH5				ND026
Inishfree Bay (Trá Inis Fraoigh)	CGS	IGH13				ND027
Inishowen Head	CGS	IGH13				ND028
Inishtrahull	CGS, may be recommended for NHA	IGH5				ND029
Kinnagoe Bay	CGS, recommended for NHA	IGH13				ND030
Knockalla	CGS	IGH10				ND031
Lackagh Bridge	CGS, may be recommended for NHA	IGH5	IGH11			ND032
Lagh Hill	CGS	IGH5				ND033
Lough Keel Fan (Fean Loch Caol)	CGS	IGH14				ND034
Lough Swilly (Loch Súilí)	CGS	IGH13				ND035
Malin Flat	CGS	IGH7				ND036
Malin Head	CGS, recommended for NHA	IGH13	IGH7			ND037
Melmore Migmatite (Miogmaitít an Mhill Mhóir)	CGS	IGH11				ND038
Moville to Greencastle	CGS, recommended for NHA	IGH5				ND039
Muckish Mountain (An Mhucais)	CGS, may be recommended for NHA	IGH15				ND040
Mullaghderg (Mullach Dearg)	CGS, recommended for NHA	IGH11				ND041
Mulroy Bay (An Mhaoil Rua)	CGS, recommended for NHA	IGH7	IGH13			ND042
Owenator River (Abhainn an Toir)	CGS	IGH14				ND043
Poisoned Glen (Cró Nimhe)	CGS, recommended for NHA	IGH14				ND044
Pollet Great Arch (Stua Mór Phollaide)	CGS	IGH13				ND045
Pollnalong (Poll na Long)	CGS	IGH5				ND046
Quigley's Point (Cabry River)	CGS, may be recommended for NHA	IGH15				ND047
Quigley's Point (Lough Foyle)	CGS	IGH13				ND048
Rosepenna (Machaire Loiscthe)	CGS	IGH5				ND049

DRAFT

Rough Point Sill	CGS	IGH11				ND050
Sheep Haven (Cuan na gCaorach)	CGS, recommended for NHA	IGH13				ND051
The Rosses (Na Rosa)	CGS	IGH14				ND052
Tory Island (Toraigh)	CGS	IGH13				ND053
Trawbreaga Bay	CGS	IGH13				ND054
Tremone Bay	CGS, recommended for NHA	IGH5				ND055

South Donegal County Geological Sites

Site Name	Designation	IGH Primary	IGH Secondary	IGH Third	IGH Fourth	GIS Code
Ballyshannon	CGS; may be recommended as Geological NHA	IGH 8				DL001
Barnesmore Gap	CGS; recommended as Geological NHA	IGH 7				DL002
Barnesmore Granite	CGS	IGH 11				DL003
Breesy Hill	CGS; may be recommended as Geological NHA	IGH 5				DL004
Brockagh (Na Brocacha)	CGS	IGH 11				DL005
Bundoran Bay	CGS; recommended as Geological NHA	IGH 3	IGH 8	IGH 13		DL006
Clady River	CGS	IGH 8				DL007
Clooney	CGS	IGH 11				DL008
Columbkille Lough	CGS	IGH 6				DL009
Crohy Head (Ceann na Cruaiche)	CGS	IGH 15	IGH 6	IGH 13		DL010
Donegal and Inver Bays (Bánna Dhún na nGall agus Inbhir)	CGS; may be recommended as Geological NHA	IGH 7	IGH 13			DL011
Doorin Point	CGS	IGH 13	IGH 11			DL012
Dunmore Head Breccia Pipe	CGS	IGH 11				DL013
Edergole	CGS; may be recommended as Geological NHA	IGH 8				DL014
Fairies Bridge	CGS	IGH 13				DL015
Glenaboghil (Gleann na mBuachaill)	CGS	IGH 15				DL016
Kildoney Point	CGS	IGH 8				DL017
Kilkenny Breccia Pipe	CGS	IGH 11				DL018
Kilrean Appinite	CGS; recommended as Geological NHA	IGH 11				DL019
Kiltyfanned Lough (Loch Choillte Feannaid)	CGS; recommended as Geological NHA	IGH 5				DL020
Laghy Quarries	CGS	IGH 8				DL021

DRAFT

Largymore Syncline (Cuaschlaonas na Leargadh Móire)	CGS; may be recommended as Geological NHA	IGH 3	IGH 8			DL022
Lough Boyle	CGS	IGH 5				DL023
Lough Finn (Loch Finne)	CGS	IGH 7				DL024
Lough Lareen	CGS; may be recommended as Geological NHA	IGH 5				DL025
Loughros More Bay	CGS	IGH 13				DL026
Maghera Strand (Trá an Mhachaire)	CGS	IGH 13				DL027
Malin Bay (Bá Mhálanna)	CGS; recommended as Geological NHA	IGH 5				DL028
Mountcharles Sandstone Mine	CGS	IGH 15	IGH 8			DL029
Muckros Head (Cionn Mhucrois)	CGS	IGH 8	IGH 13			DL030
Naran Hill	CGS	IGH 11				DL031
Oughtarnid	CGS	IGH 5				DL032
Parkmore Dyke	CGS	IGH 11				DL033
Pollnapaste	CGS; recommended as Geological NHA	IGH 1				DL034
Rathlin O'Birne Island (Reachlainn Uí Bhirn)	CGS	IGH 13				DL035
River Finn Meanders (Lúba na Finne)	CGS	IGH 14				DL036
Sheskinarone Site 1 (Seascann an Róin - Suíomh 1)	CGS	IGH 6				DL037
Sheskinarone Site 2 (Seascann an Róin - Suíomh 2)	CGS; may be recommended as Geological NHA	IGH 6	IGH 15	IGH 11		DL038
Skelpoonagh Bay (Sceilp Úna)	CGS; may be recommended as Geological NHA	IGH 5	IGH 6			DL039
Slieve League Carboniferous (Sliabh Liag Carbónmhar)	CGS	IGH 8				DL040
Slieve League Cliffs (Aillte Shliabh Liag)	CGS; may be recommended as Geological NHA	IGH 13	IGH 7			DL041
Slieve Tooey Coast (Cósta Shliabh Tuaidh)	CGS	IGH 13				DL042
St John's Peninsula	CGS; may be recommended as Geological NHA	IGH 13	IGH 1	IGH 7	IGH 8	DL043
St John's Point	CGS; recommended as Geological NHA	IGH 3	IGH 8	IGH 12		DL044
Stralinchy	CGS; may be recommended as Geological NHA	IGH 5				DL045

DRAFT

The Pullauns	CGS; recommended as Geological NHA	IGH 1				DL046
Trabane (An Trá Bhán)	CGS	IGH 7	IGH 13			DL047

Geological conservation issues and site management

Since **geodiversity is the often forgotten foundation for much of the biodiversity** which has been identified for conservation through SAC or NHA designation, it is unsurprising that many of the most important geological sites are actually in the same areas as SAC and NHA sites. In these areas, the geological heritage 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 types of site identified by the Geoheritage 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. They typically have a feature or features of specific interest such as fossils or minerals or they are a representative section of a particular stratigraphical sequence of rocks. **The second type of site is a larger area of geomorphological interest, i.e. a landscape that incorporates features that illustrate the processes that formed it**. The Quaternary theme includes such sites. In south Donegal, aerially scoured valleys and subglacial bedforms such as drumlins, and in north Donegal rock glaciers, glaciofluvial meltwater channels, and morainesare characteristic of the larger sites encompassed under the IGH 7 Quaternary Theme. Extensive areas of Donegal’s landscape were affected by glaciation, which can present a problem for geoheritage as, although unique and impressive, they can be too extensive to consider as ‘sites’.

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 Donegal. A lack of awareness in the past, has led to the loss of important geological sites and local character, throughout the country. A Draft Landscape Characterization Assessment (including a Seascape Character Assessment and a Settlement Character Assessment) was carried out in 2015. Such an assessment should provide a tool to help future planning decisions maintain the character of the county. The Strategic Environmental Assessment Statement of the Donegal County Development Plan (2012-2018) also includes the mapping of environmental vulnerabilities, including SAC, NHA and CGS sites, in order to identify areas of the county most sensitive to development. 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 comparison to biological sites. Geological features are typically quite robust and generally few restrictions are required in order to protect the scientific interest. In some cases, paradoxically, the geological interest may even be served better by a development exposing more rock. **The important thing is that the relevant planning department is aware of the sites and, more generally, that consultation can take place if**

DRAFT

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

In many counties, working quarries may have been listed because they are the best representative sections available of specific rock sequences, in areas where exposure is otherwise poor. No restriction is sought on the legitimate operation of these quarries. However, maintenance of exposure after quarry closure is generally sought in agreement with the operator and planning authority in such a case. At present, two working quarries in south Donegal and two in north Donegal contain features that are now included as County Geological Sites. Issues specific to these types of sites are briefly explored in a set of Geological Heritage Guidelines for the Extractive Industry, published jointly by the Geological Survey Ireland and the Irish Concrete Federation in 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 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.

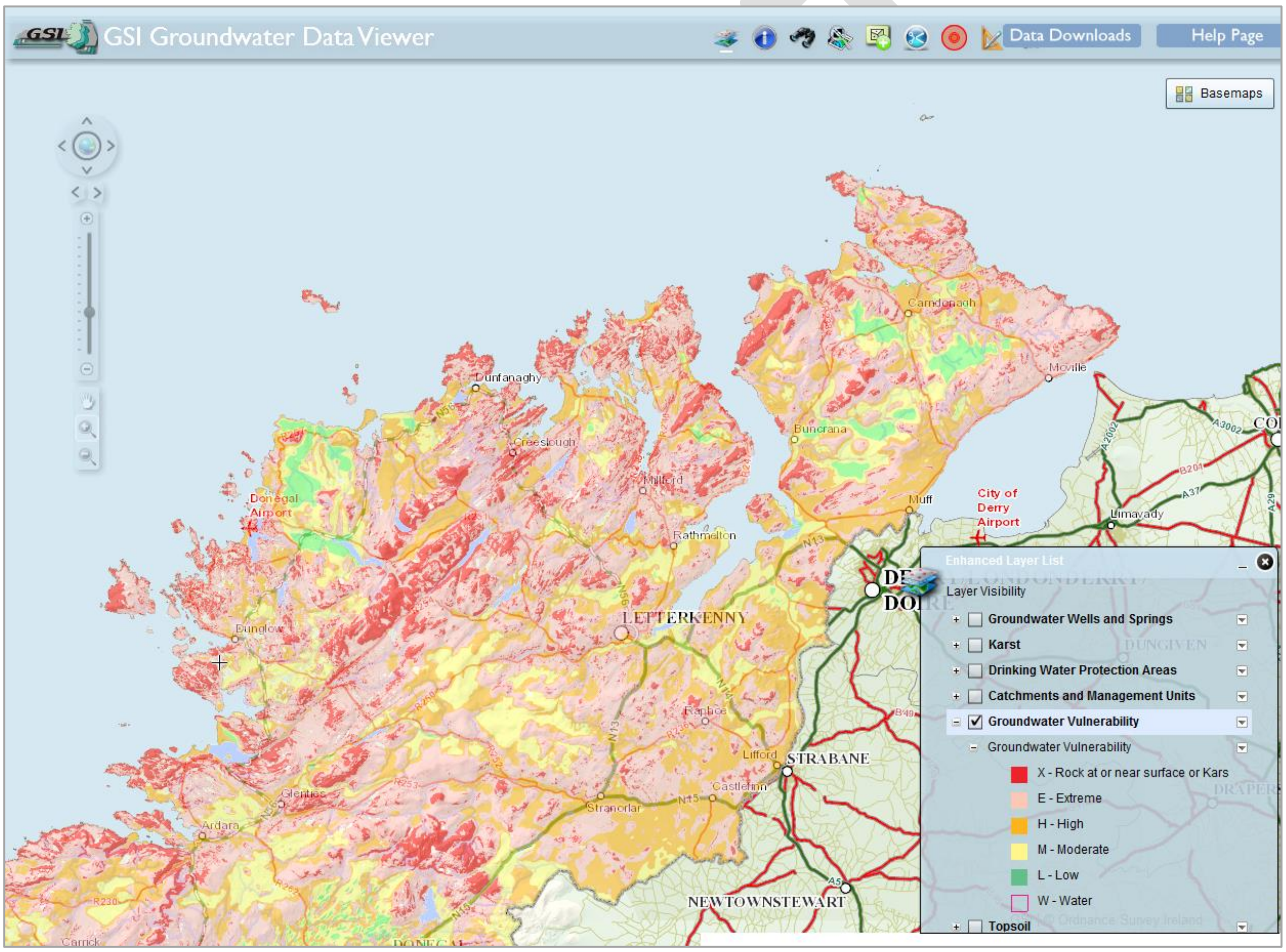
Nationally, specific sites may require restrictions and a typical case might be at an important fossil locality, a rare mineral locality or an important glaciofluvial deposit, where a permit system may be required for genuine research, but the opportunity for general collecting may need to be controlled. Several of Donegal's sites may require such an approach, notably the Sheskinarone beryl site and several nationally important fossil localities in south Donegal. Visitors should be reminded to take home photos, not specimens.

The only interpretive centre for geology and geomorphology is in south Donegal at the Kilclooney Dolmen Centre, beween Ardara and Portnoo. The field studies exhibit there has been scaled back due to pressure for alternative usage of the room. These local initiatives deserve to be supported by the County Council, as they help provide residents and visitors with a context and direction for consideration of geological heritage in the county.

Waste dumping

An occasional problem throughout the country, is the dumping of rubbish in the countryside. The dumping of waste, for example along coastal cliff sections, 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 or springs. Groundwater Protection Schemes (DELG 1999) help to combat pollution risks to groundwater by zoning the entire land surface within counties into different levels of groundwater vulnerability. Such a scheme was completed for Donegal County Council by the Geological Survey Ireland in 2006, ranking the county land surface into vulnerability categories of 'Extreme', 'High', 'Moderate' and 'Low', and helping planners in assessing which developments are suitable or not in certain areas of Donegal. The location and management of potentially polluting activities in each groundwater protection zone is by means of a groundwater protection response matrix for each activity or group of activities, which describes: (i) the degree of acceptability of each activity; (ii) the conditions to be applied and, in some instances, (iii) the investigations that may be necessary prior to decision-making. The Donegal Groundwater Protection Scheme was revised in 2012 and the maps reissued. This involved a significant amount of drilling in areas where new information had become available on depths of sediment in drumlin areas across Donegal, and involved a revision of the depth-to-bedrock and groundwater vulnerability maps for the scheme.

The Groundwater Vulnerability Map of County Donegal and the Groundwater Protection Scheme for the county can be seen on the Geological Survey Ireland website [https://www.gsi.ie/en-ie/programmes-and-projects/groundwater/Pages/Data-and-Maps.aspx].



Groundwater Vulnerability Map of County Donegal (GSI Groundwater Data Viewer)

Dumping Prohibited sign on Oileán Toraigh above cliffs where dumping of rubbish ongoing.

Cliff section on Oileán Toraigh – site of fly-tipping and dumping over cliff edge.

Cliff section on Oileán Toraigh where dumping of rubbish ongoing (close up).

New exposures in development

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

Geoparks

An extremely interesting development in geological heritage, not just in Europe but internationally, has been the rapid recent growth and adoption of the Geopark concept. A **Geopark is a territory** with a well-defined management structure in place (such as Local Authority support), **where the geological heritage is of outstanding significance and is used to develop sustainable tourism opportunities**. Initially, it was largely a European Geoparks Network (EGN) but since 2004 has expanded worldwide as the Global Geoparks Network (GGN) and the Geoparks now have full UNESCO status [see www.globalgeopark.org and www.europeangeoparks.org]. 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. The Geopark branding therefore helps promote the geological heritage resource so that the community can benefit from it.

In Ireland there are three UNESCO Global Geoparks. One is the cross-border Marble Arch Caves Global Geopark in counties Fermanagh and Cavan [see www.marblearchcavesgeopark.com/ and http://www.cavancoco.ie/marble-arch-caves-unesco-global-geopark.htm]. The Copper Coast Geopark in County Waterford also joined the network in 2001 [see www.coppercoastgeopark.com]. The Burren and Cliffs of Moher Geopark in County Clare is the latest member [2011; see www.burrengeopark.ie/]. In addition, there are aspirant groups exploring the work and infrastructure required for applications in other areas such as Joyce Country and Western Lakes in Mayo and Galway and the Mourne Gullion Strangford area in Northern Ireland.

Although Donegal currently has no aspiring geotourism projects, it has a wealth of internationally renowned geology that could form the basis for a potential Geopark. The entire Slieve League and Inishowen peninsula areas, in particular, might be a candidate on the basis of their Dalradian bedrock and spectacular geomorphology (e.g. raised beaches, adjacent fjord at Inishowen), assuming sufficient local drive to use the outstanding geology to further develop sustainable tourism. Aside from the geology, the Slieve League peninsula is also noted for its archaeology, biodiversity and surviving traditional culture while the Inishowen peninsula is also noted for its archaeology, biodiversity and as a prominent geographical location at the most northerly part of Ireland (and its importance in terms of meteorology, shipping, the Irish Geodetic Datum.. The tentative list of candidate sites for Ireland regarding World Heritage Sites may be an alternative avenue for the area's recognition and promotion. However, WHS status tends to embrace single dramatic sites (such as the Giant's Causeway), whereas UNESCO Global Geopark membership requires an area with more than one site.

The following major national and international walking trail initiatives and geodetic Datum site also present possible opportunities for the inclusion and promotion of geological heritage within their ambit.

International Appalachian Trail (IAT) - Irish Landfall

Ireland has joined in the effort to extend the International Appalachian Trail (IAT) to all parts of the once-continuous, pre-Atlantic Appalachian-Caledonian mountain belt. The existing IAT stretches from the northern terminus of the Appalachian Trail at Mount Katahdin in the US state of Maine, through eastern Canada to the Atlantic coast of Newfoundland. Ten European countries have now joined the IAT and more plan to do so. When expansion is complete, the IAT will be the largest trail network and one of the largest outdoor adventure brands in the world, with a presence in 21 countries and three continents. More details can be found at http://www.iat-sia.org/index.php.

Landfall of the IAT in Ireland and Europe has been designated as Slieve League in County Donegal. Geological Survey Ireland has prepared a brochure on behalf of the IAT-Ireland consortium explaining this selection as a first step in rolling out the trail across Ireland. The brochure can be viewed at: http://www.gsi.ie/News/International+Appalachian+Trail+%28IAT%29+-+Irish+Landfall.htm

The Wild Atlantic Way

The Wild Atlantic Way is a new long-distance driving route supported by Fáilte Ireland that represents potential opportunities for the inclusion and promotion of geological heritage along the route. The route takes in the entire west coast of Ireland from Donegal to Cork, over a distance of 2,750 km. In Donegal it starts on the Inishowen peninsula, and follows the coast road via Fanad, Rossguill, Dunfanaghy, Gortahork, Bloody Foreland, Gweedore, the Rosses, Dunglow and follows the coast road via Portnoo to Ardara, Glencolumbkille, Slieve League, Killybegs, Donegal town, Ballyshannon and Bundoran. See www.failteireland.ie/wildatlanticway.

Malin Head Vertical Datum

The Malin Head Vertical Datum is fixed as Mean Sea Level of the tide gauge at Malin Head, County Donegal. It was adopted as the National Datum in 1970 from readings taken between January 1960 and December 1969. All heights on Irish National Grid mapping since then are in International metres above this datum. Earlier maps (e.g. County Series) used the Poolbeg Lighthouse (Dublin) datum (given in Imperial feet). Malin Head datum is approximately 2.7m above the Poolbeg Lighthouse datum.

Proposals and ideas for promotion of geological heritage in Donegal

The clear and significant inclusion of geological heritage in the County Donegal Heritage Plan 2007-2013 was a most welcome and positive step, for a topic that is often undervalued and poorly known in the wider community. This audit is an action plan of the 2007-2013 Heritage Plan. The new Donegal Heritage Plan (2014-2019) is currently being prepared, and it is hoped that it will continue pursuing objectives that promote geological heritage within the county.

DRAFT

This section examines selected points in the 2007-2013 CHP relating to geological heritage and provides specific suggestions as to how these may be implemented, supported or enhanced by the audit of geological heritage sites in the county.

The County Development Plan (2012-2018) has also made specific reference to protection of county geological sites proposed under Geological Survey Ireland's Geoheritage Programme (see Appendix 1).

DONEGAL HERITAGE PLAN 2007-2013 ACTIONS

Objective 1: To raise awareness and promote appreciation of County Donegal's natural, built and cultural heritage.

1.6. Identify landforms of significance (geological and geomorphological) in County Donegal and promote their natural heritage values
Audit Action: The audit provides a currently definitive list of geological and geomorphological sites along with detailed descriptions of features therein. Site boundaries are defined and incorporated into GIS format to assist the planning function of the council. The report provides a basis for promotion of geological heritage through future publications (hard copy, web-based, etc.) and signage. However, ongoing review in future years for additional sites will be required. Some vigilance on the ground at sites will be required to ensure they are not damaged. The Geological Survey Ireland should be consulted on any planning application that is potentially impacting upon an identified County Geological Site.

1.7. Raise awareness of the natural heritage of County Donegal through an annual promotional campaign
Audit Action: The individual site reports, photographs and associated digital files can be adapted for use in annual promotional campaigns relating to natural heritage. It would also be possible to produce a panel-based exhibition, based on images from this audit with appropriate captions, and some additional research covering human dependence on geology and resources. In addition, the Geoschol four-page leaflet on the geology of Donegal, aimed at primary level, can be made available or through a link to it on the Geoschol website (www.geoschol.com).

1.12. Publish a newsletter on natural, built and cultural heritage issues in County Donegal
Audit Action: Various issues related to heritage promotion and protection are raised both in the main report for this audit and in the individual site reports and can be used in a newsletter on this subject.

Objective 2: To collect, publish and disseminate data and information about County Donegal's heritage.

2.16. Establish a database of, and disseminate information on, industrial heritage in the county
Audit Action: Site reports for Crohy Head talc mine, Mountcharles Sandstone mine, Glentogher Mine (Lead-Silver), Carrowtrasna Mine (Talc) and Muckish Mountain (Quartz Sands) provide information on an important aspect of industrial heritage in the county.

2.31. Produce and make accessible a comprehensive heritage bibliography for County Donegal as a

research and educational tool
Audit Action: The report includes an extensive geological bibliography providing detailed information on the geology of Donegal and on specific county geological sites.

Objective 3: To promote best practice in the management and care of our natural, built and cultural heritage.
Audit Action: This report contains specific recommendations for protection and care of geological heritage sites, both individually and generally in the context of county development.

Objective 4: To develop interest and knowledge in County Donegal's heritage through access, education and training.

4.4. Identify, develop and promote nature walks in urban and rural areas
Audit Action: The site reports, photographs, maps and digital files included in the audit report can be used to assist with development of walking trails, particularly in rural areas where such trails may pass close to county geological sites that can provide interesting stopping points along the route.

4.6. Produce a DVD/CD-ROM on the evolution of a Donegal landscape
Audit Action: Some of the sites in the audit could serve as a basis for such a DVD/CD-ROM, e.g. Slieve League Cliffs, Malin Head, Bloody Foreland, Errigal. The audit reports illustrate various geological and geomorphological features and provide valuable information on the geological controls on landscape development as well as a supporting bibliography.

4.7. Establish, promote and provide interpretation at selected places of natural, built and cultural heritage interest
Audit Action: The individual site reports, photographs and associated digital files could be used as a basis for interpretative signage or literature for individual sites.

4.10. Establish an interactive heritage website for the purposes of education and interpretation
Audit Action: The digital data, including GIS site boundaries and associated metadata, photographs and text, can be easily incorporated into a heritage website.

4.11. Identify and establish themed heritage trails in the county
Audit Action: Several parts of Donegal contain clusters of County Geological Sites that could serve as the basis for local geology-themed heritage trails. County Donegal as a whole could be the basis for a geological heritage trail that covers the main geological periods and rock types found in Donegal. The site reports and associated digital data provide the necessary basic information for developing such trails.

4.12. Produce educational and information materials to assist in the interpretation of selected heritage sites and topics in the county
Audit Action: The site reports, photographs, maps and digital data can be used as the basis for printed material, a physical exhibition and as internet resources, all aiming to disseminate the audit results to a much wider audience. It is to be hoped that resources may be available in future to produce a 'public-friendly' book on the geological heritage of the county in a similar manner to Sligo,

DRAFT

Meath, Fingal, Waterford and Roscommon.

Objective 5: To inform public policy and advocate the strategic and integrated management of heritage.

5.7. Produce a series of guidance leaflets on heritage topics
Audit Action: The main report in this audit contains specific recommendations for dealing with geological heritage sites in the context of the county planning process and for enhancing protection of geological sites in the context of county development.

5.8. Undertake an inventory of heritage assets in the ownership/care of Donegal County Council
Audit Action: While most of the sites covered by this audit are on private land, some are on public land, notably coastal foreshore sites. Such sites identified by the audit include, for example, important fossil localities and outcrop localities such as Tremone Bay or Fahan Pier which may require active conservation by the county council to protect them from unscrupulous collectors and from damage through shoreline protection measures or coastal development.

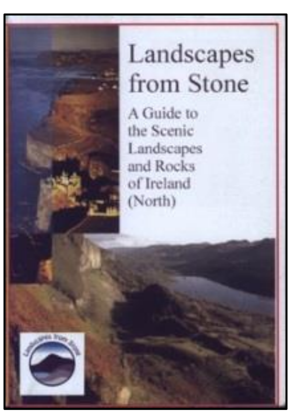
Promotion of geological heritage sites may lead to an increase in visitor traffic that will require careful management. Many existing single track access roads lack adequate passing places and some sites will need enhanced parking or turning spaces. Others have significant potential as tourist attractions but need a proper access footpath. Appropriate consideration of access factors could be included in the next County Heritage Plan.

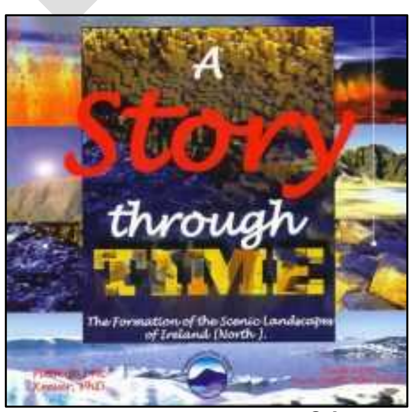
Specific ideas for projects

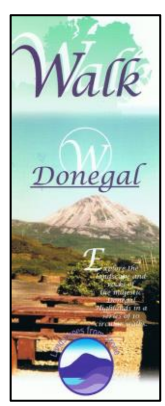
Leaflets
A project called 'Landscapes from Stone', run jointly between the Geological Survey Ireland and The Geological Survey of Northern Ireland produced a series of walking and driving guides as leaflets in the year 2000. For Donegal, *Walk Donegal* remains in print (there was also *Explore Donegal*, currently out of print) and covers several of the areas covered by this audit, including the western end of the Slieve League peninsula. This guide is non-technical and broader in scope than just geology. There is plenty of scope for other and different leaflets.

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

DRAFT



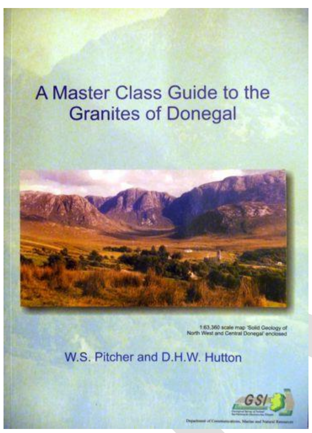


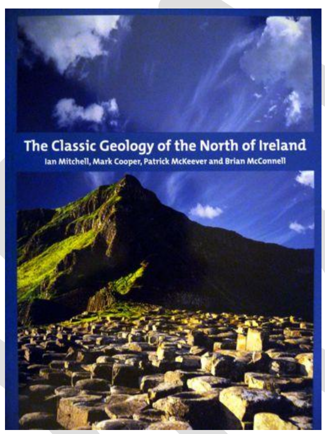


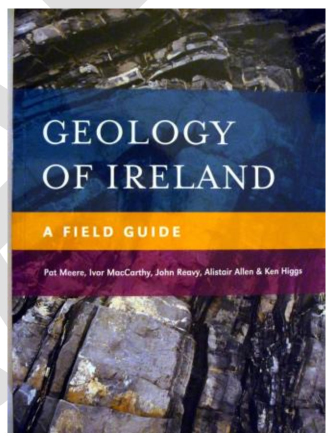
Guides

There are numerous publications on the geology of Donegal, including some field guides, the most notable being "A Master Class Guide to the Granites of Donegal" (2002) by Pitcher and Hutton, which includes detailed information on a number of the sites in this audit.

The more recent "Field Guide to Irish Geology" (2013) by Meere *et al.* covers the geology in the area around Glencolumbkille while "The Classic Geology of the North of Ireland" (2010) by Mitchell *et al.* also includes some sites in the area. Most publications are directed at a scientific audience so there is certainly scope for others aimed at non-specialists. Aside from the guides mentioned above, there are few existing guides to the geology of Donegal, apart from literature produced within the geotourism projects funded through Peace and Reconciliation schemes. There is scope for guides at different levels of detail and accessibility to non-specialists. A wide range of leaflets, booklets, books and other media are all feasible, but the research and production of appropriate text and images is a difficult task to do well without appropriate experience, and adequate time and resources. **It is suggested that with only modest editing and reorganisation the content of this report would comprise a good general guide to the geological heritage of County Donegal, in a broadly similar style to those books produced for Sligo, Meath, Fingal, Waterford and Roscommon following audits for those counties.**







Signboards

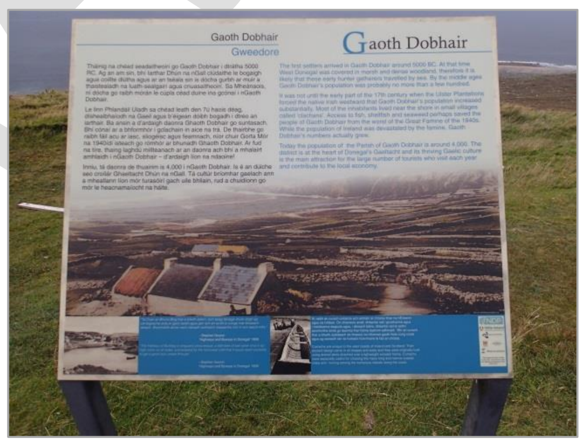
Simple explanatory or interpretive signboards may be advisable at key geological heritage locations, such as those presently installed at Malin Head. However, if these are considered, their locations and individual siting should be very selective, since a proliferation of different interest groups may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

Malin Head signboard: "Malin's Unique Geology"

The subject of panels, and the successful integration of text and graphics are a fine art to complete successfully, and the Geoheritage Programme can offer input if signs are planned for key visitor localities.

Existing signs about wildlife and culture (e.g. Malin Village bridge) could be complemented by a simple sign explaining local features of observable geological or geomorphological interest.

Information sign at Cnoc Fola (Bloody Foreland)



Information sign at Gaoth Dobhair (Gweedore)

DRAFT

Information and walking route sign on ***Oileán Toraigh (*Tory Island)**

Information at Fanad

DRAFT

Museum exhibitions

As a result of the work to produce this report, the material for a panel based exhibition could be relatively easily compiled. 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 the county museum, Council offices or County Library branches. The model could follow that produced for Carlow and for Dun Laoghaire-Rathdown.

New media

There are increasing numbers of examples of new methods of promoting Earth Sciences, via mobile phone applications and other electronic media. Self-guiding apps on specific sites would be one of these, such as those produced by Ingenious Ireland for Dublin city geology and the recently launched app for tourists in the Burren and Cliffs of Moher Geopark. Plans for such products would require some considerable effort to produce and imaginative effort, with the sites being scattered across the county. Producing apps for main tourist areas, such as the Slieve League peninsula, the Gweedore or the Inishowen peninsula, might be a good starting point.

Earth Science Ireland Group and magazine [www.earthscienceireland.org]

The group Earth Science Ireland was an all-Ireland group promoting awareness of earth sciences and supporting educational provision in the subject. A main vehicle for the efforts was the twice a year magazine Earth Science Ireland (until 2019) which was distributed free to thousands of individuals, schools, museums, centres and organisations.

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 Donegal is already part of the available material (see Appendix 7). Working links to the Heritage section of Donegal County Council website, and to other heritage websites, should be established.

Geological Heritage Research Archive

The list of references provided in this report would be a valuable resource on which to base and establish a Research Archive, similar to that produced in the Burren and Cliffs of Moher Geopark, with downloadable (or links to) free access papers and reports. This resource would prove valuable to researchers and communities seeking technical information on the county's geology and geomorphology. This resource could be served on, for example, the County Library website.

DRAFT

A Summary of the Geology of Donegal

Introduction

There are six main geological subdivisions of events and rock types (referred to as chapters or stories) that resulted in the formation of the geology we observe today in County Donegal. These are summarised below in chronological order and are expanded upon with respect to both the north and south regions of Donegal as per the individual audits which are combined in this report.

1. The oldest rocks are gneisses, coarsely crystalline banded metamorphic rocks. Inishtrahull off northern Donegal is composed of these gneisses (metamorphosed igneous rocks) originally formed around 1800 Ma ago. The rocks around Lough Derg are complexly deformed quartz-rich sedimentary rocks of uncertain origin.
2. Mixed sedimentary and volcanic rocks, including sediments of Precambrian glaciations, were deposited between about 800 and 600 million years ago. These were metamorphosed to schists during the early stages of a series of mountain-building events known as the Caledonian orogeny (between 475 and 385 Ma ago) to make up the Dalradian Supergroup which occurs over large areas of Donegal.
3. During the later stages of the Caledonian orogeny, several large granite plutons were intruded into the older rocks (420 – 385Ma). Donegal is a globally renowned area for the study of granites.
4. Erosion of the mountains of the Caledonian orogeny led to the formation of sedimentary deposits of continental red-bed facies (old red sandstone, ORS) between 355 and 410Ma ago. The red-beds were overlain by marine limestones of the Lower Carboniferous period (300-355Ma) as a shallow sea spread over Donegal in equatorial latitudes.
5. Volcanic activity associated with the opening up of the Atlantic Ocean around 65Ma ago resulted in the formation of basalt rocks and feeder dykes that cut through the older rocks in sheets.
6. The last Ice Age, which began around 1.6 Ma ago resulted in many of the landscapes we see today and sediments deposited over the bedrock.

1. Paragraph summary

North Donegal

The story of Donegal's geological history comprises six main chapters. The first chapter covers Ireland oldest rocks, found on Inishtrahull, off Malin Head, which were formed originally as igneous rocks around 1800 Ma, before undergoing a complex series of episodes of deformation and metamorphism deep in the earth's crust, forming gneisses (coarsely crystalline banded metamorphic rocks). The second chapter tells of the younger strata that make up the Dalradian Supergroup that were deposited between 800 and 600 million years ago, which include sandstones, mudstone, limestones, igneous rocks*[these aren't sediments] and glacial sediments. These rocks underlie much of the area of northeast Donegal and the areas in the region of Gortahork, Dunfanaghany, Rosguill, and Fanad (roughly anywhere granite is not found). The Dalradian sediments were in turn metamorphosed and deformed between 475 and 385 Ma by the Caledonian orogeny. This mountain-building event that also saw the emplacement in the northwestern part of the county of the Donegal Granites around 400 million years ago makes up the third chapter. The fourth chapter relates to the sedimentary deposits of continental red-bed facies (Old Red Sandstone) sediments (dated between 355 and 410Ma) which are found at Ballymastocker and Knockalla at Fanad. These ORS sediments formed from the erosion of the Caledonian mountains mentioned in the previous chapter. The continental ORS sediments were quickly covered by marine limestones of the Lower Carboniferous period (300-355Ma) as sea levels rose. Later Carboniferous sediments include thick sandstones formed in off-shore deltas. The Carboniferous sediments are preserved in an area along the southwest shore of Lough Foyle around Muff and Quigley's Point. The fifth chapter jumps forward in time to around 65 Ma, when the North Atlantic Ocean started to open (and continues to do so). The crustal rifting and volcanic activity associated with this event is well represented by the basalts of Antrim and the Giant's Causeway to the east. Following erosion over several hundred million years, the last two million years have had most impact on the landscape in Donegal. The sixth and final chapter in the story of north Donegal's geological history tells of the Ice Ages, which in Ireland began around 1.6 million years ago, and were characterised by repeated cold periods interspersed with warm periods that saw glaciers form in the mountainous areas such as the Derryveagh Mountains. The glaciers eroded the high ground, carved out corries and sculpted superb landscape features such as the Poisoned Glen, moulded bedrock outcrops, and blanketed much of the lower ground with till. The rock they ground down was deposited as till in thick blankets over much lower ground, now seen as drumlins around Mulroy Bay and Sheep Haven. Following the end of the last glaciation around 11,600 years ago, extensive land uplift and coastal erosion has given rise to the spectacular coastal landscapes of north Donegal, such as raised beaches, relic and extant cliffs, beaches and dune systems.

South Donegal

Donegal's geological history comprises six main stories. The oldest rocks, found in the southeast around Lough Derg, were originally deposited sometime after 1713 Ma as quartzo-felspathic sedimentary rocks, before undergoing a complex series of episodes of deformation and metamorphism deep in the earth's crust. The younger sediments that make up the Dalradian Supergroup were deposited between 800 and 700 million years ago at the opening of the Iapetus Ocean and include sandstones, mudstone, limestones and glacial sediments. These rocks underlie much of the area of central south Donegal. The Dalradian sediments were in turn metamorphosed and deformed between 475 and 385 Ma by the Grampian orogeny at the closure of the Iapetus Ocean. The end of this orogeny or mountain-building event saw the emplacement, in the northwestern part of south Donegal, of the Donegal Granite batholith around 400 million years ago. Erosion of the mountains formed during the Grampian orogeny led to the formation of thick deposits of continental red-bed facies (Old Red Sandstone) sediments (355-410 Ma) in rivers and floodplains around what is now Donegal Bay. These sediments were quickly covered by marine limestones of the Lower Carboniferous Period (300-355 Ma) as sea levels rose. Later Carboniferous sediments include thick sandstones formed in off-shore deltas. The Carboniferous sediments are preserved in an area around Donegal Bay. Around 65 million years ago (Palaeogene Period), the North Atlantic Ocean started opening up and volcanic activity occurred, with an outpouring of plateau basalts. The feeder dykes for these now eroded basalts include the many dolerite dykes and sills of the Donegal dyke swarm in south Donegal (61-62 Ma). These events culminated in plate separation and opening of the Atlantic along the northwest European margin at 53 Ma in the early Eocene Epoch. That series of uplifts, beginning in the Paleocene Epoch, gave rise to the land-sea distribution observed today. The final landscape shape was sculpted by ice sheets during the Ice Age, and by the deposition of glacial till and sediments throughout the county. These are especially well exposed in coastal cliffs around Donegal and Inver Bays. Since glaciation, extensive coastal erosion has given rise to the spectacular coastal geomorphology of south Donegal, including steep cliffs, sea arches and caves.

DRAFT

AGE (Million Years Ago)	ERA	PERIOD	EVENTS IN DONEGAL	IF THIS TIMESCALE WERE A DAY LONG
2.6	Cenozoic	Quaternary	Series of ice ages, scouring of landscape and deposition of drumlins and moraines. Spread of vegetation, growth of lowland bogs, arrival of man.	Ice ages began 38 seconds before midnight
23.03		Neogene	Opening of North Atlantic, intrusion of dolerite dykes. Erosion.	Begins at 11:52 pm
66		Palaeogene	Opening of North Atlantic, intrusion of dolerite dykes. Erosion.	Palaeogene period begins at 11.40 pm
145	Mezozoic	Cretaceous	Erosion. *No record of rocks of this age in Donegal.*	11.14 pm
201		Jurassic	Uplift and erosion. *The age of dinosaurs.* *No record of rocks of this age in Donegal.*	10.55 pm
252		Triassic	*Desert sandstones deposited in NE Ireland. No record of rocks of this age in Donegal.*	10.41 pm
298	Palaeozoic	Permian	*Dykes intruded during earliest rifting between North America and Europe. No record of rocks of this age in Donegal.*	10.32 pm
359		Carboniferous	Northwards marine transgression reached Donegal by early Carboniferous. Deposits of near-shore and deltaic clastic sediments and limestone.	10.08 pm
419		Devonian	Caledonian mountain building during latest Silurian and early Devonian, intrusion of Donegal batholith over same period. Final closure of Iapetus. Rapid erosion.	9.50 pm
443		Silurian	Earliest intrusions of the Donegal Batholith; initiation of major sinistral shearing.	9.39 pm
485		Ordovician	*Iapetus closure initiated early in Ordovician.* Deformation, regional and thermal metamorphism of Dalradian during Grampian orogeny.	9.28 pm
541		Cambrian	*Opening and widening of the Iapetus Ocean.* Deposition of the Dalradian Supergroup extended into the Cambrian period.	9.08 pm
1000	NeoProterozoic	Precambrian	Slishwood Division rocks deformed and metamorphosed deep in the earth's crust. Dalradian rocks deposited between c. 800 and 550 Ma, earliest deformation of lower Dalradian rocks c. 630Ma.	6.43 pm
1600	MesoProterozoic		Deposition of Slishwood Division begins after 1700 Ma	4.00 pm
2500	PalaeoProterozoic		*Igneous material added to crust c. 1978 Ma, melted and intruded as magmatic arc, deformed during Ketilidian orogeny to form Inishtrahull of north coast of Donegal*	10.48 am
4000	Archaean		*Oldest known rocks on Earth.*	3.00 am
4600	Priscoan		*Age of the Earth.*	Begins 1 second after midnight

The Geological Timescale and County Donegal.

2. Simple summary

North Donegal

The region of north Donegal comprises five main subdivisions of bedrock (Map 1): the Rhinns Complex, the Dalradian Supergroup, Devonian Granites, the Devonian Old Red Sandstone, and the Carboniferous Clastics.

The greater extent of the north Donegal region is underlain by Precambrian rocks, with Palaeoproterozoic orthogneisses (deformed and metamorphosed intrusive igneous rocks) occurring on the islands around Inishtrahull and the Tor Rocks, northeast of Malin Head. These coarsely crystalline banded metamorphic rocks, the oldest rocks in north Donegal, and in Ireland, formed around 1780 million years ago. These rocks are part of the Rhinns Complex, a suite of Palaeoproterozoic basement rocks. Isotopic data indicates that the Rhinns Complex represents the addition of igneous material to the crust at c. 1,800 Ma, during Proterozoic events associated with an extensive 1,900–1,700 Ma mobile belt around the southern margin of Laurentia-Baltica. The Rhinns Complex rocks of north Donegal are similar to rocks in Colonsay and Islay in Scotland and are really a part of Greenland, forming a link between the Ketilidian province of the Svecofennian orogeny of Scandinavia.

The most abundant rocks found throughout the entire county are the Dalradian Supergroup metasedimentary (and intermittent igneous) rocks. These rocks were deposited as sediments during Neoproterozoic times, and were later metamorphosed to form schists (metamorphic mudstones and muddy sandstones) and quartzites (metamorphic sandstones) during the mountain forming events of the Ordovician Period. The Dalradian Supergroup also contains abundant igneous intrusions throughout the metasedimentary rock sequences. The Dalradian stratigraphy is subdivided into four successions in County Donegal; two on either side of the Leannan Fault (see Map 1). A succession consists of a largely coherent stratigraphical sequence that may contain unconformities or disconformities. Northwest of the Leannan Fault, earlier deposits of Dalradian Appin Group age form the Creeslough Succession, found in NW Donegal. This succession is separated by the Knockateen Slide from the Kilmacrenan Succession, comprising rocks of later Appin and Argyll Group age. The Kilmacrenan Succession is found in north central Donegal (to the east of the Donegal Granite) and across the NW Inishowen peninsula. Both Creeslough and Kilmacrenan Successions contain quartzites, pelitic and psammitic schists, limestones and dolomites. The key correlation horizon within the Kilmacrenan Succession is the Port Askaig Tillite, which forms a regionally important glacial marker that has been traced into Mayo and Connemara and northeast to Argyllshire in Scotland. The thin-bedded slabby quartzites at the base of the Slieve Tooey Formation are also easily recognized.

Elsewhere, the north Donegal landscape is dominantly occupied by intrusive granite bodies which were emplaced between around 420 and 390 million years ago. The intrusion of these granite plutons, collectively known as the Donegal Batholith, into the Dalradian rocks in north Donegal took place during the mountain building (orogeny) events of the late Silurian to early Devonian age. The granites were emplaced as molten rock that was squeezed up and into large faults and fissures in the crust. This molten material later cooled and crystallised at depths of several kilometres below the land surface.

Radiometric dating of the individual granite plutons (Thorr Granite, Fanad Granite, Toories Granite, Tullagh Point Granite, Trawenagh Bay Granite and Main Donegal Granite) in north Donegal indicates that they were emplaced at great depth between about 420 Ma and 390 Ma. Emplacement was followed by several kilometres of uplift and erosion. Of the north Donegal plutons, the Thorr Granite and Fanad Granite are the oldest. The Trawenagh Bay Granite and Main Donegal Granite are the youngest, with the Tullagh Point Granite, Rosses Granite and Toories Granite emplaced in between. Whilst all are referred to as 'granite', the plutons all vary in mineral composition, and each one is itself a complex body of varying mineral composition and structure. Each of the plutons is accompanying by numerous granitic dykes. When the Main Donegal Granite was intruded and crystallising, it was subjected to regional scale shearing, which resulted in the pluton being drawn out in an elongate shape (NE-SW orientation).

Minor occurrences of Palaeozoic sedimentary rocks are found in north Donegal, such as the Devonian sandstones and conglomerates on Knockalla Mountain (west side of Lough Swilly) near Ballymastocker, and the Carboniferous sandstones at the southwest head of Lough Foyle. Minor intrusive igneous rocks ranging in ages from Neoproterozoic to Tertiary also occur in the region, however their extent is not sufficient to be included on Map 1 or on published maps such as the GSI Sheet 1 1:100,000 scale maps.

Late Cretaceous times saw the maximum transgression of chalk seas over Ireland. It is most likely that if these rocks occurred in Donegal, they were removed by erosion associated with thermal uplift and the outpouring of basalts fed through the Donegal dyke swarm around 62–61 Ma (Paleocene). This basalt plateau has also since been removed by erosion. These events culminated in plate separation and opening of the Atlantic along the northwest European margin at 53 Ma in the early Eocene. That series of thermal uplifts, beginning in the Paleocene, gave rise to the land-sea distribution observed today. A further very significant period of uplift began in the Neogene.

South Donegal

The oldest rocks in south Donegal are those of the Precambrian Slishwood Division (pre-Dalradian or very oldest Dalradian), a large inlier of paragneisses, or psammites, and other metamorphic rocks extending from Lough Derg to Ballyshannon. Originally deposited sometime after 1713 Ma as quartzo-felspathic sedimentary rocks, they have undergone a complex series of episodes of deformation and metamorphism. Some psammites still retain evidence of their original sedimentary structures, although a typical Slishwood Division psammite has predominantly granoblastic textures. The rocks were subsequently folded into a regional antiform during the Caledonian orogeny.

The contact between the Slishwood Division and the Dalradian Supergroup is the Lough Derg Slide, one of a number of regionally important thrust planes in south Donegal. The Dalradian stratigraphy is subdivided into four successions in Donegal, two on either side of the Leannan Fault. A succession consists of a largely coherent stratigraphical sequence that may contain unconformities or disconformities.

Northwest of the Leannan Fault, earlier deposits of Dalradian Appin Group age form the Creeslough Succession, found in south Donegal mainly between the Gweebarra and Loughros Beg estuaries. This succession is separated by the Knockateen Slide from the Kilmacrenan Succession, comprising rocks of later Appin and Argyll Group age. The Kilmacrenan Succession is found on the Slieve League peninsula and between the Main Donegal Granite and the Leannan Fault.

Both Creeslough and Kilmacrenan Successions contain quartzites, pelitic and psammitic schists, limestones and dolomites. The key correlation horizon within the Kilmacrenan Succession is the Port Askaig Tillite, which forms a regionally important glacial marker that has been traced into Connemara and northeast to Argyllshire in Scotland. The thin-bedded slabby quartzites at the base of the Slieve Tooey Formation are also easily recognized.

In south Donegal rocks of Devonian age rest on Slishwood Division rocks in the southeast.

The intrusion of the granite plutons in south Donegal took place after the Grampian orogeny and before the Acadian orogeny. Radiometric dating of the Barnesmore, Ardara, Trawenagh Bay and Main Donegal Granite intrusions indicates that they were emplaced at great depth between about 425 Ma and 397 Ma, i.e. during the late Silurian to early Devonian. Emplacement was followed by several kilometres of uplift and erosion, but the Barnesmore granite was only finally unroofed after the deposition of the Lower Carboniferous sequence several tens of millions of years later.

Deposition of the Lower Carboniferous Tournasian rocks of the Donegal basin began during subsidence. There then followed a marine transgression, with deposition across a carbonate platform with marginal marine deltaic sediments. This was succeeded by overlying deltaic progradation and retreat. There is evidence in the folds and faults developed in the Carboniferous of Largymore, Shalwy, Muckros, St John’s Point and elsewhere that there was a phase of compression associated with the Variscan orogeny at the end of the Carboniferous period in south Donegal.

Late Cretaceous times saw the maximum transgression of chalk seas over Ireland. If these rocks existed over Donegal they must have been removed by erosion associated with thermal uplift and the outpouring of basalt fed through the Donegal dyke swarm around 62–61 Ma. This basalt plateau has also since been removed by erosion. These events culminated in plate separation and opening of the Atlantic along the northwest European margin at 53 Ma in the early Eocene. That series of uplifts, beginning in the Paleocene, gave rise to the land-sea distribution observed today. A further very significant period of uplift began in the Neogene.

The most significant force to shape the form of the county as we see it today was the Ice Age which ended about 10,000 years ago. Large ice sheets covered the county for thousands of years and eroded the rocks beneath. This gave rise to large areas of aerially scoured landscape with classic glacial features such as U-shaped valleys and corries. As the ice eventually melted away, the meltwaters deposited sediments as landforms such as moraines and drumlins. One example in south Donegal is the field of drumlins around Donegal and Inver Bays. This field is so large that it can only be fully appreciated using satellite or air photo images.

At the end of glaciation, relative sea level fell and the land of Ireland rose as the weight of the ice was removed. Raised platforms and other coastal features, such as sea caves located above the high-tide mark, record this process. In the Holocene Period, since glaciation, extensive coastal erosion has given

DRAFT

rise to the spectacular coastal geomorphology of south Donegal, including steep cliffs, sea arches and caves.

Quaternary Geology County Donegal

North Donegal

The north Donegal landscape hosts an array of dramatically scenic landforms, many of which trace their formation to the glaciations of the Pleistocene Epoch of the Quaternary Period, or Ice Age, which occurred at irregular intervals over a period of 1.6 million years. With the end of the Ice Age around 12,000 years ago, the postglacial Holocene Epoch commenced, which was and continues to be characterised by the relatively warm climate.

Throughout the cold periods of the Pleistocene, glaciers formed in corries in the Derryveagh Mountains and eventually sculpted out the iconic Donegal landscape features such as the Poisoned Glen. The rock they ground down was deposited as till in thick blankets over much lower ground, now seen as drumlins around Mulroy Bay and Sheep Haven. The name “drumlin”, used internationally, comes from the Irish 'dromnin' meaning 'low hill'. Drumlins are mounds of debris left behind by melting ice sheets and are typically streamlined in the direction of ice-sheet flow. The ice sheet flowed generally south to north across north Donegal, a fact illustrated by the orientations of the crag and tails and drumlins, which are aligned south to north in general.

Glaciofluvial sands and gravels are deposited by meltwater issuing from a melting glacier. These deposits are usually well sorted, with the gravels often rounded. Outwash sands and gravels floor the Swilly Valley southwest of Letterkenny; these have been overlain by alluvium deposited by the modern River Swilly. Glacial meltwater erosion has cut some spectacular meltwater channels in north Donegal. The Pennyburn Valley north of Derry and the valley of the Glentogher River through which the L79 road runs are other good examples.

Towards the end of the last glacial period as the great ice sheets of the northern hemisphere melted, returning the vast amounts of water they contained to the oceans, sea-levels began to rise and from a level in excess of 100 metres below those of today. As they did so areas which had been depressed by the weight of ice and which had not yet recovered to their current height were inundated by the sea. As the land surface began to rise in response to the removal of the weight of the ice sheets, beaches which had been deposited in the inundated areas rose with the land and were left high and dry as raised beaches. Since the Ice Age, during the Holocene, the modern drainage pattern was superimposed on the deglacial channel network, resulting in some areas of haphazard drainage among the boulder clay, as well expressed along the Owenator River. At this time peat also formed across much of the Donegal landscape. Alluvial floodplains flank many of the larger rivers, for example the Foyle and the Swilly. During this time along the coast, headlands, bays, cliffs, sea stacks, arches and caves have been eroded by the sea, while beaches, bars, spits, tombolos, lagoons and windblown sand dunes have formed. The modern Donegal coastline began to develop after the postglacial sea-level stabilised at its present level more than 5,000 years ago. In that period the modern beaches (e.g. Kinnagoe, Ballymastocker) and low ground such as at Rosepenna and near Burnfoot were formed and blown sand collected in the form of sand dunes such as at Five Finger Strand.

South Donegal

The landscape in south Donegal area, dominated as it is by high Caledonian (northeast - southwest) trending mountains, is outstanding for its legacy of glacial features. The glaciations of the Pleistocene Epoch, which are responsible for the shaping of the majority of the Irish landscape, as well as the deposition of unlithified sediments over more than 90% of Ireland's bedrock geology, occurred at irregular intervals over a period of 1.6 million years. The end of the Ice Age, 10,000 years ago, marked the end of the Pleistocene Epoch and heralded the beginning of the postglacial, Holocene Epoch, characterised by the relatively warm climate that has continued to the present day.

The Pleistocene Epoch consisted of alternating climate of warm (interglacial) and cold (glacial) periods during which ice sheets expanded to cover large parts of the mid-latitude areas that are ice-free today. In Ireland, the ice sheet of the last cold period reached its maximum extent about 20,000 years ago. At this time ice covered the entire area of south Donegal. This ice belonged to the Donegal Ice Cap which coalesced with several ice domes situated further south to form an ice sheet which covered the whole country. During glacial maximum ice extended outwards from the ice shed at the centre of this ice cap in the Derryveagh Mountains. The ice shed ran north-south between Muckish and Lough Muck.

As ice moves over its substrate, pieces of rock are incorporated into its basal layers, making the ice very abrasive. It subsequently scours and erodes, polishes and moulds the land surface over which it flows into the forms visible today. Striae are grooves or scratches cut into bedrock by this abrasive ice and are therefore aligned with the flow direction of the ice. They therefore represent past ice movements. Striae are well displayed around Barnesmore Gap and in The Rosses, north of Dunglow. Roche moutonnées are moulded rock forms, generally polished on the up-ice side and plucked on the down-ice side, and are another good indicator of past ice movement. These forms are common across the sheet area but are particularly well displayed on the Glengesh Plateau and on the flanks of The Poisoned Glen. The ice also carried stones (erratics) far from their source; especially notable are the granite erratics strewn across the quartzite peak of Errigal and metasediments on granite bedrock around Drumfin. These also tell us of the direction of ice flow.

All these directional indicators demonstrate that in this area ice moved northeast and northwest from the ice shed. The northeast moving ice was forced to sweep gently northward along Inishowen, Lough Swilly, Mulroy Bay and Sheep Haven in north Donegal. Many of the distinctive ice-breached cols of the Errigal-Muckish ridge *e.g.* Muckish Gap were cut by ice moving from south to north at this time. During the final stages of glaciation as the ice grew thinner topography provided a much stronger control on ice flow, with ice flow channelled around the highest mountains and along the well-developed glaciated (U-shaped) valleys of the area, such as the Poisoned Glen. There are many well developed corries in the Derryveagh Mountains (*e.g.* Lough Maam and Lough Slieve Snaght, below Slieve Snaght, and Lough Feeane and Lough Nabrackbaddy under under Aghla Mor and Aghla Beg respectively). These deep basins, usually containing a small lake, were carved out of the mountain sides by glacier ice and were generally the first areas in which ice accumulated, and last vacated, during periods of glaciation.

The material incorporated into the ice was eventually deposited, either directly by the ice as till (boulder clay) or by meltwater, during deglaciation, as sorted gravel, sand, silt or clay. The glacial deposits are quite thin on the upland areas where bedrock dominates, but on the lowlands till thicknesses of over 30m are common in the areas dominated by drumlins. Drumlins are streamlined hills generally composed of till deposited under a moving ice mass, and their long axes parallel ice flow direction. These drumlins are widespread below the 120m contour line around Donegal and Inver Bays. Therefore, in the areas where they are present in the map area they also provide valuable information on direction of ice flow.

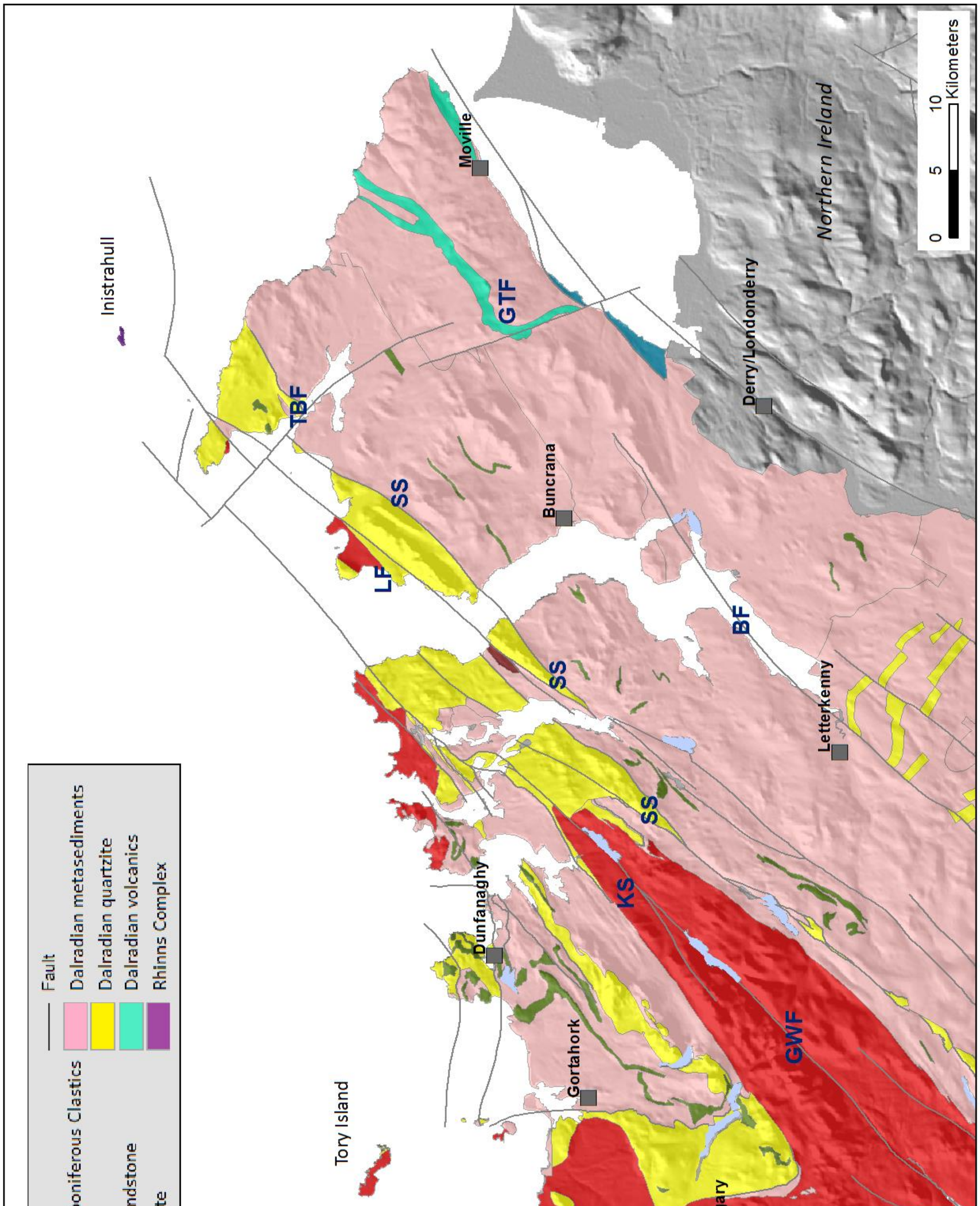
As the ice sheet shrank during deglaciation fine examples of moraines were formed at the retreating ice margin. Particularly fine lateral moraines can been seen along either side of the Barnesmore Gap. The most impressive moraine in Donegal has been formed offshore, and is currently below sea level, where multibeam sonar soundings made in 2002 by the MV Celtic Voyager revealed the presence of a narrow subsea moraine bank extending across the mouth of Donegal Bay.

Glaciofluvial sands and gravels are deposited by meltwater issuing from a melting glacier. These deposits are usually well sorted, with the gravels often rounded. Outwash sands and gravels floor the Swilly Valley southwest of Letterkenny; these have been overlain by alluvium deposited by the modern River Swilly.

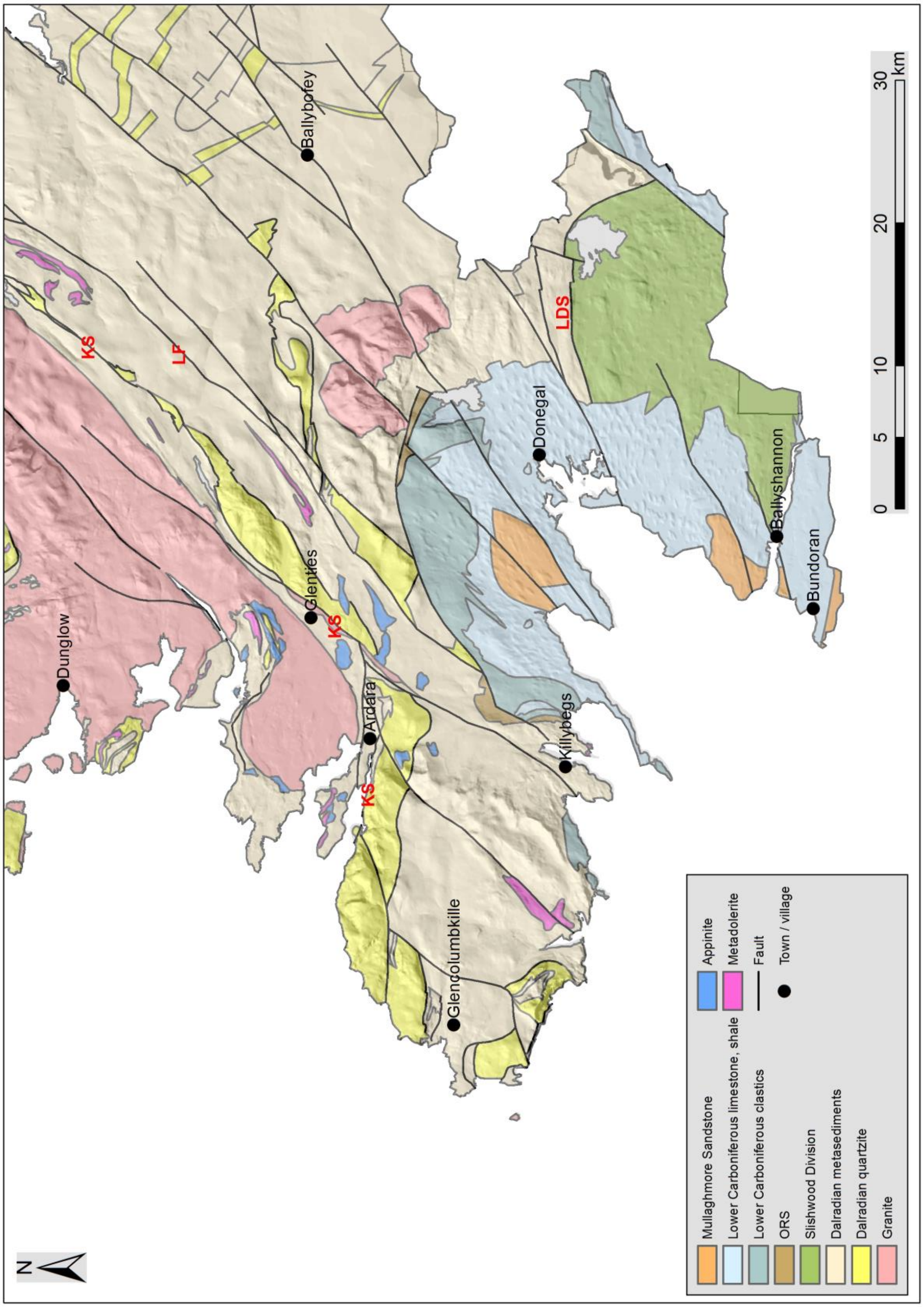
Glacial meltwater erosion has cut some spectacular meltwater channels in south Donegal. The Pennyburn Valley north of Derry and the valley of the Glentogher River through which the L79 road runs are other good examples.
Towards the end of the last glacial period as the great ice sheets of the northern hemisphere melted, returning the vast amounts of water they contained to the oceans, sea-levels began to rise and from a level in excess of 100 metres below those of today. As they did so areas which had been depressed by the weight of ice and which had not yet recovered to their current height were inundated by the sea. As the land surface began to rise in response to the removal of the weight of the ice sheets, beaches which had been deposited in the inundated areas rose with the land and were left high and dry as raised beaches.

The modern coastline began to develop after the postglacial sea-level stabilised at its present level more than 5,000 years ago. In that period the modern beaches (*e.g.* Maghera Strand) and spits (*e.g*. Loughros More) were formed and blown sand collected in the form of sand dunes (also at Loughros More). The accumulation of sand spits and blown sand is balanced by the erosion of other parts of the coastline, most spectacularly at the 600m high cliffs of Slieve League and the delicate looking sea arches of the Fairy Bridges.

In the 10,000 years since deglaciation, in the Holocene Epoch, the warmer climate has effected a large change on the environment. Postglacial sediments in the map area include river alluvium and peat. Alluvial floodplains flank many of the larger rivers, for example the Foyle, the Swilly and the River Finn, where a fine set of meanders has developed, east of Fintown. Peat is common in south Donegal, particularly as blanket bog. This type of bog is associated with upland areas where poor drainage enables the build up of oxygen-starved, partially decomposed biomass. The development of blanket bog began about 4,000 years ago, and blanket peat is common flanking the Derryveagh Mountains, often covering extensive fields of roche moutonnées, *e.g.* Muckish Mountain. Estuarine silts and clays have been laid down in Donegal Bay and at Maghera Strand and Loughros More.



Simplified Geological Map of North Donegal.
LF: Leannan Fault; GTF: Glentogher Fault; GWF: Gweebara Fault;
SS: Swilly Slide; BF: Belshade Fault; TBF: Trawbreaga Fault; KS: Knockateen Slide



Simplified Geological Map of South Donegal.
LF: Leannan Fault; KS: Knockateen Slide; LDS: Lough Derg Slide

Geological heritage versus geological hazards

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

The difference between human timescales and geological timescales can be difficult to comprehend but, for many geological processes, there are periods of sudden activity encompassing major events, and then quiet periods in between. The sites in this audit represent evidence of past geological environments and processes, such as magmatic intrusion deep within the earth's crust, tropical coral seas, swampy deltas, glacial erosion of the land surface and so on. However, a few sites represent the active geomorphological or land-forming processes of today. These sites, generally upland or coastal in Donegal, are dynamic environments and can be subject to constant or intermittent, sometimes sudden, change.

Landslides and bog flows

Geological Survey Ireland has been compiling national data on landslides since 2004 (https://www.gsi.ie/en-ie/data-and-maps/Pages/Geohazards.aspx#landslides). Five such events have been recorded in north Donegal. 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 in the 2006 publication "Landslides in Ireland" published by Geological Survey Ireland and the Irish Landslides Working Group.

Flooding

There are two types of flooding which need consideration.

1. River flooding occurs inland when the rainfall exceeds the capacity of the ground to absorb moisture, and the river channels cannot adequately discharge it to the sea. The OPW website, www.floods.ie, can be consulted for details of individual flood events in County Donegal. Some 257 events are recorded across the entire county (as of November 2014). Many of these are in urban settings, such as Donegal, Ballyshannon, Letterkenny and Gweedore, where rainfall exceeds the capacity of the local drains.
2. Karstic flooding can occur when underground passages are unable to absorb high rainfall events. South Donegal has only very limited karst or known caves while north Donegal has none, so this is not an issue for the county.

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. Large groundwater supplies in south Donegal such as at Ballyshannon and Pettigo and in north Donegal such as at Carndonagh, Culdaff, Fanad, and Magherabeg/Veagh require Source Protection Plans, which have been delineated for them by Geological Survey Ireland and the Environmental Protection Agency (EPA).

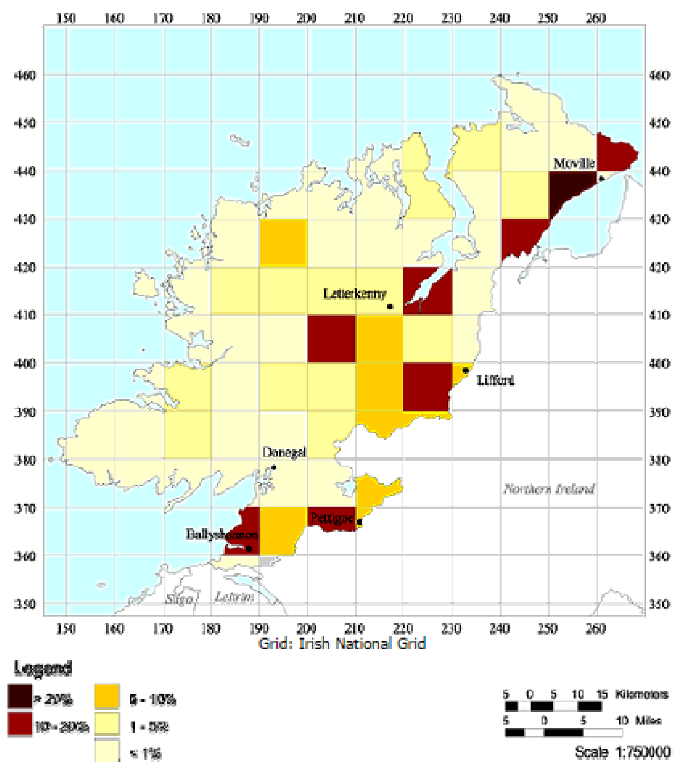
Sea level rise, coastal erosion and sedimentation

Geological heritage sites in coastal areas are particularly vulnerable to wave erosion. The joint hazards of gradual sea level rise and high waves caused by increasing storminess need to be considered in any promotion of coastal geological heritage sites and in future planning. It should be remembered that coasts are dynamic geological environments, with changes to be expected in both erosion and deposition as normal features.

In south Donegal the records of Killybegs tide gauge show the effects on sea level by tides and storm surges. The most vulnerable places are the strand-lined coasts from Bundoran to Murvagh; Inner Donegal Bay from Laghy to Mountcharles; Inver; Loughrosbeg and Loughrosmore estuaries; Naran visitor car park and golf course and outer parts of Dungloe Bay. A complementary hazard is the silting up and dredging requirement of the navigation channels at Burtonport, Donegal Town and Ballyshannon.

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 Environmental Protection Agency (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.



Radon Map of Donegal

Areas coloured light or dark brown on the map are High Radon Areas.

Glossary of geological terms

Geological Term	Definition
Adit	a horizontal or only gently inclined mine tunnel dug to access coal or mineral ore, or to drain, ventilate or further develop a mine
Alkali basalt	basalt poor in silica (SiO_2) and relatively rich in sodium (Na) and potassium (K), compared to other basalts
Aggregate	crushed rock - raw material generally used in the construction industry.
Alluvial Deposit	unconsolidated clay, silt, sand and gravel, deposited by a body of running water
Alluvial Fan	a fan-shaped deposit formed where a fast flowing river levels out and slows, typically from the mountain foot onto the plain.
Alluvium	a term for unconsolidated clay, silt, sand and gravel, deposited by a body of running water
Amphibolite	a metamorphic rock rich in the minerals amphibolite and plagioclase
Andesite	a volcanic rock of intermediate composition (between rhyolite and basalt)
Aplite	a fine to medium-grained igneous rock found as veins within coarser-grained plutonic igneous rocks.
Appinite	plutonic igneous rock formed from hydrous magma of mantle origin, dioritic in composition, i.e. rich in hornblende, also containing plagioclase feldspar and/or alkali feldspar, with or without quartz; typically associated with breccia pipes in Donegal
Aquifer	a water saturated rock unit.
Argillaceous rock	rock composed of silt- or clay-sized particles
Arkose	sandstone containing 25% or more feldspar
Basalt	a dark fine-grained extrusive igneous rock (lava) composed mostly of the minerals plagioclase feldspar, olivine, pyroxene and amphibole
Basic	any igneous rock rich in iron and/or magnesium and containing little or no quartz
Basic Rocks	rocks which contain a relatively low percentage of silica, e.g. basalt
Basin	topographically low areas on the Earth's crust, of tectonic origin, in which sediments have accumulated
Batholith	large igneous intrusion (100 km^2 or more)
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
Bivalve	mollusc with two hinged shells of similar shape and size
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
Blowhole	a chamber with a narrow cliff-top opening through which water is forced by waves driven against the base of the cliff
Boudinage	deformation of rock that leads to pulling apart of competent rock layer within it to create a series of separated fragments (*boudins*) enclosed by less competent rock layers
Boulder Clay	unconsolidated, unsorted glacial deposits consisting of boulders and cobbles mixed with very finely ground-up rock or silt. Also known as till
Bouma sequence	idealized sequence of sedimentary structures observed in sediments deposited by turbidity currents
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	igneous or sedimentary rock comprising of large angular fragments within finer grained material
Breccia pipe	roughly cylindrical intrusion of brecciated material, linked to volcanism or granite intrusion; associated with appinites in Donegal
Bryozoa	invertebrates belonging to the phylum Bryozoa, ranging from Ordovician to present, often found as frond-like, net-like or stick-like fossils.
Calc schist	schist rich in calcareous material
Calc silicate	silicate mineral containing calcium as a major component
Calcarenite	limestone comprising sand-sized (0.006-2.0 mm) grains of either quartz or calcareous clasts in a calcareous matrix
Calcareous	containing significant calcium carbonate
Calcite	a pale mineral composed of calcium carbonate, which reacts with dilute hydrochloric acid
Calc-psammite	psammite rich in calcareous material.
Caledonian	relates to Caledonian orogeny that took place towards the end of the Lower Palaeozoic era,

DRAFT

	affecting Ireland, Scotland, Scandinavia and Greenland
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
Clast	an individual constituent, grain or fragment of a sediment or rock, usually produced by mechanical weathering (disintegration) of a larger rock mass
Clastics	sediments composed of clasts, fragments of pre-existing rocks
Cleavage	a flat plane of breakage caused by compressive deformation of rocks, e.g. the splitting of slate
Clints	tabular block of limestone in a limestone pavement
Concordant contact	where the margin of an igneous intrusion is parallel to the structure (bedding, schistosity, etc.) of the enclosing country rock
Conglomerate	sedimentary rock comprising of large rounded fragments in a finer matrix
Corrie	a horseshoe-shaped, steep-walled valley formed by glacial erosion.
Cortlandite	coarse-grained member of appinite series, consisting of olivine, hornblende and pyroxene
Crag and tail	a steep resistant rock mass (crag), with sloping softer sediments (tail) protected from glacial erosion or deposited as glacial debris on the crag's 'downstream' side.
Crenulation/Crenulation cleavage	small ascale folding, of the order of milimetres, superimposed on larger scale folding of earlier foliations
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 Supergroup	thick late-Precambrian (c. 900Ma) to mid-Cambrian (c. 550Ma) sequence of sediments, limestones and volcanic rocks in Ireland and Scotland
Debris flow	a geological phenomenon in which water-laden masses of soil and fragmented rock rush down mountainsides, funnel into stream channels, entrain objects in their paths, and form thick, muddy deposits on valley floors. Also occurs on glacial ice.
Decline	inclined tunnel providing access to underground mine workings
Deformation	physical alteration of rocks and minerals under conditions of high pressure, e.g. orogeny
Delta	a usually triangular alluvial deposit at the mouth of a river, or a similar deposit at the mouth of a tidal inlet, caused by tidal currents
Dendritic	branching.
Desilication	alteration of rock resulting in removal of quartz
Devolatilization	loss of dissolved volatile compounds from magma as compounds pass out of solution into a free gas phase, typically in response to a drop in containing pressure
Diamictite	lithified, poorly-sorted deposits comprising clasts of various sizes in a mud matrix
Diatreme	volcanic vent formed by explosive action, typically filled with coarse angular fragments of rocks derived both from nearby sources and deeper parts of the crust
Dimension stone	stone that is quarried and cut to specific shapes and sizes
Diorite	coarse-grained igneous rock containing plagioclase feldspar, hornblende and biotite with or without minor quartz
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
Discordant contact	where the margin of an igneous intrusion is not parallel to or cuts across the structure (bedding, schistosity, etc.) of the enclosing country rock
Dolerite	dark fine-grained igneous intrusive rock, similar in composition to gabbro and basalt, found in dykes where relatively rapid cooling has prevented development of a coarse texture
Dolomite	calcium- and magnesium-bearing carbonate mineral; also a rock composed of the mineral
Dropstone	a clast or boulder that falls from a melting ice sheet into fine, soft sediment below
Drumlin	a streamlined mound of glacial drift, rounded or elongated in the direction of the original flow of ice
Dry Oxbow	caving term, where the river takes a more direct route through a cave and abandoning part of the stream, leaving it dry (see also stream oxbow).
Ductile fault	a fault along which rocks stretch and bend, rather than break brittly.
Dune	a hill of sand built by either wind or water flow.
Dune slack	lowlying depressions, often wet or water-filled, between sand dunes.
Dyke	a sub-vertical sheet-like igneous intrusion, typically in-filling a fracture in the earth's crust
Echinoid	echinoderm in which body of organism was enclosed in disc-shaped body made of interlocking plates covered by spines
Eclogite facies	metamorphic facies in which basic igneous rocks subjected to high pressure and intermediate

DRAFT

	temperature are characterized by the growth of pyrope garnet and omphacite pyroxene
Epidote	a calcium aluminium iron silicate mineral, often green coloured.
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.
Exsolution textures	some mineral phases are in solid solution together at high temperatures but during cooling of the host igneous rocks undergo unmixing, leading to separation of the phases and development of intergrowth textures
Extrusive	an igneous body emplaced (erupted) at the Earth's surface as lava.
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 stream, either under a lake or under air
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	the most abundant mineral in the earth's crust, composed of variable proportions of potassium, sodium and calcium in combination with silicon, aluminium and oxygen
Feldspathic	containing significant quantity of feldspar
Felsic	containing at least one of the light coloured minerals feldspar, leucite, nepheline or silica
Floodplain	a flat or nearly flat land area adjacent to a stream or river that experiences occasional or periodic flooding.
Fluvial	pertaining to a river or stream
Fold(ing)	flexure in layered rocks caused by compression
Foliation	a finely spaced planar parting caused by compressive deformation of rocks
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
Gabbro	a dark coarsely crystalline intrusive (plutonic) igneous rock composed mostly of plagioclase feldspar, olivine, pyroxene and amphibole
Gastropod	a marine, freshwater or terrestrial invertebrate with a shell which has a conical or helical spiral shape (a snail)
Glacial	of or relating to the presence and activities of ice or glaciers
Glacial striae	markings left on the surface of pebbles / boulders / bedrock by moving ice sheets.
Glaciofluvial	pertaining to the meltwater streams flowing from wasting glacier ice and especially to the deposits and landforms produced by such streams
Gneiss	coarse-grained, banded rock formed during high-grade metamorphism where light-coloured and dark-coloured bands are produced by separation of dark minerals (e.g. biotite, hornblende) and quartzo-feldspathic minerals into parallel bands
Grading / graded bedding	a sorting effect with the coarsest material at the base of the bed and finest grained material at the top.
Granite	a coarsely crystalline intrusive igneous rock composed mostly of quartz and feldspar
Granoblastic texture	metamorphic rock texture where minerals form a mosaic of equidimensional, anhedral (lacking crystal shape) grains
Granodiorite	an igneous rock similar to granite but containing more of the mineral plagioclase and also more iron and magnesium-bearing minerals
Granophyre	intrusive rock of granitic composition in which quartz and feldspar occur in characteristic angular interlocking texture
Granulite	coarse-grained, equigranular high-grade metamorphic rock containing quartz, feldspar and anhydrous Fe-Mg-bearing minerals such as pyroxene and garnet
Greenschist facies	metamorphic facies in which rocks subjected to moderate pressure and temperature are characterized by the growth of chlorite ± actinolite ± albite ± epidote ± quartz
Greisen	alteration of granite by hot, water-rich fluids to form rock dominated by quartz and muscovite , often in association with metallic mineralization
Greywacke	an impure sandstone, characterised by poorly-sorted, angular grains in a muddy matrix, that was deposited rapidly by turbidity currents (submarine avalanches).
Grike	a solutionally widened vertical fracture separating clints on a limestone pavement
Grit	historic term, synonym for sandstone
Gully	a deep valley created by running water eroding sharply into bedrock or subsoil.

DRAFT

Horizon	may refer to a single layer of rock such as a coal seam, an ash layer, or other geological 'event'
Hornblende	hydrous (OH-bearing) silicate mineral containing Ca, Fe and Mg as major components
Hornfels	massive, fine-grained contact metamorphic rock formed by recrystallization adjacent to an igneous intrusion
Hummock	a small hill or knoll in the landscape, which may be formed by many different processes.
Ice margin	the edge of an ice sheet or glacier
Ichnofauna	trace fossils, i.e. sedimentary structures formed by the behaviour of animals, e.g. burrows
Igneous	a rock or mineral that solidified from molten or partially molten material i.e. from a magma
Interbeds (glacial)	beds of glacial sediment deposited found between beds of non-glacial sediment
Interglacial	the time interval between glacial stages, or pertaining to this time.
Intrusive	an igneous rock emplaced within the Earth's crust, not extruded like lava
Intrusive rock	an igneous rock emplaced within the Earth's crust, not extruded onto its surface like lava
Isthmus	narrow strip of land linking two broader areas of land
Joint	a fracture in a rock, which shows no evidence of displacement
Kame-kettle	an irregularly shaped hill or mound composed of sand, gravel and till that accumulates in a depression on a retreating glacier, and is then deposited on the land surface with further melting of the glacier. Kames are often associated with kettles, and this is referred to as kame and kettle topography.
Karst	general term used for landscapes formed by weathering of soluble rocks, usually limestone, by surface water and/or groundwater
Karstification	the process of forming karst
Kettle hole	a shallow, sediment-filled body of water formed by retreating glaciers or draining floodwaters.
Knock and lochan	lowland area comprising alternating small hills (*cnoc*, e.g. roches moutonnees) and hollows (often filled by water to form lakes, *loch*)
Laminated	the finest example of stratification or bedding, typically exhibited by shales and fine-grained sandstones.
Lamprophyre	uncommon, basic or ultrabasic potassium-rich igneous rocks occurring typically as dykes and small intrusions
Lava	magma extruded onto the Earth's surface, or the rock solidified from it
Leucosome	light-coloured quartzo-feldspathic band or zone found between dark-coloured melanosome in regionally metamorphosed or partially melted rocks; the leucosome represents the partially melted component containing quartz and feldspar, the melanosome the undissolved or unmelted mineral residue left over from original rock after removal of quartz and feldspar.
Lherzolite	ultrabasic rock, most common variety of peridotite
Limestone	a sedimentary rock consisting chiefly of calcium carbonate (CaCO3), primarily in the form of the mineral calcite; it is mostly formed by the accumulation of calcareous shells, cemented by calcium carbonate precipitated from solution
Lithology	the description of rocks on the basis of such characteristics as colour, composition and grain size
Lodgement	process by which debris is released from the sliding base of a moving glacier/ice sheet and plastered or 'lodged' onto the glacier bed; also describes tills emplaced by this process (i.e. lodgement till).
Mafic	term applied to typically dark-coloured silicate minerals and rocks containing a relatively high proportion of iron- and magnesium-bearing minerals
Magma	molten rock that cools to form igneous rocks
Mantle	the main part of the Earth between the crustal plates and the core
Marble	metamorphosed limestone
Massive bedding / texture	a rock or rock unit, such as a bed, with no obvious internal structure
Meander	a bend in a sinuous watercourse or river which forms when moving water in a stream erodes the outer banks and widens its valley, and the inner part of the river has less energy and deposits fine sediment.
Melanosome	dark-coloured band or zone found between light-coloured, quartzo-feldspathic band or zone (*leucosome*) in regionally metamorphosed or partially melted rocks; the melanosome represents the undissolved or unmelted mineral residue left over from original rock after removal of quartz and feldspar
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).
Meltwater	water from melted snow or ice.
Meltwater channel	a channel cut by glacial meltwater, either under, along or in front of an ice margin.
Metabasite	metamorphosed basic igneous rock
Metadolerite	metamorphosed dolerite
Metagabbro	metamorphosed gabbro

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

Metamorphic aureole zone of country rock, in contact with an igneous intrusion, which has undergone metamorphism due to the heat of the intruding magma

Metamorphic facies a set of mineral assemblages that are characteristic of specific metamorphic grade (or conditions of temperature and pressure)

Metapelite metamorphosed pelitic or fine-grained sediments

Metasediments metamorphosed sediments

Metasomatism, metasomatic a variety of metamorphism where chemical components are introduced into and/or removed from a rock, typically via a volatile phase

Micaceous mica-rich

Microfossil a fossil too small to be observed without the aid of a microscope.

Micrographic texture fine-scale intergrowth of quartz and feldspar in the groundmass of granite, formed as a late-stage growth from liquid trapped between earlier-formed crystals; characteristic texture of granophyre

Migmatite mixed rock formed under very high metamorphic grade where partial melting produces a light-coloured granitic component (leucosome) that is mixed with the remaining, typically darker-coloured material (melanosome)

Miospores A spore or pollen grain less than 200 micrometres (μm) in diameter

Misfit stream a stream which is too small to have eroded the valley in which it flows, as is often the case with streams now flowing in meltwater channels.

Monzodiorite plutonic, coarse-grained igneous rock with plagioclase feldspar, alkali feldspar, hornblende and biotite with or without minor quartz, in which plagioclase is the dominant feldspar; monzodiorite differs from diorite in having a significant component of alkali feldspar

Monzonite similar to monzodiorite except that the proportions of plagioclase and alkali feldspar are broadly similar

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

Mullion structure a form of boudinage where parallel rods or prisms of competent rock, typically oriented parallel to a fold axis, are formed by stretching of a competent bed

Mylonite rock produced in fault and shear zones where tectonic deformation causes mechanical crushing and grinding (*cataclasis*) of existing rocks; mylonite is typically a fine-grained, laminated rock

Myrmekite irregular, worm-like intergrowths of quartz in plagioclase feldspar, generally developed at a late-stage during crystallization of granitic rock

Nappe a large block of crust, typically sheet-like, that has been moved a large distance (several km or more) above a thrust fault from its original position

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

Orogen the part of the earth's crust affected by orogeny

Orogeny the creation of a mountain belt by tectonic activity

Orthoclase a feldspar mineral.

Orthogneiss gneiss produced by metamorphism of original igneous rock

Ostracod small crustaceans, typical arthropods whose bodies are enclosed in two shells, their fossils resembling tiny bivalves

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

Outlier area of younger bedrock completely surrounded by older bedrock

Paragneiss gneiss produced by metamorphism of original sedimentary rock

Pegmatite a very coarse-grained igneous rock, generally of granitic composition but including intermediate and basic varieties

Pelite a metamorphosed mudstone

Peridotite coarse-grained ultramafic rock, made up of olivine (>40%) and pyroxene, derived from the upper mantle; includes variety *lherzolite*

Periglacial very cold but non-glacial climatic conditions

Perthite feldspar texture where plagioclase, typically occurring as parallel lath-like growths, forms intergrowths in alkali feldspar during cooling in a process known as "exsolution", i.e. unmixing of minerals previously in solid solution together

Phenocryst a large mineral grain within a finer-grained igneous rock

Phyllite oliated pelite.

Planform an object's outline when viewed from above

Plate Tectonics a theory 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

DRAFT

Platform — a continental area of relatively flat or gently sloping, mostly sedimentary strata, overlying a basement of consolidated igneous or metamorphic rocks.

Pluton — an igneous intrusion formed at sufficient depths to allow for the slow growth (crystallisation) of large crystals

Plutonic — originating at great depth

Porphyroblast — a large well-shaped crystal within a finer-grained matrix that formed during metamorphic recrystallization

Porphyry — an igneous rock with large crystals set in a fine-grained matrix

Psammite — metamorphosed sandstone, arkose or quartzite

Pseudomorph — a mineral that replaces another but retains the form (morphology) of the original

Pyrite — iron sulphide, pale yellow/gold coloured mineral, commonly occurring as cubes and often called 'fool's gold'

Quartz — the second most abundant mineral in the earth's crust, composed of silicon and oxygen (SiO_2)

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

Raft — large body of country rock entrained in an igneous body, such as a granite, during intrusion of the igneous rock, now visible as an isolated body separated from its original surroundings

Retrograde metamorphism — recrystallization of pre-existing rocks as temperature and pressure are reduced after the peak of metamorphism; retrograde metamorphism occurs where some fluid remains in the system to catalyze reactions and typically involves hydration of minerals in contrast to the dehydration that characterizes prograde metamorphism

Ribbed moraine — a subglacially (i.e. under a glacier or ice sheet) formed type of moraine that mainly occurs in Fennoscandia, Scotland, Ireland and Canada; ribbed moraines cover large areas that were previously overlain by ice and occur mostly in what is believed to have been the central areas of the ice sheets.

Ribbon Lake — a long, narrow and deep, lake occupying the floor of a U-shaped glacial valley

Roof pendant — vertically oriented block of country rock, projecting downwards into and enclosed by an igneous intrusion, a remnant of the roof zone of the intrusion

Sandflat — a sand-dominated intertidal area which is submerged at high tide and exposed at low tide, normally associated with inlets, estuaries or shallow bays

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

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

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 giving the rock a fabric known as schistosity

Schistosity — planar alignment of platy minerals in metamorphic rocks in response to pressure, giving rise to a strong planar fabric throughout the rock

Scree — loose debris or talus deposits comprising angular stones and boulders

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

Semipelite — metamorphosed siltstone

Shaft — a vertical or inclined 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

Shear zone — an elongate area or region where rocks have undergone intense deformation

Sill — a tabular mass of igneous rock that has been intruded horizontally between layers of existing rock

Siltstone — similar to mudstone but with a predominance of silt-sized (3.9–62.5 µm) particles

Skarn — calc-silicate rock formed by chemical reaction between limestone and adjacent rocks of different composition leading to replacement of original carbonate by calc-silicate minerals

Slate — metamorphosed mudstone, i.e. a fine-grained rock produced under conditions of high pressure, characterized by a cleavage along which the rock splits easily

Slide — in Donegal geology, a slide is synonymous with a *thrust fault*

Solifluction lobes — lobes of debris that have accumulated as a result of the slow, downslope movement of water saturated material under the influence of gravity.

Spinel — non-silicate mineral consisting typically of various elements, including Mg, Fe, Mn, Cr, etc., in combination with Al and O; the spinel series includes magnetite and chromite

Stratabound — confined to a single stratigraphic unit

Stratiform — (of a mineral deposit) formed parallel to the bedding planes of the surrounding rock [term used under Rejected sites/Pollan Bay]

Stratigraphy — the study of stratified (layered) sedimentary and volcanic rocks, especially their sequence in time

DRAFT

and correlation between localities

Stream oxbow caving term, similar to an oxbow lake at the surface where the river/stream takes a more direct route and cuts off a meander loop. A stream Oxbow occurs in caves where the river is flowing through the new direct route as well as the original meander loop.

Stromatolites an algal deposit usually found in shallow water

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

Syenite a coarse-grained grey igneous rock composed mainly of alkali feldspar and ferromagnesian minerals such as hornblende

Subduction the sinking of one crustal plate beneath the edge of another through the process of plate tectonic.

Syncline basin-shaped fold in which upper strata are younger than lower, underlying strata

Syringopora colonial coral in which stem-like skeletal parts that protected the living organism formed mound-like accumulations

Talc Mg-rich platy or sheet-like mineral (phyllosilicate), with the lowest hardness (1) on the standard Mohs scale (1-10) of hardnes.

Talc schist metamorphic rock composed mostly of talc in which schistosity is defined by alignment of platy talc crystals

Tectonic banding banding in rock that is a consequence of deformation rather than reflecting original rock texture

Texture of rock the sizes and shapes and interelationships of particles in a rock

Thrust fault a low-angle (< 45°) reverse fault

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 also called diamictite and mixtite, is made up of till, later cemented to form rock

Tombolo a narrow depositional landform such as a sand spit or bar that connects an island to the mainland or to another island (it has a beach on each of its sides).

Tonalite an igneous, plutonic (intrusive) rock, of felsic composition, with phaneritic texture. Feldspar is present as plagioclase (typically oligoclase or andesine) with 10% or less alkali feldspar. Quartz is present as more than 20% of the rock.

Tor a large, free-standing rock outcrop that rises abruptly from the surrounding smooth and gentle slopes of a rounded hill summit or ridge crest

Transgression an incursion of the sea over land area

Transpression a tectonic regime where compression is combined with movement along the strike (strike-slip movement) of a fault

Trilobites extinct arthropods

Turbidity Current underwater density current carrying suspended sediment at high speed down a subaqueous slope. The resulting deposit is called a turbidite.

Ultrabasic rock an igneous rock with a very low (< 45%) silica (SiO_2) content, typically with little or no feldspar, and rich in one or more mafic minerals such as pyroxene, olivine and amphibole

Ultramafic rock rocks in which >90% of the constituent minerals are dark-coloured (mafic) Fe- and Mg-rich minerals; partial synonym for "ultrabasic", a broader term that also includes some rocks that are not rich in Fe or Mg

Unconformable a sedimentary rock that was not deposited in chronological sequence with the rock on which it rests but rather after a significant period had passed during which the underlying rocks had undergone erosion

Unconformity a buried erosion surface separating two rock masses or strata of different ages, indicating that sediment deposition was not continuous

U-shaped valley also known as a glacial trough, this is formed by the process of glaciation and has a characteristic U shape, with steep, straight sides and a flat bottom. Glaciated valleys are formed when a glacier travels across and down a slope, carving the valley by the action of scouring.

Volcanic Rock any rock produced from volcanic material, e.g. ash, lava

Volcaniclastic rock material, derived from a volcanic eruption, re-deposited as a sedimentary rock, e.g. a sandstone, as an aggregate of small particles.

Xenolith fragment of rock of different composition enclosed in igneous rock during magma intrusion

Zaphrentid coral solitary, cup- or inverted-horn-shaped coral

DRAFT

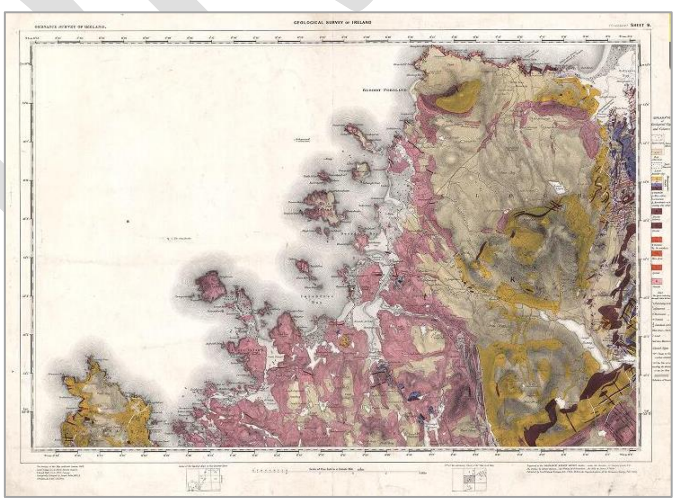
Data sources on the geology of Donegal

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 (called GOLDMINE) is freely available online, into which about half a million documents and maps have been scanned. This means that any user can search on screen for data of relevance to them. **Data is available free of charge**.

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

1:100,000 Map Report Series
All historical, modern and other mapping has been compiled into very useful maps and reports that describe the geology of the entire country. Sheet 3/4 covers South Donegal while Sheets 1/2 and 3/4 collectively cover north Donegal.

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



Sheet No. 9 – Gweedore GSI 1:63,360 geological map. Published in 1889

DRAFT

19th century one-inch maps and Memoirs

Information from the detailed 19th century mapping was distilled into one-inch-to-one-mile maps, of which parts of Sheets 9, 10, 11, 15, 16, 17, 22, 23, 24, 25, 30, 31 and 32 cover South Donegal and parts of Sheets 1, 2, 3, 4, 5, 6, 9, 10, 11, 12, 15, 16, and 17 cover north Donegal. 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 (EMD, currently of the Department of Communications, Climate Action and Environment) carries an obligation on the exploration company to lodge records of the work undertaken, for public access. These records are held by the Geological Survey and are available as Open File Data, once a period of time has expired. They may include geological interpretations, borehole logs, geophysical and geochemical surveys and so on. Licences relate to numbered prospecting areas, and these are available on a map from EMD. See also www.mineralsireland.ie

MinLocs Data

The MinLocs Database records all known mineral occurrences, however small, from Geological Survey Ireland records, such as 19th century field sheets and Open File data. Also available on the Geological Survey Ireland online Viewer.

Historic Mine Records

Abandonment plans and varied other material exists for the various mining ventures in the country, including Crohy head talc mine.

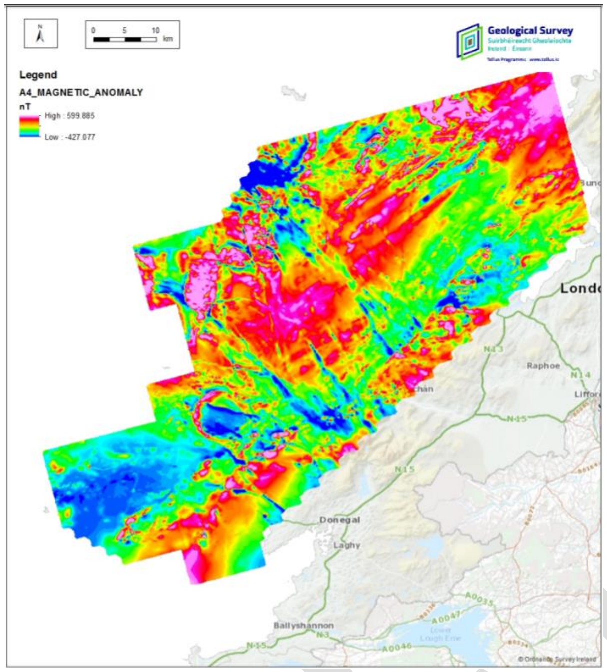
Subsoils Mapping

Since a Groundwater Protection Scheme has been completed (revised 2012) for County Donegal by Geological Survey Ireland, a recently completed map of the subsoil types and depths across County Donegal exists, as well as the previously completed bedrock mapping. This provides a significant resource in general terms as well as for groundwater protection. Customised output is possible. Further more detailed compilation of glacial geology datasets, including a revision published by Geological Survey Ireland in late 2015, provides more options. Digital mapping of many different datasets is now available via the Geological Survey Ireland website: www.gsi.ie

Tellus Data

The Tellus survey is a Geological Survey Ireland national programme to gather geochemical and geophysical data, in order to examine the chemical and physical properties of our soil, rocks and water. 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. The EU INTERREG IVA **Tellus Border** project, which included County Donegal, was successfully completed in 2013.

DRAFT



Residual magnetic anomaly for A4 Block Donegal (2017)

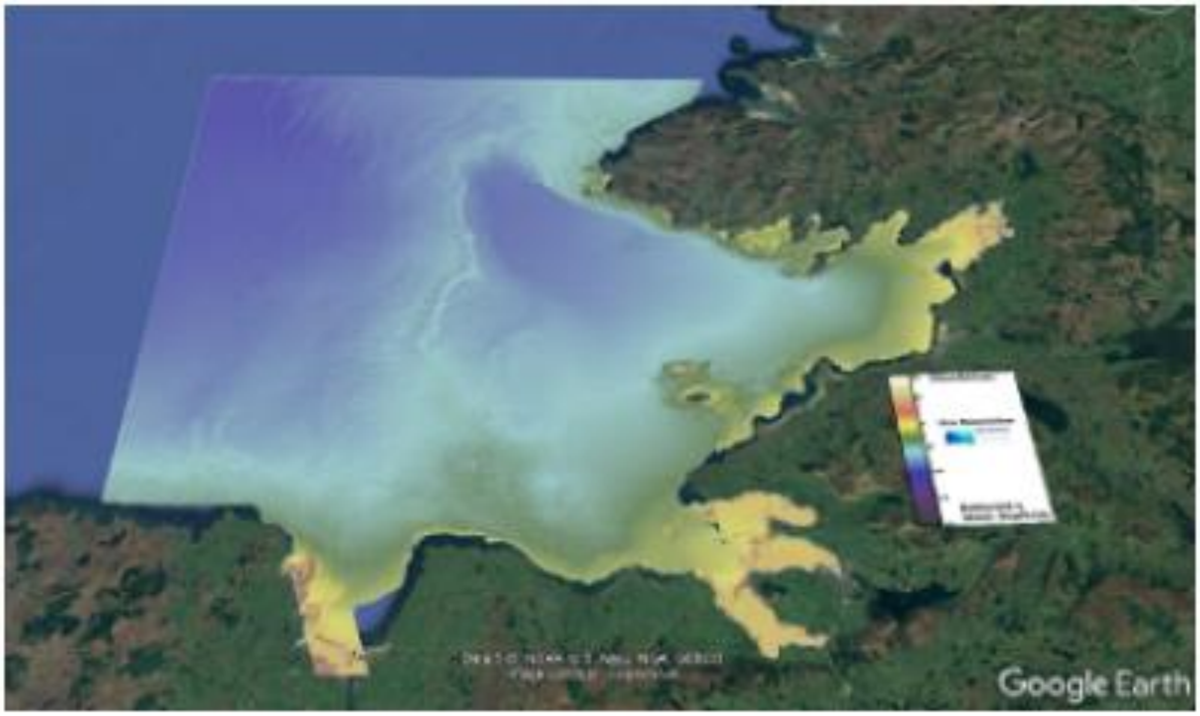
County Donegal was surveyed during 2017 (A4 Block) and data was released in early 2018. All data from Tellus is freely available online at https://www.gsi.ie/en-ie/data-and-maps/Pages/Geophysics.aspx

INFOMAR data

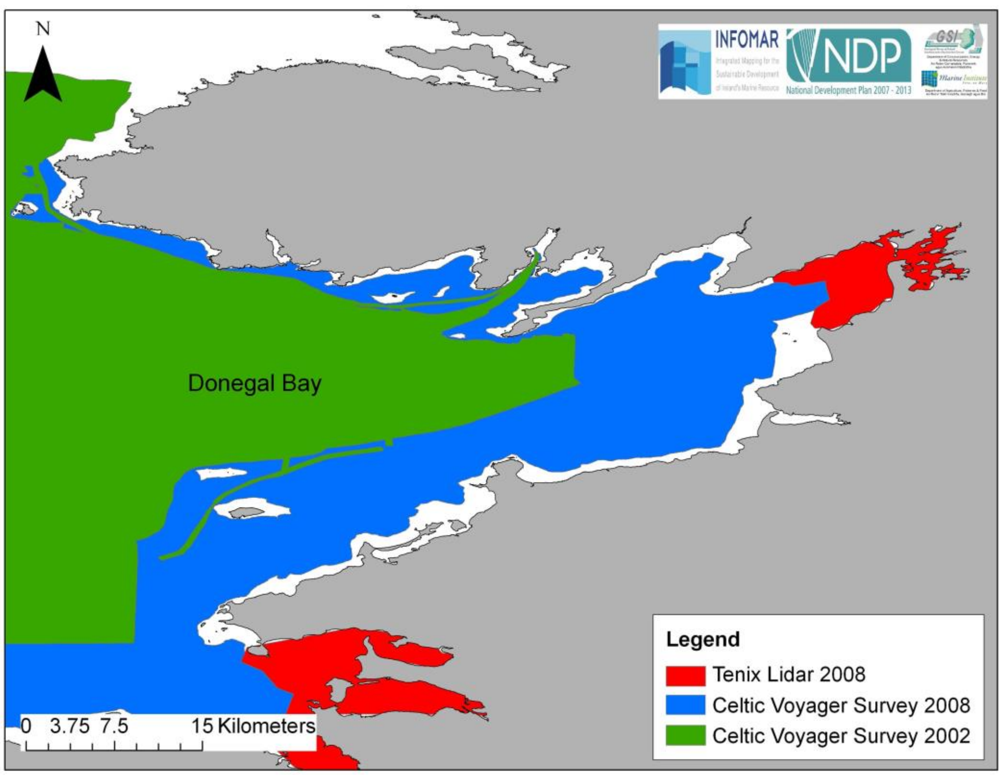
The original Irish National Seabed Survey, carried out by Geological Survey Ireland and the Marine Institute (1999-2005), focused on deep-water mapping at the outer margins of Ireland's territorial seabed, moving closer shoreward over time. Its successor programme, INFOMAR (*INtegrated mapping FOr the sustainable development of Ireland's MArine Resource*) is in the process of mapping inshore areas, identifying 26 priority bays, including Donegal Bay. It should be noted that Donegal's adjacent continental shelf covers at least twice the area of the county onshore. The INFOMAR survey operations have also been conducted at Sheep Haven and Gola Island.

INFOMAR survey operations for Donegal have extended Donegal Bay farther inshore from existing coverage. For more information about INFOMAR data, see: https://www.infomar.ie/

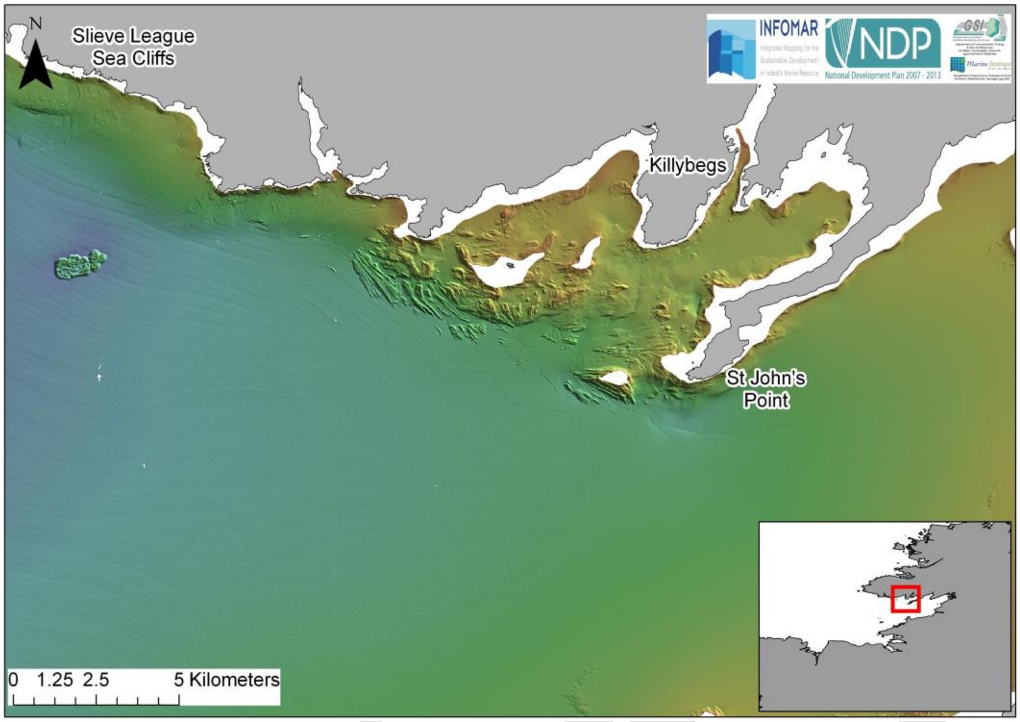
There may be scope for integrating 3D onshore and offshore INFOMAR data (see the EMODnet - European Marine Observation and Data Network http://www.emodnet.eu), as in the Copper Coast Geopark, County Waterford where it has been successfully used to develop various 3D films and video fly-throughs as tourism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



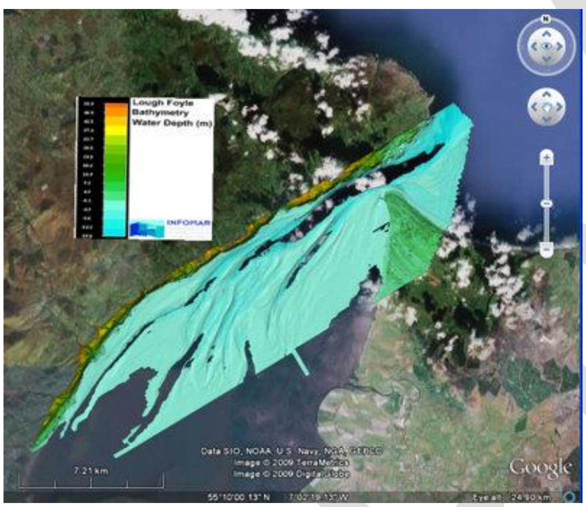
Bathymetry LIDAR map of Donegal Bay



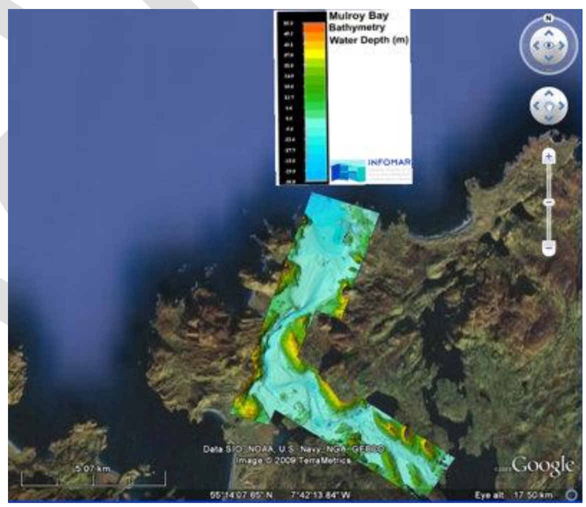
INSS and INFOMAR surveys carried out in Donegal Bay, 2002-2008.



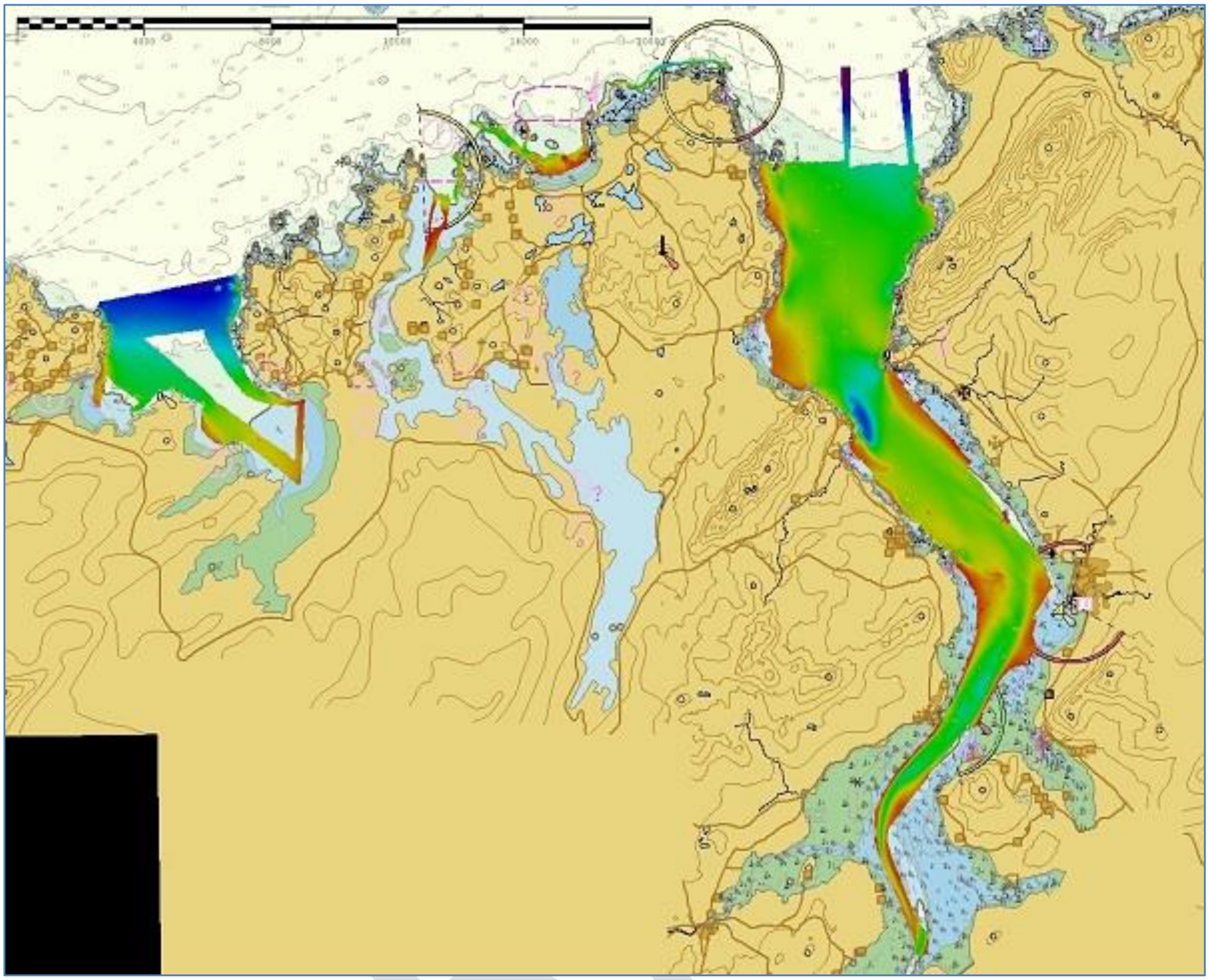
MBES image showing a section of coastline from Slieve League cliffs in the west to St. John's Point in the east.



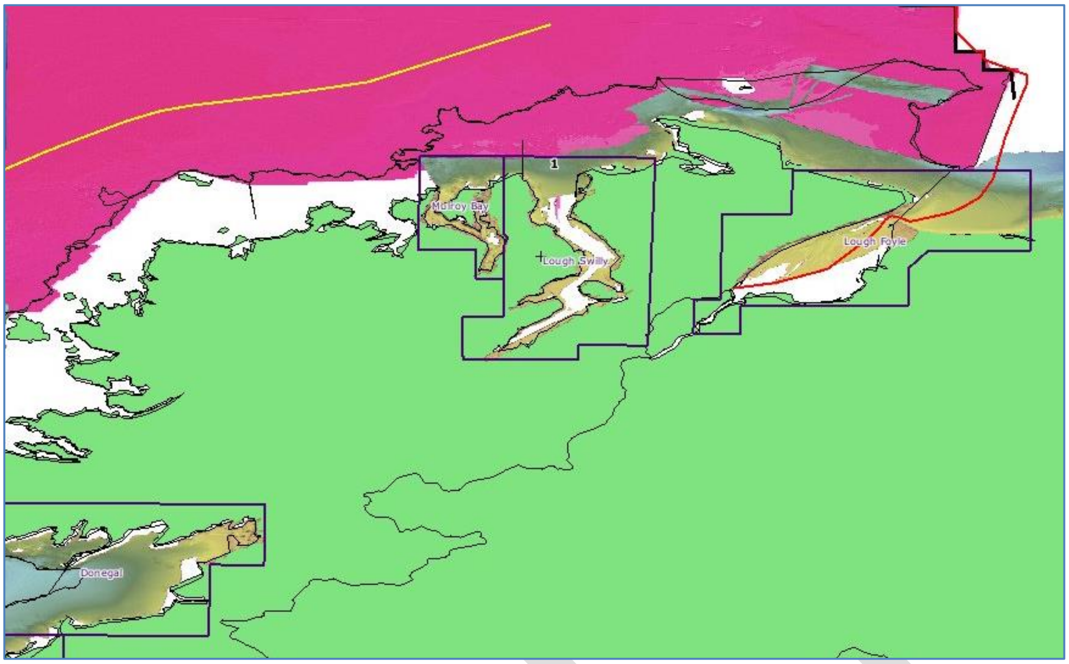
Lough Foyle LIDAR Survey coverage



Mulroy Bay LIDAR Survey coverage



Survey coverage of Lough Swilly, Mulroy Bay and Sheephaven Bay (RV Keary and the Cosantóir Bradán, Summer 2014)



INSS and INFOMAR surveys carried out off north Co. Donegal (2002-2014)

DRAFT

Shortlist of Key Geological References

North Donegal Audit

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

BIRD, E. 2010. Ireland, in Encyclopedia of the World's Coastal Landforms Bird, E. (ed). Dordrecht, Springer Science and Business Media, p. 545-556.

EDWARDS, K. J. and WARREN, W. P. (eds.) 1985. The Quaternary History of Ireland. Academic Press, 382 pp.

HOLLAND, C. H. and SANDERS, I. (eds.) 2009. The Geology of Ireland. 2009 (Second Edition) Dunedin, Edinburgh. 568 pp.

Flowerdew, M. and McKeever, P.J. 2001. Walk Donegal. Geological Survey of Northern Ireland, Belfast.

GRAY, M. 2004. Geodiversity: Valuing and Conserving Abiotic Nature. John Wiley & Sons Ltd, Chichester

HOLLAND, C. H. and SANDERS, I. (eds.) 2009. The Geology of Ireland. (Second Edition) Dunedin, Edinburgh. 568 pp.

KENNAN, P. 1995. Written in Stone. Geological Survey Ireland. 50 pages.

LONG, C.B. 2009. What you wanted to know about the Dalradian but didn't like to ask. Earth Science Ireland, Issue 6, p. 7-10. See http://www.earthscienceireland.org/.

LONG, C.B. and McCONNELL, B. 1997. Geology of North Donegal. A geological description to accompany the Bedrock Geology 1:100,000 Scale Map Series, Sheet 1 and part of Sheet 2, North Donegal, with contributions from O'Connor, P., Claringbold, K., Cronin, C. and Meehan, R. Geological Survey Ireland. viii + 79 pp.

LONG, C.B. and MCCONNELL, B. 1999. Geology of South Donegal. A geological description to accompany the Bedrock Geology 1:100,000 Scale Map Series, Sheet 3/4, South Donegal. With contributions from Alsop, G.I, O'Connor, P., Claringbold, K. and Cronin, C. Geological Survey Ireland. 116 pp.

McCABE A. M. 2008. Glacial geology and geomorphology: the landscapes of Ireland. Dunedin Academic Press, Edinburgh. 274pp.

MEERE, P. MACCARTHY, I, REAVY, J., ALLEN, A. and HIGGS, K. 2013. Geology of Ireland: A Field Guide. The Collins Press. 256 pp.

MITCHELL, G.F. and RYAN, M., 1997. Reading the Irish Landscape. Town House Press, 397 pp.

DRAFT

Mitchell, W.I. (ed.) 2004. The Geology of Northern Ireland: Our Natural Foundation (second edition). Geological Survey of Northern Ireland, Belfast.

Mitchell, I., Cooper, M., McKeever, P.J. and McConnell, B. 2010. The Classic Geology of the North of Ireland. Geological Survey of Northern Ireland, Belfast. 94 pp.

Pitcher, W.S. and Berger, A.R. 1972. The Geology of Donegal: A study of Granite emplacement and unroofing. Wiley-Interscience, New York and London. 435 pp.

South Donegal Audit

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

Holland, C. H. and Sanders, I. eds. (2009) The Geology of Ireland. 2009 (Second Edition) Dunedin, Edinburgh. pp568.

Flowerdew, M and McKeever, P J. (2001) Walk Donegal. Geological Survey of Northern Ireland, Belfast.

Long, B. 2009. What you wanted to know about the Dalradian but didn't like to ask. *Earth Science Ireland*, Issue 6, pages 7-10.

Long, C.B. and McConnell, B. (1999) Geology of South Donegal. A geological description to accompany the Bedrock Geology l:l00,000 Scale Map Series, Sheet 3/4, South Donegal. Geological Survey Ireland. 116 pp.

Mitchell, W.I. ed. (2004) The Geology of Northern Ireland Our Natural Foundation (second edition) Geological Survey of Northern Ireland, Belfast.

Mitchell, I, Cooper, M. McKeever, P. and McConnell, B. (2010) The Classic Geology of the North of Ireland.

Pitcher, W.S. and Berger, A.R. (1972) The Geology of Donegal: A study of Granite emplacement and unroofing. Wiley-Interscience, New York and London. 435 pp.

Full Geological references

See Appendix 2 for the full reference list of papers, books, articles and some unpublished reports etc. relating to the geology and geomorphology of County Donegal.

Quaternary References

The references in Appendix 3 are all relating to the Quaternary, or Ice Age, geology of County Donegal.

Mining References

The references in Appendix 4 are all relating to the Mining and Mineralogy of north Donegal. Assistance with locating these references may be provided by the Mining Heritage Trust of Ireland if required.

DRAFT

Further sources of information and contacts

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

Web sites of interest

www.gsi.ie - for general geological resources
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

Acknowledgements

The authors of the south Donegal Audit would like to gratefully acknowledge the assistance of Joe Gallagher, Heritage Officer from Donegal County Council in the development of this project. Funding from the Heritage Council and Donegal County Council is also acknowledged. We also acknowledge the many members of the Geoheritage Programme (IGH) Expert Panels who helped define the sites which were considered for County Geological Site status. Barry Long is thanked for his considerable input and stimulating discussions that helped improve understanding of Donegal geology. Dr Brian McConnell is thanked for providing additional data and material. Dr John Graham is also acknowledged for his helpful comments. Dr Matthew Parkes is gratefully acknowledged for helpful suggestions and his ongoing support to the Geoheritage Programme.

Malcolm McClure acknowledges with thanks Helene Burningham of University College London for discussions on geomorphology of the west coast of Donegal; Darragh McDonough of Donegal County Council GIS section for help with mapping; Michael Philcox for providing access to his unpublished reports on the Carboniferous of the Donegal Basin; Ruth McManus, editor of Irish Geography, for permission to reproduce the map of glaciation on Slieve League Peninsula; Tim Cranley for providing background on mineral exploration in Donegal; and in particular Una McClure for practical support during the period of field surveys.

In addition the authors of the north Donegal Audit would like to gratefully acknowledge the assistance of Joe Gallagher, Heritage Officer from Donegal County Council in the development of this project. Funding from the Heritage Council and Donegal County Council is also acknowledged. We also acknowledge the many members of the Geoheritage Programme (IGH) Expert Panels who helped define the sites which were considered for County Geological Site status.

DRAFT

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 Geoheritage and Planning Programme of Geological Survey Ireland and the local authority Heritage Officer.

Geology is now recognised as an intrinsic component of natural heritage in three separate pieces of legislation or regulations, which empower and require various branches of Government, and statutory agencies, to consult and take due regard for conservation of geological heritage features: Planning and Development Act 2000 [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 opposite illustrates the essential process, established by theGeoeritage Programme (IGH) in Geological Survey Ireland, over the course of numerous county audits since 2004.

Geological Heritage in the Donegal County Development Plan 2012-2018

The current County Donegal Development Plan includes many policies, actions and objectives that address the promotion and protection of geological and related heritage, as summarised below.

The SEA Statement on the Strategic Environmental Assessment of the CDP includes environmental vulnerabilities (section 2.3), under which areas of the County most sensitive to development were mapped, including Natura 2000 (SAC, SPA), Natural Heritage Area (NHA), Proposed Natural Heritage Area (pNHA), Geological sites and Aggregate Potential areas.
Under section 6.1 (Natural Heritage) of the CDP there is reference to the preparation of a Landscape Character Assessment to provide a framework for the identification, assessment, protection, management and planning of the landscape (and seascape) of County Donegal (NH-O-7); and to the protection of the character of the landscape (NH-O-8).

Section 7.1 (Extractive Industry and Geology) outlines the Council's policy to protect County Geological Sites (CGS), with the requirement for an accompanying detailed report to ensure an informed decision where there is potential significant harm to the CGS. Planning permission will not be granted unless there are overriding considerations of public importance to the County.

The CDP Environmental Report (Appendix C) sets out the existing known and available baseline environmental data for the County that have contributed to configuring the Strategic Environmental Objectives as presented in Section 8.0. This provides an environmental picture of the County that all emerging policies and objectives of the plan must be assessed and evaluated against. Table 20 lists the 114 CGS (including those to be designated as geological NHAs), as originally identified by the IGH

Programme for the whole of County Donegal, for information purposes. It is envisaged that this table will be updated with the latest site data available from both the south and north Donegal audits.

The completed audits for Donegal continue to contribute to and support the above policies of this and future Donegal County Development Plans.

DRAFT

County Geological Sites - a step by step guide

Commission and delivery of an audit of geological heritage sites within the Local Authority area

This is normally an objective in the County Heritage Plan, and is achieved with funding from the Heritage Council, the Local Authority and the Geological Survey of Ireland. The result is a report with proposals for County Geological Sites (CGS)

↓

Integration of County Geological Sites into Planning System

This is normally the task of the Heritage Officer to communicate the results of the audit of County Geological Sites to colleagues within the Planning Department and the Local Authority generally, so that they can be used immediately for informal guidance

↓

Integration of County Geological Sites into County Development Plan on its revision cycle

The IGH Programme recommends that the Planning Department of the Local Authority proposes the list of recommended County Geological Sites for inclusion in the County Development Plan on its next normal cycle of revision. The CGS list may be subject to amendment based on planning advice, community representation and public input to the Draft Plan, as well as Councillor’s decisions during the adoption process

↓

County Geological Sites and Natural Heritage Areas

Some CGS may have been coincident with existing pNHA layers in the Planning Department GIS. As the Geological Survey of Ireland IGH work programme progresses, recommendations for geological NHAs will be made to the National Parks and Wildlife Service. The Planning Department may then receive notification of new NHAs which include some of the CGS sites which will then receive statutory protection as NHAs

↓

Promotion of County Geological Sites

The Heritage Officer supported by colleagues, GSI etc can promote educational, research and amenity use of CGS

Consultation on County Geological Sites

If any planning application is received which affects a CGS, the GSI should be routinely consulted as a prescribed body

Appendix 2. Bibliography – Bedrock Geology

GEOLOGY REFERENCES WITH DIRECT REFERENCE TO:

North Donegal

AKAAD, M.K. 1956a. The Ardara granitic diapir of County Donegal, Ireland. Quarterly Journal of the Geological Society of London 112, 263-288.

AKAAD, M.K. 1956b. The northern aureole of the Ardara pluton of County Donegal. Geological Magazine 93, 377-392.

AL-RAWI, M.M. 1972. Stratigraphy and sedimentology of the basal Carboniferous sandstones in the Donegal syncline, N.W. Ireland. Unpublished Ph.D. thesis, University of London.

ALSOP, G.I. 1987. The Dalradian of central Donegal, Ireland: An example of a polyphase mid-crustal thrust zone. Unpublished Ph.D. thesis, University of Durham.

ALSOP, G.I. 1988. Unpublished manuscript map, incorporating unpublished 1987 thesis map and unpublished extension (dyeline).

ALSOP, G.I. 1991. Gravitational collapse and extension along a mid-crustal detachment: the Lough Derg Slide, northwest Ireland. Geological Magazine 128, 345-354.

ALSOP, G.I. 1992a. Reversals in the polarity of structural facing across an early ductile thrust: the Central Donegal Slide, northwest Ireland. Geological Journal 27, 3-14.

ALSOP, G.I. 1992b. Late Caledonian sinistral strike-slip displacement across the Leannan Fault system, northwest Ireland. Geological Journal 27, 119-125.

ALSOP, G.I. 1992c. Gravity-driven extensional collapse of an oblique ductile thrust; the Ballybofey Slide, northwest Ireland. Irish Journal of Earth Sciences 11, 165-175.

ALSOP, G.I. 1992d. Progressive deformation and the rotation of contemporary fold axes in the Ballybofey Nappe, north-west Ireland. Geological Journal 27, 271-283.

ALSOP, G.I. 1993. Sequential generation of listric shear bands during protracted ductile thrusting within the Ballybofey Nappe, north-west Ireland. Irish Journal of Earth Sciences 12, 1-12.

ALSOP, G.I. 1994a. The geometry and structural evolution of a crustal-scale Caledonian fold complex: the Ballybofey Nappe, northwest Ireland. Geological Magazine 131, 519-537.

ALSOP, G.I. 1994b. Relationships between distributed and localized shear in the tectonic evolution of a Caledonian fold and thrust zone, northwest Ireland. Geological Magazine 131, 123-136.

ALSOP, G.I. 1996. Tectonic analysis of progressive secondary deformation in the hinge of a major Caledonian fold nappe, north-western Ireland. Geological Journal 31, 217-233.

ALSOP, G.I., BRYSON, R. and HUTTON, D.H.W. 2001. Tectonic and kinematic evolution witin mid-crustal orogenic root zones: a case study from the Caledonides of northwestern Ireland. Geological Magazine 138,193-221.

ALSOP, G.I. and HUTTON, D.H.W. 1990. A review and revision of Dalradian stratigraphy in central and southern Donegal, Ireland. Irish Journal of Earth Sciences 10, 181-198.

DRAFT

ALSOP, G.I. and HUTTON, D.H.W. 1993. Major southeast-directed Caledonian thrusting and folding in the Dalradian rocks of mid-Ulster: implications for Caledonian tectonics and mid crustal shear zones. Geological Magazine 130, 233-244.

ALSOP, G.I. and HUTTON, D.H.W. 1994. Reply to discussion on major southeast-directed Caledonian thrusting and folding in the Dalradian rocks of mid-Ulster: implications for Caledonian tectonics and mid-crustal shear zones. Geological Magazine 131, 419-421.

ALSOP, G.I., BRYSON, R. and HUTTON, D.H.W. 1998. Ductile transpression and localization of deformation along tectonic boundaries in the Caledonides of northwestern Ireland. Geological Magazine 135, 699-718.

Alsop, G. I., Prave, A. R., Condon, D. J., and Phillips, C. A. 2000. Cleaved clasts in Dalradian conglomerates: possible evidence for Neoproterozoic compressional tectonism in Scotland and Ireland? Geological Journal, 35, (2), 87-98.

ANDERSON, J.G.C. 1948. The occurrence of Moinian rocks in Ireland. Quarterly Journal of the Geological Society of London 103, 171-190.

ANDERSON, T.B. 1978. Day 5: The Rosguill Peninsula: structure and stratigraphy of the Dalradian Appin Group. In: Anderson, T.B., Hutton, D.H.W., Phillips, W.E.A. and Roberts, J.C. Field guide to a traverse in the north-western Irish Caledonides. Geological Survey Ireland Guide Series 3, 45-50.

ANDERTON, R. 1980. Distinctive pebbles as indicators of Dalradian provenance. Scottish Journal of Geology 16, 143-152.

ARTHUR, M.J. and HUTTON, D.H.W. 1987. Discussion on a tectonic model for the emplacement of the Main Donegal Granite, NW Ireland. Journal of the Geological Society of London 144, 201-203.

ARTHURS, J.W. 1994. Discussion on major southeast-directed Caledonian thrusting and folding in the Dalradian rocks of mid-Ulster: implications for Caledonian tectonics and mid-crustal shear zones. Geological Magazine 131, 417-421.

ATHERTON, M.P. 1980. The occurrence and implications of chloritoid in a contact aureole andalusite schist from Ardara, County Donegal. Journal of Earth Sciences, Royal Dublin Society 3, 101-10

ATHERTON, M.P. and GHANI, A.A. 2002. Slab breakoff: a model for Caledonian, Late Granite syn-collisional magmatism in the orthotectonic (metamorphic) zone of Scotland and Donegal, Ireland. Lithos 62, 65-85.

BARRACLOUGH, A.K. 1981. Sedimentology of the Crinan Grits and associated Dalradian sediments in Argyll and Donegal. Unpublished Ph.D. thesis, University of Strathclyde.

BAYLISS, J. 1988. The geology of NW Inishowen, County Donegal, Ireland. Unpublished B.Sc. thesis, Queen's University, Belfast.

BELL, A. 1992. The Donegal Granites: Dimension Stone Potential. Geological Survey Ireland Report Series 92/3. 139pp.

BERGER, A.R. 1971. The origin of banding in the Main Donegal Granite, NW Ireland. Geological Journal 7, 347-358.

BERGER, A.R. 1980. The structural setting of the Main Donegal Granite; comments on a recent interpretation. Geological Journal 15, 3-6.

BLISS, G.M., GRANT, P.R., MAX, M.D. and DIVER, W.L. 1978. Sedimentary and diagenetic features in the Sessiagh-Clonmass Formation of the Dalradian Ballachulish Subgroup. Geological Survey Ireland Bulletin 2, 189-204.

BLUCK, B.J. and DEMPSTER, T.J. 1991. Exotic metamorphic terranes in the Caledonides: Tectonic history of the Dalradian block, Scotland. Geology 19, 1133-1136.

BOWES, D.R. and HOPGOOD, A.M. 1975. Structure of the gneiss complex of Inishtrahull, Co. Donegal. Proceedings of the Royal Irish Academy 75B, 369-390.

BROWN, G.C., FRANCIS, E.H., KENNAN, P. and STILLMAN, C.J. 1985. Caledonian igneous rocks of Britain and Ireland. In: Harris, A.L. (ed.) The Nature and Timing of Orogenic Activity in the Caledonian Rocks of the British Isles. Memoir of the Geological Society of London 9, 1-15 and plate 1.

BULLERWELL, W. 1961. The gravity map of Northern Ireland. Irish Naturalists' Journal 13, 255-257.

BURKE, K.C., CUNNINGHAM, M.A., GALLAGHER, M.J. and HAWKES, J.R. 1964. Beryl in the Rosses Granite, northwest Ireland. Economic Geology, 59, 1539-1550.

CAREY, M.J. 1995. The petrology and emplacement of the Fanad Granite, County Donegal, Ireland. Unpublished Ph.D. thesis, University of Dublin.

CHENEVIX-TRENCH, J.R. 1975. The Lower Dalradian rocks of the Fortwilliam and Creeslough areas. Unpublished Ph.D. thesis, University of Newcastle upon Tyne.

CHURCH, W.R. 1964. Metamorphic eclogites from Co. Donegal, Eire. Indian Mineralogist I.M.A. New Delhi, Special Number, 22-23.

CONDON, D.J. and PRAVE, A.R. 2000. Two from Donegal: Neoproterozoic glacial episodes on the northeast margin of Laurentia, Geology, 28, 10, 951-954

DALY, J.S. and MENUGE, J.F. 1989. Nd isotopic evidence for the provenance of Dalradian Supergroup sediments in Ireland. Terra Abstracts 1, 12.

DALY, J.S., MUIR, R.J. and CLIFF, R.A. 1991. A precise U-Pb zircon age for the Inishtrahull syenitic gneiss, County Donegal, Ireland. Journal of the Geological Society, London 148, 639-642.

DEMPSEY, C.S., HALLIDAY, A.N. and MEIGHAN, I.G. 1990. Combined Sm-Nd and Rb-Sr isotope systematics in the Donegal granitoids and their petrographic implications. Geological Magazine 127, 75-80.

DEWEY, J.F. and SHACKLETON, R. M. 1984. A model for the evolution of the Grampian tract in the early Caledonides and Appalachians. Nature, London 312, 115-121.

DICKIN, A.P. 1992. Evidence for an Early Proterozoic crustal province in the North Atlantic region. Journal of the Geological Society of London 149, 483-486.

DICKIN, A.P. and BOWES, D.R. 1991. Isotopic evidence for the extent of early Proterozoic basement in Scotland and northwest Ireland. Geological Magazine 128, 385-388.

DICKINSON, B. 1973. The Leannan Fault in the Malin Head Peninsula, Co. Donegal, Eire. Geological Journal 8, 399-405.

ELSDON, R. 1986. Petrology, structure and age of the Rough Point sill, Donegal. Geological Journal 21, 151-168.

ELSDON, R. and TODD, S.P. 1989. A composite spessartite-appinite intrusion from Port-na-Blagh, County Donegal, Ireland. Geological Journal 24, 97-112.

EVANS, D. 1973. A Shallow Seismic Survey in Lough Swilly and Trawbreaga Bay, Co. Donegal. Proceedings of the Royal Irish Academy. Section B: Biological, Geological and Chemical Science, 73, 207-216

EVANS, D. and WHITTINGTON, R.J. 1976. The submarine extensions of the Thorr and Fanad plutons, County Donegal. Proceedings of the Royal Irish Academy 76B, 111-120.

EYLES, C.H. 1988. Glacially- and tidally-influenced shallow marine sedimentation of the Late Precambrian Port Askaig Formation, Scotland. Palaeogeography, Palaeoclimatology, Palaeoecology 68, 1-25.

EYLES, C.H. and EYLES, N. 1983. Glaciomarine model for upper Precambrian diamictites of the Port Askaig Formation, Scotland. Geology 11, 692-696.

FERNÁNDEZ-DÁVILA U., M. 1969. The petrology and mode of emplacement of the Rosguill Pluton, County Donegal, Eire. Unpublished M.Sc. thesis, University of Liverpool.

FETTES, D.J., LONG, C.B., BEVINS, R.E., MAX, M.D., OLIVER, G.J.H., PRIMMER, T.J., THOMAS, L.J. and YARDLEY, B.W.D. 1985. Grade and time of metamorphism in the Caledonide orogen of Britain and Ireland. In: Harris, A.L. (ed.), The Nature and Timing of Orogenic Activity in the Caledonian Rocks of the British Isles. Memoir of the Geological Society of London 9, 41-53 and plate 3.

FITCHES, W.R., MUIR, R.J., MALTMAN, A.J. and BENTLEY, M.R. 1990. Is the Colonsay-west Islay block of SW Scotland an allochthonous terrane? Evidence from Dalradian tillite clasts. Journal of the Geological Society of London 147, 417-420.

FLOWERDEW, M.J. and DALY, J.S. 2005. Sm-Nd mineral ages and P-T constraints on the pre-Grampian high grade metamorphism of the Slishwood Division, Northwest Ireland. Irish Journal of Earth Sciences 23, 107-123.

FRANCIS, P. J., and KELLY, J.G. 1982. A Beach Find of a Jurassic Ammonite in Co Donegal. The Irish Naturalists' Journal. 401-402.

FRENCH, W.J. 1960. Appinitic intrusions associated with the granodioritic pluton of Ardara, County Donegal. Unpublished Ph.D. thesis, King's College, University of London.

FRENCH, W.J. 1966. Appinitic intrusions clustered around the Ardara pluton, County Donegal. Proceedings of the Royal Irish Academy 64B, 303-322.

FRENCH, W.J. 1977. Breccia-pipes associated with the Ardara pluton, County Donegal. Proceedings of the Royal Irish Academy 77B, 101-117.

FRENCH, W.J. 1978. Lamprophyric dykes associated with the appinitic intrusions of County Donegal. Scientific Proceedings of the Royal Dublin Society 6A, 97-107.

FRENCH, W.J. and PITCHER, W.S. 1959. The intrusion-breccia of Dunmore, County Donegal. Geological Magazine 96, 69-74.

GEOLOGICAL SURVEY OF NORTHERN IRELAND 1977. Geological map of northern Ireland (first edition). Sheet 1, 1:250,000. Geological Survey of Northern Ireland.

DRAFT

GEOLOGICAL SURVEY OF NORTHERN IRELAND 1997. Northern Ireland. Solid geology (second edition). 1:250,000. Keyworth, Nottingham; British Geological Survey.

GEOLOGICAL SURVEY OF NORTHERN IRELAND. 1994. Kesh. Northern Ireland Sheet 32 and part of 31. Solid Geology. 1:50,000. Keyworth, Nottingham; British Geological Survey.

GEOLOGICAL SURVEY OF NORTHERN IRELAND. 1995. Londonderry. Northern Ireland Sheet 11. Solid and Drift Geology. 1:50,000. (Keyworth, Nottingham: British Geological Survey).

GINDY, A.R. 1953. The plutonic history of the district around Trawenagh Bay, County Donegal. Quarterly Journal of the Geological Society of London 108, 377-411.

HALL, A. 1966. The Ardara pluton: A study of the chemistry and crystallization of a contaminated granite intrusion. Proceedings of the Royal Irish Academy 65B, 203-235.

HALLIDAY, A.N. 1984. Coupled Sm-Nd and U-Pb systematics in late Caledonian granites and the basement under northern Britain. Nature, London 307, 229-233.

HALLIDAY, A.N., AFTALION, M. and LEAKE, B.E. 1980. A revised age for the Donegal granites. Nature, London 284, 542-543.

HALLIDAY, A.N., GRAHAM, C.M., AFTALION, M. and DYMOKE, P. 1989. The depositional age of the Dalradian Supergroup: U-Pb and Sm-Nd isotopic studies of the Tayvallich Volcanics, Scotland. Journal of the Geological Society of London 146, 3-6.

HARRIS, A.L. and PITCHER, W.S. 1975. The Dalradian Supergroup. In: Harris, A.L., Shackleton, R.M., Watson, J., Downie, C., Harland, W.B. and Moorbath, S. (eds), A correlation of Precambrian rocks in the British Isles. Geological Society of London Special Report 6, 52-75.

HARRIS, A.L., BALDWIN, C.T., BRADBURY, H.J., JOHNSON, H.D. and SMITH, R.A. 1978. Ensialic basin sedimentation: the Dalradian Supergroup. In: Bowes, D.R. and Leake, B.E. (eds), Crustal evolution in northwestern Britain and adjacent areas. Geological Journal spec. issue 10, 115-138.

HARRIS, A.L., HASELOCK, P.J., KENNEDY, M.J. and MENDUM, J.R., with contributions by C.B. LONG, J.A. WINCHESTER and P.W.G. TANNER. 1994. The Dalradian Supergroup in Scotland, Shetland and Ireland. In: Gibbons, W. and Harris, A.L. (eds), A revised correlation of Precambrian rocks in the British Isles. Geological Society of London Special Report 22, 33-53.

HIGGS, K. 1984. Stratigraphic palynology of the Carboniferous rocks in northwest Ireland. Geological Survey Ireland Bulletin 3, 171-202.

HOLDER, M.T. 1981. Some aspects of intrusion by ballooning: The Ardara pluton. In: Coward, M.P. (ed.) Diapirism and gravity tectonics: Report of a tectonic studies group. Journal of Structural Geology 3, 93.

HOWARTH, R.J. 1967. The Boulder Bed group (Dalradian) of County Donegal, Eire. Unpublished Ph.D. thesis, University of Bristol.

HOWARTH, R.J. 1970. Principal components analysis of the geochemistry and mineralogy of the Portaskaig Tillite and Kiltyfanned Schist (Dalradian) of County of Donegal, Eire. Mathematical Geology 2, 285-302.

HOWARTH, R.J. 1971. The Portaskaig Tillite succession of County Donegal. Proceedings of the Royal Irish Academy 71B, 1-35.

HOWARTH, R.J., KILBURN, C. and LEAKE, B.E. 1966. The Boulder Bed succession at Glencolumbkille, County Donegal. Proceedings of the Royal Irish Academy 65B, 117-156.

HULL, E., KINAHAN, G.H., NOLAN, J., CRUISE, R.J., EGAN, F.W., KILROE, J.R., MITCHELL, W.F. and M`HENRY, A., with petrographical notes by J.S. HYLAND 1891. Explanatory memoir to accompany Sheets 3, 4, 5 (in part), 9, 10, 11 (in part), 15 and 16 of the maps of the Geological Survey Ireland comprising Northwest and Central Donegal. Memoirs of the Geological Survey Ireland.

HUTTON, D. 1978. Day 4: The Creeslough area: structure and stratigraphy of Dalradian metasediments in north-west Donegal. In: Anderson, T.B., Hutton, D.H.W., Phillips, W.E.A. and Roberts, J.C. Field Guide to a traverse in the north-western Irish Caledonides. Geological Survey Ireland Guide Series 3, 37-44.

HUTTON, D. 1981. The Main Donegal Granite: Lateral wedging in a synmagmatic shear zone. In: Coward, M.P. (ed.), Diapirism and gravity tectonics: Report of a tectonic studies group. Journal of Structural Geology 3, 93.

HUTTON, D.H.W. 1977a. The structure of Lower Dalradian rocks of the Creeslough area, Co. Donegal, with special reference to tectonic slides. Unpublished Ph.D. thesis, Queen's University, Belfast.

HUTTON, D.H.W. 1977b. A structural cross-section from the aureole of the Main Donegal Granite. Geological Journal 12, 99-112.

HUTTON, D.H.W. 1979a. Metadolerite age relationships in the Dalradian of northwest Donegal, Ireland and their orogenic significance. Geological Journal 14, 171-178.

HUTTON, D.H.W. 1979b. Dalradian structure in the Creeslough area, NW Donegal, Ireland. In: Harris, A.L., Holland, C.H. and Leake, B.E. (eds), The Caledonides of the British Isles - reviewed. Geological Society of London Special Publication 8, 239-41.

HUTTON, D.H.W. 1979c. The strain history of a Dalradian slide: using pebbles with low fluctuations in axis orientation. Tectonophysics 55, 261-273.

HUTTON, D.H.W. 1981. The structural setting of the Main Donegal Granite; a reply to comments on a recent interpretation. Geological Journal 16, 149-151.

HUTTON, D.H.W. 1982. A tectonic model for emplacement of the Main Donegal Granite, NW Ireland. Journal of the Geological Society of London 139, 615-631.

HUTTON, D.H.W. 1988. Granite emplacement mechanisms and tectonic controls: inferences from deformation studies. Transactions of the Royal Society of Edinburgh: Earth Sciences 79, 245-255.

HUTTON, D.H.W. 1992. Granite sheeted complexes: evidence for the dyking ascent mechanism. Transactions of the Royal Society of Edinburgh: Earth Sciences 83, 377-382.

HUTTON, D.H.W. and ALSOP, G.I. 1995. Extensional geometries as a result of regional scale thrusting: tectonic slides of the Dunlewy-NW Donegal area, Ireland. Journal of Structural Geology 17, 1279-1292.

HUTTON, D.H.W. and ALSOP, G.I. 1996a. The Swilly Slide: A major synmetamorphic, extensional, ductile fault in the Dalradian of Donegal. Irish Journal of Earth Sciences 15, 41-57.

HUTTON, D.H.W. and ALSOP, G.I. 1996b. The Caledonian strike-swing and associated lineaments in NW Ireland and adjacent areas: sedimentation, deformation and igneous intrusion patterns. Journal of the Geological Society, London 153, 345-360.

DRAFT

HUTTON, D.H.W. and ALSOP, G.I. 2004. Evidence for a major Neoproterozoic orogenic unconformity within the Dalradian Supergroup of NW Ireland. Journal of the Geological Society, London 161. 1-12.

INSTITUTE OF GEOLOGICAL SCIENCES. 1983. Malin. Sheet 55N 08W. Solid Geology. 1:250,000. Institute of Geological Sciences.

IYENGAR, S.V.P., PITCHER, W.S. and READ, H.H. 1954. The plutonic history of the Maas area, County Donegal. Quarterly Journal of the Geological Society of London 110, 203-228.

JOHNSTON, J.D. 1995. Pseudomorphs after ikaite in a glaciomarine sequence in the Dalradian of Donegal, Ireland. Scottish Journal of Geology 31, 3-9.

JOHNSTON, J.D. 1997. Localization of mid-crustal thrust ramps by metadolerite sheets in the Dalradian of northwest Ireland. Geological Magazine 134, 199-212.

JOLLEY, S.J. 1996. A mid-crustal linked ductile thrust zone, Breaghy Head, NW Donegal, Ireland. Journal of the Geological Society, London 153, 341-344.

KENNAN, P.S. 1997. Granite: A Singular Rock. Royal Dublin Society, Occasional Papers in Irish Science and Technology 15, 1-16.

KENNEDY, M.J. 1975. The Fleur de Lys Supergroup: stratigraphic comparison of Moine and Dalradian equivalents in Newfoundland with the British Caledonides. Journal of the Geological Society of London 131, 305-310.

KILBURN, C., PITCHER, W.S. and SHACKLETON, R.M. 1965. The stratigraphy and origin of the Portaskaig Boulder Bed Series (Dalradian). Geological Journal 4, 343-360.

Kilroe, J.R. and Mitchell, W.F. 1890. One inch geological map, Sheet 22, Glen Bay, Co. Donegal. Geological Survey Ireland.

KING, R.F. 1966. The magnetic fabric of some Irish granites. Geological Journal 5, 43-66.

KIRKLAND A.L., ALSOP, G.I. and PRAVE, A.R. 2008. The brittle evolution of a major strike-slip fault associated with granite emplacement: a case study of the Leannan Fault, NW Ireland. Journal of the Geological Society 165, 341-352.

KIRWAN, P.J., DALY, J.S. and MENUGE, J.F. 1989. A minimum age for the deposition of the Dalradian Supergroup sediments in Ireland. Terra Abstracts 1, 16.

KNILL, D.C. and KNILL, J.L. 1961. Time relations between folding, metamorphism, and emplacement of granite in Rosguill, County Donegal. Quarterly Journal of the Geological Society of London 117, 273-302.

KNILL, J.L. 1963. A sedimentary history of the Dalradian Series. In: Johnson, M.R.W. and Stewart, F.H. (eds), The British Caledonides. Oliver and Boyd, Edinburgh, 99-121.

Le BAS, M.J. and STRECKEISEN, A.L. 1991. The IUGS systematics of igneous rocks. Journal of the Geological Society of London 148, 825-833.

Le MAITRE R.W. (editor), BATEMAN, P., DUDEK, A., KELLER, J. et al. 1989. A Classification of Igneous rocks and Glossary of Terms: Recommendations of the International Union of Geological Sciences Subcommission on the Systematics of Igneous Rocks. Blackwell Scientific Publications, Oxford.

DRAFT

LEAKE, B.E. 1978. Granite emplacement: the granites of Ireland and their origin. In: Bowes, D.R. and Leake, B.E. (eds), Crustal evolution in northwestern Britain and adjacent regions. Geological Journal, Special Issue 10, 221-248.

LEAKE, B.E. 1982. Volcanism in the Dalradian. In: Sutherland, D.S. (ed.), Igneous rocks of the British Isles. Wiley-Interscience, Chichester, 45-50.

LEAKE, B.E. 1990. Granite magmas: their sources, initiation and consequent emplacement. Journal of the Geological Society of London 147, 579-589.

MacINTYRE, R.M., Van BREEMEN, O., BOWES, D.R. and HOPGOOD, A.M. 1975. Isotopic study of the gneiss complex, Inishtrahull, County Donegal. Scientific Proceedings of the Royal Dublin Society 5A, 301-309.

MARCANTONIO, F., DICKIN, A.P., McNUTT, R.H. and HEAMAN, L.M. 1988. A 1800-million-year-old Proterozoic terrane in Islay with implications for the crustal structure and evolution of Britain. Nature, London 335, 62-64.

MAX, M.D. 1977. Geological diving report at Malin Head, Co. Donegal. July 1977. Geological Survey Ireland Unpublished Report iv + 12pp. + appendices + 1 figure.

MAX, M.D. 1981. Geology of the sea area adjacent to Malin Head, Ireland. Progress in Underwater Science (New Series of the Report of the Underwater Association for Scientific Research Ltd.) 6, 65-69.

MAX, M.D. and INAMDAR, D.D. 1985. Magnetic and generalised geological compilation map of Ireland, 1:1,000,000 scale. Geological Survey Ireland.

MAX, M.D. and LONG, C.B. 1979. Basic volcanic rocks in the Dalradian of Ireland. In: Harris, A.L., Holland, C.H. and Leake, B.E. (eds), The Caledonides of the British Isles - reviewed. Geological Society of London Special Publication 8, 585-589.

MAX, M.D. and LONG, C.B. 1985. Pre-Caledonian basement in Ireland and its cover relationships. Geological Journal 20, 221-227.

MAX, M.D. and RIDDIHOUGH, R.P. 1975. The continuation of the Highland Boundary Fault in Ireland. Geology 3, 206-210.

McBRIDE, J.H., SNYDER, D.B., ENGLAND, R.W. and HOBBS, R.W. 1996. Dipping reflectors beneath old orogens: a perspective from the British Caledonides. GSA Today 6, 1-6.

McBRIDE, J.H., SNYDER, D.B., TATE, M.P., ENGLAND, R.W. and HOBBS, R.W. 1996b. Upper mantle reflector structure and origin beneath the Scottish Caledonides. Tectonics 14, 1351-1367.

McCALL, G.J.H. 1954. The Dalradian geology of the Creeslough Area, Co. Donegal. Quarterly Journal of the Geological Society of London 110, 153-173.

McCALLIEN, W.J 1936. A note on Dalradian pillow lavas, Strabane, County Tyrone. Proceedings of the Royal Irish Academy 43B, 13-22.

McCALLIEN, W.J. 1935. The metamorphic rocks of Inishowen, County Donegal. Proceedings of the Royal Irish Academy 42B, 407-442.

McCALLIEN, W.J. 1937. The geology of the Rathmullan district, County Donegal. Proceedings of the Royal Irish Academy 44B, 45-59.

McCONNELL, B.J. and LONG, C.B. 1997. Geology of North Donegal. Bedrock Geology 1:100,000 Scale Map Series, Sheet 1 and part of Sheet 2, North Donegal. With minerals information by Flegg, A.M., Stanley, G. and Claringbold, K. Geological Survey Ireland.

McERLEAN, M.A. 1992. A new shear criterion for rocks deformed in the magmatic state: examples from the Thorr Granite, Co. Donegal. Transactions of the Royal Society of Edinburgh: Earth Sciences 83, 494.

McERLEAN, M.A. 1993. Granitoid emplacement and deformation: a case study of the Thorr Pluton, Ireland, with contrasting examples from Scotland. Unpublished Ph.D. thesis, University of Durham.

MENEILLY, A.W. 1982. Regional structure and syntectonic granite intrusion in the Dalradian of the Gweebarra Bay area, Donegal. Journal of the Geological Society of London 139, 633-646.

MENEILLY, A.W. 1983. Development of early composite cleavage in pelites from west Donegal. Journal of Structural Geology 5, 83-97.

MORGAN, S. 1995. Discussion "The Ardara pluton, Ireland: deflating an expanded intrusion" a paper by R.H. Vernon and S.R. Paterson. Lithos 35, 129-133.

MUIR, R.J., FITCHES, W.R. and MALTMAN, A.J. 1992. The Rhinns Complex: A missing link in the Proterozoic basement of the North Atlantic region. Geology 20, 1043-1046.

MUIR, R.J., FITCHES, W.R. and MALTMAN, A.J. 1994. The Rhinns Complex: Proterozoic basement on Islay and Colonsay, Inner Hebrides, Scotland, and on Inishtrahull, NW Ireland. Transactions of the Royal Society of Edinburgh: Earth Sci. 85, 77-90.

MURTHY M.V.N. 1948. Camptonitic dyke rocks from Inishowen, County Donegal, Ireland. Transactions of the Geological Society of Glasgow 21, 205-206.

NAGGER, M.H., and ATHERTON, M.P. 1970. The composition and metamorphic history of some aluminum silicate-bearing rocks from the aureoles of the Donegal granites. Journal of Petrology 11, 549-589.

NOBLE, S.R., HYSLOP, E.K. and HIGHTON, A.J. 1996. High-precision U-Pb monazite geochronology of the c.806Ma Grampian Shear Zone and the implications for the evolution of the Central Highlands of Scotland. Journal of the Geological Society, London 153, 511-514.

O'Connor, M.C., Cooper, J.A.G., McKenna, J., and Jackson, D.W.T. 2010. Shoreline management in a policy vacuum: A local authority perspective. Ocean & Coastal Management, 53, 12, 769-778.

O'CONNOR, P.J., LONG, C.B., KENNAN, P.S., HALLIDAY, A.N., MAX, M.D. and RODDICK, J.C. 1982. Rb-Sr isochron study of the Thorr and Main Donegal Granites, Ireland. Geological Journal 17, 279-295.

O'CONNOR, P.J., REIMANN, C. and KURZL, H. 1988. A geochemical survey of Inishowen, Co. Donegal. Geological Survey Ireland Report Series RS 88/1 (Geochemistry). 41 pages.

O'CONNOR, P.J., LONG, C.B. and EVANS, J.A. 1987. Rb-Sr whole-rock isochron studies of the Barnesmore and Fanad plutons, Donegal, Ireland. Geological Journal 22, 11-23.

OBAID, T.M.S. 1967. Certain minor intrusions in County Donegal, Eire. Unpublished Ph.D. thesis, University of Liverpool.

OGLETHORPE, R.D.J. 1987. A mineralogical and chemical study of the interaction between granitic magma and pelitic country rock, Thorr Pluton, Co. Donegal, Eire. Unpublished Ph.D. thesis, University of Liverpool.

DRAFT

Parkes, M.A., Johnson, D., Simms, M.J. and KELLY, J.G. 1999. Geological guidance of speleogenesis in marble of the Dalradian Supergroup, County Donegal, Ireland. Cave and Karst Science, 26, 115-124.

PATERSON, S.R. and VERNON, R.H. 1995. Bursting the bubble of ballooning plutons: A return to nested diapirs emplaced by multiple processes. Bulletin of the Geological Society of America 107, 1356-1380.

PITCHER, W.S. 1950a. The igneous and metamorphic geology of the Thorr district, County Donegal. Unpublished Ph.D. thesis, Imperial College, University of London.

PITCHER, W.S. 1953a. The migmatitic older granodiorite of Thorr district, County Donegal. Quarterly Journal of the Geological Society of London 108, 413-446.

PITCHER, W.S. 1953b. The Rosses granitic ring-complex, County Donegal, Eire. Proceedings of the Geologists' Association 64, 153-182.

PITCHER, W.S. 1969. Northeast-trending faults of Scotland and Ireland, and chronology of displacements. In: Kay, M. (ed.), North Atlantic-Geology and Continental Drift. Memoir of The American Association of Petroleum Geologists 12, 724-733.

PITCHER, W.S. 1978. The anatomy of a batholith. Journal of the Geological Society of London 135, 157-182.

PITCHER, W.S. 1979. The nature, ascent and emplacement of granitic magmas. Journal of the Geological Society of London 136, 627-662.

PITCHER, W.S. 1987. Granites and yet more granites forty years on. Geologische Rundschau 76, 51-79.

PITCHER, W.S. 1992. The Rosses multi-pulse pluton: fractures and fractals. Transactions of the Royal Society of Edinburgh: Earth Sciences 83, 497.

PITCHER, W.S. 1997. The nature and origin of granite. Second edition. Chapman and Hall, London., xvi plus 387 pages.

PITCHER, W.S. and BERGER, A.R. 1972. The Geology of Donegal: A study of Granite emplacement and unroofing. Wiley – Interscience, New York and London, 435 pages.

PITCHER, W.S. and READ, H.H. 1959. The Main Donegal granite. Quarterly Journal of the Geological Society of London 114, 259-305.

PITCHER, W.S. and READ, H.H. 1960a. Early transverse dykes in the main Donegal granite. Geological Magazine 97, 53-61.

PITCHER, W.S. and READ, H.H. 1960b. The aureole of the Main Donegal granite. Quarterly Journal of the Geological Society of London 116, 1-36.

PITCHER, W.S. and READ, H.H. 1963. Contact metamorphism in relation to manner of emplacement of the granites of Donegal, Ireland. Journal of Geology 71, 261-296.

PITCHER, W.S. and SHACKLETON, R.M. 1966. On the correlation of certain Lower Dalradian successions in northwest Donegal. Geological Journal 5, 149-156.

PITCHER, W.S. and SINHA, R.C. 1958. The petrochemistry of the Ardara aureole. Quarterly Journal of the Geological Society of London 113, 393-408.

PITCHER, W.S., ELWELL, R.W.D., TOZER, C.F., and CAMBRAY, F.W. 1964. The Leannan fault. Quarterly Journal of the Geological Society of London 120, 241-273.

DRAFT

PITCHER, W.S., SHACKLETON, R.M. and WOOD, R.S.R. 1971. The Ballybofey Anticline: a solution of the general structure of parts of Donegal and Tyrone. Geological Journal 7, 321-328.

PITCHER, W.S., SOPER, N.J. and HUTTON, D.H.W. 1984. Discussion on a tectonic model for the emplacement of the Main Donegal Granite, Journal, Vol. 139, Part 5, 1982, pp. 615-631. Journal of the Geological Society of London 141, 599-602.

PORTLOCK, J.E. 1843. Report on the Geology of Londonderry and of parts of Tyrone and Fermanagh. Board of the Ordnance, Longmans, London.

POWELL, D. 1965. Comparison of calc-silicate bands from the Moine Schists of Inverness-shire with similar bands from Moine-like rocks in Donegal. Nature, London. 206, 180-181.

PRESTON, J. 1965. Tertiary feeder dykes in the West of Ireland. Proceedings of the Geological Society of London 1626, 149-150.

PRESTON, J. 1967. The Blind Rock dyke, County Donegal. Irish Naturalists' Journal 15, 286-293.

PULVERTAFT, T.C.R. 1961. The Dalradian successions and their relationships in the Churchill district of County Donegal. Proceedings of the Royal Irish Academy 61B, 255-273.

RAO, M.S. 1948. The dyke rocks of County Donegal and the adjoining part of County Tyrone, Ireland. Transactions of the Geological Society of Glasgow 21, 203-204.

RAST, N. 1963. Structure and metamorphism of the Dalradian rocks of Scotland. In: Johnson, M.R.W. and Stewart, F.H. (eds), The British Caledonides. Edinburgh, 123-142.

RICKARD, M.J. 1962. Stratigraphy and structure of the Errigal area, County Donegal, Ireland. Quarterly Journal of the Geological Society of London 118, 207-236.

RIDDIHOUGH, R.P. 1964. Magnetic survey off the north coast of Ireland. Nature, London 203, 747-748.

RIDDIHOUGH, R.P. 1968. Magnetic surveys off the north coast of Ireland. Proceedings of the Royal Irish Academy 66b, 27-41.

RIDDIHOUGH, R.P. 1969. Magnetic map of the Ardara Granite and southern County Donegal. Communications of the Dublin Institute for Advanced Studies Series D, Geophysical Bulletin No. 27, 1-3 plus map.

RIDDIHOUGH, R.P. and YOUNG, D.G.G. 1970. Gravity and magnetic surveys of Inishowen and adjoining areas off the north coast of Ireland. Proceedings of the Royal Society of London. 1644, 215-20.

ROBERTS, J. C. 1972. The structure of the Dalradian rocks between Glengad Head and Moville, eastern Inishowen, Co. Donegal. Proceedings of the Royal Irish Academy. Section B: Biological, Geological, and Chemical Science, 347-357

ROBERTS, J.C. 1973. The stratigraphy of the Middle and Upper Dalradian succession between Glengad Head and Greencastle, Inishowen, Co. Donegal. Proceedings of the Royal Irish Academy 73B, 151-164.

ROBERTS, J. C. 1975. Reddened Rocks in the Upper Dalradian Succession of North-Eastern Inishowen. The Irish Naturalists' Journal, 136-140.

RODDICK, J.C. and MAX, M.D. 1983. A Laxfordian age from the Inishtrahull platform, County Donegal. Ireland. Scottish Journal of Geology 19, 97-102.

SANDERS, I.S. 1991. Exhumed lower crust in NW Ireland, and a model for crustal conductivity. Journal of the Geological Society, London 148, 131-135.

SCOTT, P. 1974. The Thorr granodiorite, Co. Donegal, Eire - a study of a contaminated pluton. Unpublished M.Sc. thesis, University of Liverpool.

SHAW, C.S.J. and EDGAR, A. D. 1997. Post-entrainment mineral-melt reactions in spinel peridotite xenoliths from Inver, Donegal, Ireland. Geological Magazine 134, 771-779.

SMART, T.B. 1961. A study of some contact aureoles in County Donegal with special reference to the composition of andalusite-bearing rocks. Unpublished M.Sc. thesis, King's College, University of London.

SMART, T.B. 1962. The aureole of the Barnesmore granite, County Donegal. Irish Naturalists' Journal 14, 55-59.

SMELLIE, J.A.T. 1974. Compositional variation within staurolite crystals from the Ardara aureole, Co. Donegal, Ireland. Mineralogical Magazine and Journal of the Mineralogical Society 672-683.

SMITH, R.A. and JOHNSTON, T.P. 1994. Discussion on major southeast-directed Caledonian thrusting and folding in the Dalradian rocks of mid-Ulster: implications for Caledonian tectonics and mid-crustal shear zones. Geological Magazine 131, 417-421.

SOPER, N.J. 1994a. Neoproterozoic sedimentation on the northeast margin of Laurentia and the opening of Iapetus. Geological Magazine 131, 291-299.

SOPER, N.J. and ANDERTON, R. 1984. Did the Dalradian slides originate as extensional faults? Nature, London 307, 357-360.

SPENCER, M.O. and PITCHER, W.S. 1972. Solid geology of north west and central Donegal (Map 1). 1:63,360 scale.

TANNER, P.W.G. 2005. Discussion on evidence for a major Neoproterozoic unconformity within the Dalradian Supergroup of NW Ireland. Journal of the Geological Society, London 162, 221-224.

TRENCH, A. and TORSVIK, T.H. 1992. The closure of Iapetus Ocean and Tornquist Sea: new palaeomagnetic constraints. Journal of the Geological Society of London 149, 867-870.

UNITT, R.P. 1997. The structural and metamorphic evolution of the Lough Derg Complex, Counties Donegal and Fermanagh. Unpublished Ph.D. thesis, National University of Ireland, Cork.

UPTON, B.J.G., ASPEN, P. and CHAPMAN, N.A. 1983. The upper mantle and deep crust beneath the British Isles: evidence from inclusions in volcanic rocks. Journal of the Geological Society of London 140, 105-121.

van BREEMEN, O., HALLIDAY, A.N., JOHNSON, M.R.W. and BOWES, D.R. 1978. Crustal additions in late Pre-Cambrian times. In: Bowes, D.R. and Leake, B.E. (eds), Crustal evolution in northwestern Britain and adjacent regions. Geological Journal Special Issue 10, 81-106.

van STAAL, C.R., DEWEY, J.F., MacNIOCAILL, C. and McKERROW, W.S. 1998. The Cambrian-Silurian tectonic evolution of the northern Appalachians and British Caledonides: history of a complex, west and southwest Pacific-type segment of Iapetus. In: Blundell, D.J. and Scott, A.C. (eds), Lyell: the Past is the Key to the Present. Geological Society, London, Special Publications 143, 199-242.

VERNON, R.H. and PATERSON, S.R. 1993. The Ardara pluton, Ireland: deflating an expanded intrusion. Lithos 31, 17-32.

DRAFT

WARNER, M. et al. Seismic reflections from the mantle represent relict subduction zones within the continental lithosphere. Geology 24, 39-42.

WHITE, N.J. and HUTTON, D.H.W. 1985. The structure of the Dalradian rocks in West Fanad, County Donegal. Irish Journal of Earth Sciences 7, 79-92.

WHITTEN, E.H.T. 1951. Cataclastic pegmatites and calc-silicate skarns near Bunbeg, County Donegal. Mineralogical Magazine and Journal of the Mineralogical Society 29, 737-56.

WHITTEN, E.H.T. 1954. Two arfvedsonitic rhyolite intrusions from Cloghaneely, Co. Donegal. Mineralogical Magazine and Journal of the Mineralogical Society 30, 393-399.

WHITTEN, E.H.T. 1957. The Gola granite (County Donegal) and its regional setting. Proceedings of the Royal Irish Academy 58B, 245-292.

WHITTEN, E.H.T. 1959. Compositional trends in a granite: modal variation and ghost-stratigraphy in part of the Donegal granite, Eire. Journal of geophysical Research 64, 835-848.

WOLFE, M.E. 1969. A trace fossil from the Lower Dalradian, County Donegal, Eire. Geological Magazine 106, 274-276.

WOOD, R.S.R. 1970. The Dalradian of westernmost Tyrone and adjacent parts of Donegal, Ireland. Unpublished Ph.D. thesis, University of London (External).

WRIGHT, A.E. 1988. The Appin Group. In: Winchester, J.A. (ed.), Later Proterozoic stratigraphy of the northern Atlantic regions. Blackie, Glasgow and London. 177-199.

WRIGHT, G.R., ALDWELL, C.R., DALY, D. and DALY, E.P. 1982. Groundwater resources of the Republic of Ireland. In: Fried, J.J. (ed.), European Community's Atlas of Groundwater Resources, 10 volumes, Th. Schafer Druckerei GmbH, Hanover, V. 6.

YARDLEY, B.W.D. 1980. Metamorphism and orogeny in the Irish Dalradian. Journal of the Geological Society of London 137, 303-309.

YARDLEY, B.W.D., BARBER, J.P. and GRAY, J.R. 1987. The metamorphism of the Dalradian rocks of western Ireland and its relation to tectonic setting. Philosophical Transactions of the Royal Society A321, 243-270.

YARDLEY, B.W.D., LONG, C.B. and MAX, M.D. 1979. Patterns of metamorphism in the Ox Mountains and adjacent parts of western Ireland. In: Harris, A.L., Holland, C.H. and Leake, B.E. (eds), The Caledonides of the British Isles - reviewed. Geological Society of London Special Publication 8, 369-374.

YOUNG, D.G.G. 1969. The gravity anomaly map of County Donegal. Dublin Institute for Advanced Studies Geophysical Bulletin 26, 6 pages.

YOUNG, D.G.G. 1974. The Donegal granite - a gravity analysis. Proceedings of the Royal Irish Academy 74B, 63-73.

YOUNG, G.M. 1995. Are Neoproterozoic glacial deposits preserved on the margins of Laurentia related to the fragmentation of two supercontinents? Geology 23, 153-156.

DRAFT

South Donegal

AKAAD, M.K. 1956a. The Ardara granitic diapir of County Donegal, Ireland. Quarterly Journal of the Geological Society of London 112, 263-288.

AKAAD, M.K. 1956b. The northern aureole of the Ardara pluton of County Donegal. Geological Magazine 93, 377-392.

ALSOP, G.I. 1992b. Progressive deformation and the rotation of contemporary fold axes in the Ballybofey Nappe, north-west Ireland. Geological Journal 27, 27 1-283.

ALSOP, G.I. 1992. Late Caledonian sinistral strike-slip displacement across the Leannan Fault system, northwest Ireland. Geological Journal 27, 119- 125.

ALSOP, G.I. 1992d. Gravity-driven extensional collapse of an oblique ductile thrust; the Ballybofey Slide, northwest Ireland. Irish Journal of Earth Sciences 11, 165-175.

ALSOP, G.I. 1993. Sequential generation of listric shear bands during protracted ductile thrusting within the BallybofeyNappe, north-west Ireland. Irish Journal of Earth Sciences 12, 1- 12.

ALSOP, G.I. 1994a. The geometry and structural evolution of a crustal-scale Caledonian fold complex: the Ballybofey Nappe, northwest Ireland. Geological Magazine 13 1, 5 19-537.

ALSOP, G.I. 1994b. Relationships between distributed and localized shear in the tectonic evolution of a Caledonian fold and thrust zone, northwest Ireland. Geological Magazine 13 1, 123- 136.

ALSOP, G.I. 1996. Tectonic analysis of progressive secondary deformation in the hinge of a major Caledonian fold nappe, north-western Ireland. Geological Journal 3 1, 217-233.

ALSOP, G.I., BRYSON, R. and HUTTON, D.H.W. 1998. Ductile transpression and localization of deformation along tectonic boundaries in the Caledonides of northwestern Ireland. Geological Magazine 135, 699-718.

ALSOP, G.I., BRYSON, R. and HUTTON, D.H.W. 2001. Tectonic and kinematic evolution witin mid-crustal orogenic root zones: a case study from the Caledonides of northwestern Ireland. Geological Magazine138. 193-21.

ALSOP, G.I. and HUTTON, D.H.W. 1990. A review and revision of Dalradian stratigraphy in central and southern Donegal, Ireland. Irish Journal of Earth Sciences 10, 181-198

ALSOP, G.I. and HUTTON, D.H.W. 1993. Major southeast-directed Caledonian thrusting and folding in the Dalradian rocks of mid-Ulster: implications for Caledonian tectonics and mid crustal shear zones. Geological Magazine 130, 233-244.

ANDERSON, J.G.C. 1948. The occurrence of Moinian rocks in Ireland. Quarterly Journal of the Geological Societyof London 103, 171-190.

ANDERSON, J.G.C. 1954. The pre-Carboniferous rocks of the Slieve League promontory, County Donegal. Quarterly Journal of the Geological Society of London 109 (for 1953), 399-419.

ATHERTON, M.P. 1980. The occurrence and implications of chloritoid in a contact aureole andalusite schist from Ardara, County Donegal. Journal of Earth Sciences, Royal Dublin Society 3, 101-109.

ATHERTON, M.P. and GHANI, A.A. 2002. Slab breakoff: a model for Caledonian, Late Granite syn-collisional magmatism in the orthotectonic (metamorphic) zone of Scotland and Donegal, Ireland. Lithos 62. 65-85.

DRAFT

BERGER, A.R. 1971. The origin of banding in the Main Donegal Granite, NW Ireland. Geological Journal 7, 347-358.

BERGER, A.R. 1980. The structural setting of the Main Donegal Granite; comments on a recent interpretation. Geological Journal 15, 3-6.

BORRADAILE, G.J. 1974. The structure of the Moine-like rocks near Lough Derg, County Donegal Eire. Geological Journal 9, 61-64.

BURKE, K.C., CUNNINGHAM, M.A., GALLAGHER, M.J. and HAWKES, J.R. 1964. Beryl in the Rosses Granite, Northwest Ireland. Economic Geology und Bulletin of the Society of Economic Geologists 59, 1539- 1550.

CHURCH, W.R. 1964. Metamorphic eclogites from Co. Donegal, Eire. Indian Mineralogist I.M.A. New Delhi, Special Number, 22-23.

CLARINGBOLD, K., FLEGG, A., MAGEE, R. and VONHOF, J. 1994. Directory of active quarries, pits and mines in Ireland. Geological Survey Ireland Report Series RS 94/4 (Mineral Resources). 111 pages.

COLE, G.A.J. 1902. On composite gneisses in Boylagh, west Donegal. Proc. Royal Irish Academy 24 pt. 2. 203-230

COLE, G.A.J. 1922. Memoir und map of localities of minerals of economic importance und metalliferous mines in Ireland. Memoirs of the Geological Survey Ireland. Mineral Resources. 155 pages.

COLEMAN, J.C. 1965. The Caves of Ireland, Anvil Books, Tralee. (The Pullans, p.66).

CONDON, D.J. and PRAVE, A.R. 2000. Two from Donegal: Neoproterozoic glacial episodes on the northeast margin of Laurentia. Geology 28.10 951 – 954.

DALY, J.S. and MENUGE, J.F. 1989. Nd isotopic evidence for the provenance of Dalradian Supergroup sediments in Ireland. Terra Abstracts 1, 12.

DEMPSEY, C.S., MEIGHAN, I.G. and FALLICK, A.E. 1990. Desilication of Caledonian granites in the Barnesmore complex, Co Donegal: the origin and significance of metasomatic syenite bodies. Geological Journal 25, 371-380

DEWEY, J.F. and SHACKLETON, R. M. 1984. A model for the evolution of the Grampian tract in the early Caledonides and Appalachians. Nature, London 312, 115-121.

DICKIN, A.P. 1992. Evidence for an Early Proterozoic crustal province in the North Atlantic region. Journal of the Geological Society, London 149, 483-486.

DICKIN, A.P. and BOWES, D.R. 199 1. Isotopic evidence for the extent of early Proterozoic basement in Scotland and northwest Ireland. Geological Magazine 128, 385-388.

ELSDON, R. 1986. Petrology, structure and age of the Rough Point sill, Donegal. Geological Journal 21, 15 1-168.

EYLES, C.H. and EYLES, N. 1983. Glaciomarine model for upper Precambrian diamictites of the Port Askaig Formation, Scotland. Geology 11, 692-696.

FETTES, D.J., LONG, C.B., BEVINS, R.E., MAX, M.D., OLIVER, G.J.H., PRIMMER, T.J., THOMAS, L.J. AND YARDLEY, B.W.D. 1985. Grade and time of metamorphism in the Caledonide orogen of Britain and

DRAFT

Ireland. In: Harris, A.L. (ed.), The nature and timing of orogenic activity in the Caledonian rocks of the British Isles. Memoirs of the Geological Society, London 94 1-53 (and plates).

FLEGG, A.M. 1979. Steatite in Ireland. Geological Survey Ireland unpublished document. 25 pages.

FLOWERDEW, M.J. and DALY, J.S. 2005. Sm-Nd mineral ages and P_T constraints on the pre-Grampian high grade metamorphism of the Slishwood Division, Northwest Ireland. Irish Journal of Earth Sciences 23, 107-123.

FLOWERDEW, M and McKEEVER, P J. (2001) Walk Donegal. Geological Survey of Northern Ireland, Belfast.

FRENCH, W.J. 1966. Appinitic intrusions clustered around the Ardara pluton, County Donegal. Proceedings of the Royal Irish Academy 64B, 303-322.

FRENCH, W.J. 1977. Breccia-pipes associated with the Ardara pluton, County Donegal. Proceedings of the Royal Irish Academy 77B, 101-117.

FRENCH, W.J. 1978. Lamprophyric dykes associated with the appinitic intrusions of County Donegal. Scientific Proceedings of the Royal Dublin Society 6A, 97-107.

FRENCH, W.J. and PITCHER, W.S. 1959. The intrusion-breccia of Dunmore, County Donegal. Geological Magazine 96, 69-74.

GALLAGHER, S. and ELSDON, R. 1990. Spinel lherzolite and other xenoliths from a dolerite dyke in southwest Donegal. Geological Magazine 127, 177- 1 SO.

GEORGE, T.N. AND OSWALD, D.H. 1957. The Carboniferous rocks of the Donegal syncline. Quarterly Journal of the Geological Society of London. 113, 137-179.

GINDY, A.R. 1953. The plutonic history of the district around Trawenagh Bay, County Donegal. Quarterly Journal of the Geological Society of London 108, 377-411.

GRAHAM J. R. 1996. Dinantian river systems and coastal zone sedimentation in northwest Ireland. In: STROGEN, P., SOMERVILLE, I. D. & JONES, G. LL. (eds), Recent Advances in Lower Carboniferous Geology, Geological Society Special Publication No. 107, pp. 183-206.

GRAHAM, J.R. and CLAYTON, G. 1994. Late Tournaisian conglomerates from County Donegal, north-west Ireland; fault-controlled sedimentation and overstep during basin extension.

GRAY, M. 2004. Geodiversity: Valuing and Conserving Abiotic Nature. John Wiley & Sons Ltd, Chichester.

HALL, A. 1966. The Ardara pluton: A study of the chemistry and crystallization of a contaminated granite intrusion. Proceedings of the Royal Irish Academy 65B, 203-235.

HALLIDAY, A.N., AFTALION, M. and LEAKE, B.E. 1980. A revised age for the Donegal granites. Nature, London 284, 542-543.

HALLIDAY, A.N., GRAHAM, C.M., AFTALION, M. and DYMOKE, P. 1989. The depositional age of the Dalradian Supergroup: U-Pb and Sm-Nd isotopic studies of the Tayvallich Volcanics, Scotland. Journal of the Geological Society, London 146. 3-6.

DRAFT

HARRIS, A.L., BALDWIN, C.T., BRADBURY, H.J., JOHNSON, H.D. and SMITH, R.A. 1978. Ensialic basin sedimentation: the Dalradian Supergroup. In: Bowes, D.R. and Leake, B.E. (eds), Crust& evolution in northwestern Britain and adjacent areas. Geological Journal Special Issue 10, 115- 138.

HARRIS, A.L., HASELOCK, PJ., KENNEDY, M.J. and MENDUM, J.R., with contributions by C.B. Long, J.A. Winchester and P.W.G. Tanner. 1994. The Dalradian Supergroup in Scotland, Shetland and Ireland. In: Gibbons, W. and Harris, A.L. (eds), A revised correlation of Precambrian rocks in the British Isles. Geological Society, London, Special Reports 22, 33-53.

HIGGS, K. 1984. Stratigraphic palynology of the Carboniferous rocks in northwest Ireland. Geological Survey Ireland Bulletin 3, 171-202.

HOLLAND, C. H. and SANDERS, I. eds. (2009) The Geology of Ireland. 2009 (Second Edition) Dunedin, Edinburgh. pp568.

HOWARTH, R.J. 1967 The Boulder Bed group (Dalradian) of County Donegal, Eire. Unpublished Ph.D. thesis, University of Bristol.

HOWARTH, R.J. 1970. Principal components analysis of the geochemistry and mineralogy of the Portaskaig Tillite and Kiltyfanned Schist (Dalradian) of County of Donegal, Eire. Mathematical Geology 2, 285-302.

HOWARTH, R.J. 197 1. The Portaskaig Tillite succession of County Donegal. Proceedings of the Royal Irish Academy 71B. 1-35.

HOWARTH, R.J., KILBURN, C. and LEAKE, B.E. 1966. The Boulder Bed succession at Glencolumbkille, County Donegal. Proceedings of the Royal Irish Academy 65B, 117- 156.

HULL, E., KINAHAN, G.H., NOLAN, J., CRUISE, R.J., EGAN, F.W., KILROE, J.R., MITCHELL, W.F. and MCHENRY, A. (1891a) Explanatory memoir to accompany sheets 3, 4, 5 (in part), 9, 10, 11 (in part), 15 and 16 of the maps of the Geological Survey Ireland comprising Northwest and Central Donegal. Memoirs of the Geological Survey Ireland.

HULL, E., KILROE, J.R., MITCHELL, W.F. (1891b) Explanatory memoir to accompany the maps of south-west Donegal, sheets 22,23,30 and 31 (in part) of the Geological Survey Ireland (with palaeontological notes by WH Baily and petrographical notes by JS Hyland). Memoirs of the Geological Survey Ireland.

HUTTON, D. H. W. 1981; Tectonic slides in the Caledonides. Geological Society, London, Special Publications v. 9; p. 261-265

HUTTON, D.H.W. 1979a. Metadolerite age relationships in the Dalradian of northwest Donegal, Ireland and their orogenic significance. Geological Journal 14, 171-178.

HUTTON, D.H.W. 1979b. Dalradian structure in the Creeslough area, NW Donegal, Ireland. In: Harris, A.L., Holland, C.H. and Leake, B.E. (eds), The Caledonides of the British Isles-reviewed. Geological Society, London, Special Publications 8, 239-241.

HUTTON, D.H.W. 1982. A tectonic model for emplacement of the Main Donegal Granite, NW Ireland. Journal of the Geological Society, London 139, 615-631.

HUTTON, D.H.W. 1992. Granite sheeted complexes: evidence for the dyking ascent mechanism. Transactions of the Royal Society of Edinburgh: Earth Sciences 83, 377-382.

DRAFT

HUTTON, D.H.W. and ALSOP, G.I. 1996a. The Swilly Slide: A major synmetamorphic, extensional, ductile fault in the Dalradian of Donegal. Irish Journal of Earth Sciences 15, 41-57.

HUTTON, D.H.W. and ALSOP, G.I. 1996b. The Caledonian strike-swing and associated lineaments in NW Ireland and adjacent areas: sedimentation, deformation and igneous intrusion patterns. Journal of the Geological Society, London 153. 345-360.

HUTTON, D.H.W. and ALSOP, G.I. 2004. Evidence for a major Neoproterozoic orogenic unconformity within te Dalradian Supergroup of NW Ireland. Journal of the Geological Society, London, 161. 1-12.

IYENGAR, S.V.P., PITCHER, W.S. and READ, H.H. 1954. The plutonic history of the Maas area, County Donegal. Quarterly Journal of the Geological Society of London 110, 203-228.

JOHNSTON, J.D. 1993. Ice wedge casts in the Dalradian of south Donegal-evidence for subaerial exposure of the boulder bed. Irish Journal of Earth Sciences 12, 13-26.

JOHNSTON, J.D. 1995. Pseudomorphs after ikaite in a glaciomarine sequence in the Dalradian of Donegal, Ireland. Scottish Journal of Geology 31, 3-9.

JOHNSTON, J.D. 1997. Localization of mid-crustal thrust ramps by metadolerite sheets in the Dalradian of northwest Ireland. Geological Magazine 134, 199-2 12.

JONES G. LL. and SOMERVILLE I. D. Irish Dinantian biostratigraphy: practical applications. 1996. Geological Society, London, Special Publications; v. 107; p. 371-385

KENNEDY, M.J. 1975. The Fleur de Lys Supergroup: stratigraphic comparison of Moine and Dalradian equivalents in Newfoundland with the British Caledonides. Journal of the Geological Society, London 13 1, 305-310.

KILBURN, C., PITCHER, W.S. and SHACKLETON, R.M. 1965. The stratigraphy and origin of the Portaskaig Boulder Bed Series (Dalradian). Geological Journal 4, 343-360.

KILROE, J.R. and MITCHELL, W.F. 1890. One inch geological map, Sheet 22, Glen Bay, Co. Donegal. Geological Survey Ireland.

KIRKLAND A.L., ALSOP, G.I. and PRAVE, A.R., 2008; The brittle evolution of a major strike-slip fault associated with granite emplacement: a case study of the Leannan Fault, NW Ireland. Journal of the Geological Society v. 165; p. 341-352

KIRWAN, P.J., DALY, J.S. and MENUGE, J.F. 1989. A minimum age for the deposition of the Dalradian Supergroup sediments in Ireland. Terra Abstracts 1. 16.

LEGG, I.C., PYNE, J.F., NOLAN, P., McARDLE, P., FLEGG, A.M. and O'CONNOR, P.J. 1985. Mineral localities in the Dalradian and associated igneous rocks of County Donegal, Republic of Ireland and of Northern Ireland.Geological

Survey of Ireland Report Series 8.5/3 (Mineral Resources). 87 pages.

LONG, C.B. and MCCONNELL, B. 1999. Geology of South Donegal. A geological description to accompany the Bedrock Geology l:l00,000 Scale Map Series, Sheet 3/4, South Donegal. With contributions from Alsop, G.I, O'Connor, P., Claringbold, K. and Cronin, C. Geological Survey Ireland. 116 pp.

MacDERMOT, C., HIGGS, K., PHILCOX, M. and REILLY, T.A. 1983. Volume 3: Carboniferous Stratigraphy. In: A review of the geology of petroleum prospecting license 2/80, Northwest Ireland. Unpublished Report for Marinex Petroleum Ltd. Geological Survey Ireland.

MAX, M.D. and LONG, C.B. 1979. Basic volcanic rocks in the Dalradian of Ireland. In: Harris, A.L., Holland, C.H. and Leake, B.E. (eds), The Caledonides of the British Isles-reviewed. Geological Society, London, Special Publications 8, 585-589.

MAX, M.D. and LONG, C.B. 1985. Pre-Caledonian basement in Ireland and its cover relationships. Geological Journal 20, 22 1-227.

MAX, M.D., LONG, C.B. and O'CONNOR 1984. Age of the pre-Caledonian basement of the NE Ox Mountains and Lough Derg inliers, Ireland. Geological Survey Ireland Bulletin 3, 203-209.

MENEILLY, A.W. 1982. Regional structure and syntectonic granite intrusion in the Dalradian of the Gweebarra Bay area, Donegal. Journal of the Geological Society, London 139, 633-646.

MENEILLY, A.W. 1983. Development of early composite cleavage in pelites from west Donegal. Journal of Structural Geology 5, 83-97.

MITCHELL W.I. 1992; The origin of Upper Palaeozoic sedimentary basins in Northern Ireland and relationships with the Canadian Maritime Provinces. Geological Society, London, Special Publications v. 62; p. 191-202

MITCHELL, W.I. ed. (2004) The Geology of Northern Ireland Our Natural Foundation (second edition) Geological Survey of Northern Ireland, Belfast.

MITCHELL, I, COOPER, M. McKEEVER, P. and McCONNELL, B. (2010) The Classic Geology of the North of Ireland.

MOLES, N.R. and SCHAFFALITZKY, C. 1992. Gold exploration methodologies and target definition in the Donegal Dalradian. In: Bowden, A.A., Earls, G., O'Connor, P.G. and Pyne, J.F. (eds), The Irish Minerals Industry 1980-1990. Irish Association for Economic Geology, 119- 134.

NICHOLS, G. & JONES, T. M. 1992. Fusain in Carboniferous shallow marine sediments, Donegal, Ireland: the sedimentological effects of wild-fire. Sedimentology, 39, 487-502.

OBAID, T.M.S. 1971. Petrography, structure, and time of formation of adinole rocks from Rosbeg area, Co. Donegal, Ireland. Bulletin of the Faculty of Sciences, Riyadh University 3, 78-91.

O'CONNOR, P.J. 1986. Uranium mineralization in the Irish Caledonides. In: Andrew, C.J., Crewe, R.W.A., Finlay, S., Pennell, W.M. and Pyne, J.F. (eds), Geology and Genesis of Mineral Deposits in Ireland. Irish Association for Economic Geology 157-175.

O'CONNOR, P.J. 1990. Geochemical aspects of desilication in the Barnesmore Complex, County Donegal. Geological Survey Ireland Bulletin 4, 2 11-2 15.

O'CONNOR, P.J., LONG, C.B., BASHAM, I.R., SWAINBANK, I.G. and BEDDOE-STEPHENS, B. 1984. Age and geological setting of uranium mineralization associated with the Main Donegal Granite, Ireland. Transactions of the Institution of Mining and Metallurgy (Section B: Applied earth sciences) 93, B 190-194.

O'CONNOR, PJ., LONG, C.B. and EVANS, J.A. 1987. Rb-Sr whole-rock isochron studies of the Barnesmore and Fanad plutons, Donegal, Ireland. Geological Journal 22, 11-23.

DRAFT

OSWALD, D.H. 1956, for 1955. The Carboniferous rocks between the Ox Mountains and Donegal Bay. Quarterly Journal of the Geological Society of London 111, 167-186.

PARKES, M.A. CARVILLE, G. KELLY, J. AND DOWDS, S. 2001. The sandstone mines of Mountcharles, Co Donegal. Journal of the Mining Heritage Trust of Ireland 1. 3-6.

PARKES, M.A., JOHNSTON, D., SIMMS, M.J. and KELLY, J.G. 1999. Geological Guidance of speleogenesis in marble of the Dalradian Supergroup, County Donegal, Ireland. Cave and Karst Science 26 (3), 115-124.

PARKES, M.A., SIMMS, M.J. and KELLY, J.G. 2000. Pollnapaste, Lettermacaward, Co. Donegal. Irish Speleology 17, 33-36.

PHILCOX, M.E. 1982. The Ballyshannon Limestone and underlying LowerArgillaceous Limestone in five deep boreholes between Ballyshannon and Ballintra, Co. Donegal. Unpublished Report.

PITCHER, W.S. 1953b. The Rosses granitic ring-complex, County Donegal, Eire. Proceedings of the Geologists Association 64, 153-182.

PITCHER, W.S. 1969. Northeast-trending faults of Scotland and Ireland, and chronology of displacements. In: Kay, M. (ed.), North Atlantic-Geology and Continentul Drift. Memoirs of The American Association of Petroleum Geologists 12, 724-733.

PITCHER, W.S. 1987. Granites and yet more granites forty years on. Geologische Rundschuu 76, 51-79.

PITCHER, W.S. 1992. The Rosses multi-pulse Pluton: fractures and fractals. Transactions of the Royal Society of Edinburgh: Earth Sciences 83, 497.

PITCHER, W.S. and BERGER, A.R. 1972. The Geology of Donegal: A study of Granite emplacement and unroofing. Wiley-Interscience, New York and London. 435 pp.

PITCHER, W.S., ELWELL, R.W.D., TOZER, C.F., and CAMBRAY, F.W. 1964. The Leannan fault. Quarterly Journal of the Geological Society of London 120, 24 1-273.

PITCHER, W.S. and READ, H.H. 1959. The Main Donegal granite. Quarterly Journal of the Geological Society of London 114, 259-305.

PITCHER, W.S. and READ, H.H. 1960a. Early transverse dykes in the main Donegal granite. Geological Magazine 97, 53-61.

PITCHER, W.S. and READ, H.H. 1960b. The aureole of the Main Donegal granite. Quarterly Journul of the Geological Society of London 116, 1-36.

PITCHER, W.S. and READ, H.H. 1963. Contact metamorphism in relation to manner of emplacement of the granites of Donegal, Ireland. Journal of Geology 7 1, 261-296.

PITCHER, W.S. and SHACKLETON, R.M. 1966. On the correlation of certain Lower Dalradian successions in northwest Donegal. Geological Journal 5, 149-156.

PITCHER, W.S., SHACKLETON, R.M. and WOOD, R.S.R. 1971. The Ballybofey Anticline: a solution of the general structure of parts of Donegal and Tyrone. Geological Journal 7, 321-328.

PITCHER, W.S. and SINHA, R.C. 1958. The petrochemistry of the Ardara aureole. Quarterly Journal of the Geological Society of London 113, 393-408.

DRAFT

PITCHER, W.S., SOPER, N.J. and HUTTON, D.H.W. 1984. Discussion on a tectonic model for the emplacement of the Main Donegal Granite, Journal, Vol. 139. Part 5, 1982, pp. 615-631. Journal of the Geological Society, London 141, 599-602.

PITCHER, W.S. and HUTTON, D.H.W. 2003. A Master Class Guide to the Granites of Donegal. Geological Survey Ireland.

PORTLOCK, J.E. 1843. Report on the Geology of Londonderry and of parts of Tyrone and Fermanagh. Board of the Ordnance, Longmans, London.

POWELL, D. 1965. Comparison of talc-silicate bands from the Moine Schists of Inverness-shire with similar bands from Moine-like rocks in Donegal. Nature, London. 206, 180- 181.

PRESTON, J. 1965. Tertiary feeder dykes in the West of Ireland. Proceedings of the Geological Society of L,ondon 1626, 149-150.

REYNOLDS, D.L. 1954. Fluidization as a Geological Process and its bearing on the problem of Intrusive Granites. American Journal of Science. 152. 577-614

RIDDIHOUGH, R.P. 1969. Magnetic map of the Ardara Granite and southern County Donegal. Communications of the Dublin Institute for Advanced Studies Series D, Geophysical Bulletin 27, 1-3 and map.

SHAW, CS.J. and EDGAR, A. D. 1997. Post-entrainment mineral-melt reactions in spine1 peridotite xenoliths from Inver, Donegal, Ireland. Geological Magazine 134, 77 1-779.

SMART, T.B. 1962. The aureole of the Barnesmore granite, County Donegal. Irish Naturalists Journal 14,55-59.

SOPER, N.J. 1994a. Neoproterozoic sedimentation on the northeast margin of Laurentia and the opening of Iapetus. Geological Magazine 13 1, 29 1-299.

SPENCER, A.M. 197 1. Lute Pre-Cambrian glaciation in Scotland. Memoirs of the Geological Society, London 6, 1-100.

SPENCER, M.O. and PITCHER, W.S. 1972. Solid geology of north west und central Donegal (Map 1). 1:63,360 scale.

TANNER, P.W.G. 2005. Discussion on evidence for a major Neoproterozoic unconformity within te Dalradian Supergroup of NW Ireland. Journal of the Geological Society, London, 162. 221-224.

UNITT, R.P. 1997. The structural and metamorphic evolution of the Lough Derg Complex, Counties Donegal and Fermanagh. Unpublished Ph.D. thesis, National University of Ireland, Cork.

WALKER, G.P.L. and LEEDAL, G.P. 1954. The Barnesmore granite complex, County Donegal. Scientific Proceedings of the Royal Dublin Society 26,207-243.

YARDLEY, B.W.D. 1980. Metamorphism and orogeny in the Irish Dalradian. Journal of the Geological Society, London 137, 303-309.

YARDLEY, B.W.D., BARBER, J.P. and GRAY, J.R. 1987. The metamorphism of the Dalradian rocks of western Ireland and its relation to tectonic setting. Philosophical Transactions of the Royal Society A321,243-270.

DRAFT

YOUNG, D.G.G. 1969. The gravity anomaly map of County Donegal. Dublin Institute for Advanced Studies Geophysical Bulletin 26, 6 pages.

YOUNG, D.G.G. 1974. The Donegal granite-a gravity analysis. Proceedings of the Royal Irish Academy 74B, 63-73.

DRAFT

Appendix 3. Bibliography – Quaternary Geology and Geomorphology

QUATERNARY REFERENCES WITH DIRECT REFERENCE TO NORTH DONEGAL

ADDYMAN, P.V. and VERNON, P.D., 1966. A beach pebble industry from Dunaff Bay, Inishowen, Co. Donegal. Ulster Journal of Archaeology, 29, 6-15.

Ballantyne, C.K., 2010. Extent and deglacial chronology of the last British-Irish Ice Sheet: implications of exposure dating using cosmogenic isotopes. Journal of Quaternary Science, 25(4), 515-534.

Ballantyne, C.K., McCarroll, D. and Stone, J.O., 2007. The Donegal ice dome, northwest Ireland: dimensions and chronology. Journal of Quaternary Science, 22 (8), 773-783.

Benetti, S., Dunlop, P. and Ó Cofaigh, C., 2010. Glacial and glacially-related geomorphology of the north-west Irish continental margin. Journal of Maps, 2010, 30-39.

Bradwell, T., Stoker, M.S., Golledge, N.R., Wilson, C., Merritt, J., Long, D., Everest, J.D., Hestvik, O., Stevenson, A., Hubbard, A., Finlayson, A. and Mathers, H., 2008. The northern sector of the last British Ice Sheet: maximum extent and demise. Earth Science Reviews, 88 (3-4), 207-226.

Brooks, A.J., Bradley, S.L., Edwards, R.J., Milne, G.A., Horton, B. and Shennan, I., 2008. Postglacial relative sea-level observations from Ireland and their role in glacial rebound modelling. Journal of Quaternary Science, 23 (2), 175-192.

CARTER, R.W.G., 1982. Sea-level changes in Northern Ireland. Proceedings of the Geologists' Association, 93, 7-23.

CARTER, R.W.G. and WILSON, P., 1993. Aeolian processes and deposits in northwest Ireland. In: Pye, K. (Ed.), The Dynamics and Environmental Context of Aeolian Sedimentary Systems. Geological Society of London Special Publication No. 72, 173-190.

CARTER, R.W.G., DEVOY, R.J.N., SHAW, J. 1989. Late Holocene sea levels in Ireland. Journal of Quaternary Science 4, 7–24.

Charlesworth, J.K., 1924. The glacial geology of the north-west of Ireland. Proceedings of the Royal Irish Academy, 36B, 174-314.

Clark, J., McCabe, A.M., Schnabel, C., Clark, P.U., Freemand, S., Maden, C and Sheng, X.U., 2008. 10Be chronology of the last deglaciation of County Donegal, northwestern Ireland. Boreas, 38 (1), 111-118.

Colhoun, E.A., 1970. On the nature of the glaciation and final deglaciation of the Sperrin Mountains and adjacent areas in the North of Ireland. Irish Geography, 6 (2), 162-185.

COLHOUN, E.A., 1971. The glacial stratigraphy of the Sperrin Mountains and its relation to the glacial stratigraphy of northwest Ireland. Proceedings of the Royal Irish Academy, 71B, 37-52.

COLHOUN, E.A., 1972. The deglaciation of the Sperrin Mountains and adjacent areas in Counties Tyrone, Londonderry and Donegal, Northern Ireland. Proceedings of the Royal Irish Academy, 72B, 91-137.

COLHOUN, E.A., 1973. Two Pleistocene Sections in south-western Donegal and their relation to the last glaciations of the Glengesh Plateau. Irish Geography, 6, 594-609.

COOPER, A. and O'HAGAN, A.M. 2002. Scoping Study for an Integrated Coastal Zone Management (ICZM) strategy for Lough Swilly. (Report to Save the Swilly Group), Coastal Studies Research Group, University of Ulster. Available at: www.loughswilly.com/news.php. (Accessed on 03/09/2014)

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

CULLEN, C.A., 2012. Deciphering the geomorphic and sedimentary record of the last Irish Ice Sheet in NW Donegal, Ireland: implications for glacial dymnamics and decay configurations. Unpublished PhD Thesis, National University of Ireland, Galway.

DARDIS, G.F. and HANVEY, P.M., 1994. Sedimentation in a drumlin lee-side subglacial cavity, northwest Ireland. Sedimentary Geology, 91, 97-114.

DORIS, Y. 1996. Groundwater Protection in the Glen Swilly Aquifer. Unpublished M.Sc. thesis, Environmental Sciences Unit, Trinity College Dublin, in association with Minerex Environmental Ltd.

Dunlop, P., Sacchetti, F., Benetti, S., O'Cofaigh, C., Smith, M.J., Paron, P. and Griffiths, J.S., 2011. Chapter Eleven - Mapping Ireland's Glaciated Continental Margin Using Marine Geophysical Data. In Smith, M.J., Paron, P., Griffiths, J.S. (Eds.) Geomorphological Mapping: a professional handbook of techniques and applications: Developments in Earth Surface Processes. Vol. 15: 337-355. Elsevier.

Dunlop, P., Shannon, R., McCabe, A.M., Quinn, R. and Doyle, E., 2010. Marine geophysical evidence for ice sheet extension and recession on the Malin Shelf: New evidence for the western limits of the British Irish Ice Sheet. Marine Geology, 276, 86-99.

DURY, G.H., 1957. A glacially breached watershed in Donegal. Irish Geography, 3, 171.180.

DURY, G.H., 1958. Glacial morphology of the Blue Stack Area, Donegal. Irish Geography, 3, 242-253.

DURY, G.H., 1959. A contribution to the geomorphology of Central Donegal. Proceedings of the Geologists Association, 70(1), 1-26.

DURY, G.H., 1964. Aspects of the geology of Slieve League Peninsula, Donegal. Proceedings of the Geological Association, 75, 445-459.

Elliott, G.M., Shannon, P.M., Haughton, P.D.W. and Øvrebø, L.K., 2010. The Rockall Bank Mass Flow: Collapse of a moated contourite drift onlapping the eastern flank of Rockall Bank, west of Ireland. Marine and Petroleum Geology, 27, 92-107.

Elliott, G.M., Shannon, P.M., Haughton, P.D.W., Praeg, D. and O'Reilly, B., 2006. Mid- to Late Cenozoic canyon development on the eastern margin of the Rockall Trough, offshore Ireland. Marine Geology, 229, 113-132.

FLANAGAN, L.N.W., 1966. Flint implements from Straleel, Co. Donegal. Ulster Journal of Archaeology, 29, 91-94.

FOSSITT, J.A., 1994. Late-glacial and Holocene vegetation history of western Donegal, Ireland. Biology and Environment: Proceedings of the Royal Irish Academy, 94B, 1-31.

Georgiopoulou, A., Benetti S., Shannon P.M., Haughton P.D.W. and McCarron S., 2012. Gravity flow deposits in the deep Rockall Trough, Northeast Atlantic. In: Yamada Y. et al. (Eds.) Submarine Mass Movements and their Consequences – 5th International Symposium. Advances in Natural and Technological Hazards Research. Vol. 31, Part 8: 695-707. Springer, Netherlands.

DRAFT

Georgiopoulou, A., Benetti S., Shannon P.M., Sacchetti F., Haughton P.D.W., Comas-Bru L. and Krastel S., 2014. Comparison of Mass Wasting Processes on the Slopes of the Rockall Trough, Northeast Atlantic. In: Krastel S. et al. (Eds.) Submarine Mass Movements and Their Consequences, Advances in Natural and Technological Hazards Research, Vol. 37: 471-480. Springer International Publishing Switzerland.

Georgiopoulou, A., Shannon, P.M., Sacchetti, F., Haughton, P.D.W., and Benetti, S., 2013. Basement-controlled multiple slope collapses, Rockall Bank Slide Complex, NE Atlantic. Marine Geology, 336, 198-214.

HARTE, W., 1867. Notes on the physical features of the county of Donegal. Journal of the Royal Geological Society of Ireland, 1, 21-27.

HANVEY, P.M., 1987. Sedimentology and lee-side stratification sequences in late-Pleistocene drumlins, north-west Ireland. In: J. Menzies and J. Rose (Eds.), Drumlin Symposium, Balkema, Rotterdam, 241-253.

HANVEY, P.M., 1988. The sedimentology and genesis of late-Pleistocene drumlins in Counties Mayo and Donegal, western Ireland. Unpublished PhD Thesis, University of Ulster.

HANVEY, P.M., 1989. Stratified flow deposits in a late-Pleistocene drumlin in northwest Ireland. Sedimentary Geology, 62, 211-221.

KILROE, J.R., 1888. Directions of ice flow in the north of Ireland. Quarterly Journal of the Geological Society of London, 44, 827-833.

KING, E.l., HAFFIDASON, H., SEJRUP, H.P., AUSTIN, W.E.N., DUFFY, M., HELLAND, E., KLITGAARD-KRISTENSEN, D. and SCOURSE, J.D., 1998. End moraines on the northwest Irish continental shelf. Third ENAM Workshop, Edinburgh, 1998 (Abstracts Volume).

Knight, J. and McCabe, A.M., 1997. Drumlin evolution and ice sheet oscillations along the NE Atlantic margin, Donegal Bay, western Ireland. Sedimentary Geology, 111, 57-72.

Knight, J. 2003a. Geomorphic evidence for patterns of late Midlandian ice advance and retreat in the Omagh Basin. Irish Geography, 36 (1), 1-22.

KNIGHT, J., 2003b. Evaluating controls on ice dynamics in the north-east Atlantic using an event stratigraphy approach. Quaternary International, 99-100 (2003), 45-57.

LEE, M., DALY, D., McLAUGHLIN, S. and FITZSIMONS, V. 2005 County Donegal Groundwater Protection Scheme, Vol. II: Source Protection Zones. Donegal County Council. 128 pages.

Long, C.B. and McConnell, B.J., 1997. Geology of north Donegal: A geological description to accompany the bedrock geology 1:100,000 sheets. Geological Survey Ireland, Dublin.

McCabe, A.M., 1995. Quaternary geology of Donegal. In Wilson, P. (Ed.), Northwest Donegal Field Guide, Irish Association for Quaternary Studies, 15-20.

MCCABE, A.M., 2008. Glacial Geology and geomorphology: The Landscapes of Ireland. Dunedin Academic Press, 274pp.

McCabe, A.M. and Clark, P.U., 1998. Ice-sheet variability around the North Atlantic Ocean during the last deglaciation, Nature 392, 373-377.

McCabe, A.M. and Clark, P.U., 2003. Deglacial chronology from County Donegal, Ireland: implications for deglaciation of the British-Irish Ice Sheet. Journal of the Geological Society, London, 160 (6), 847-856.

McCabe, A.M. and Clark, P.U., & CLARK, J. 2005. AMS14 C dating of deglacial events in the Irish Sea Basin and other sectors of the British–Irish ice sheet. Quaternary Science Reviews, 24 (14), 1673-1690.

MCCABE, A.M. and DARDIS, G.F., 1989. A geological view of drumlins in Ireland. Quaternary Science Reviews, 8, 169-177.

MCCABE, A.M., BOWEN, D.Q. and PENNEY, D.N., 1993. Glaciomarine facies from the western sector of the last British ice sheet, Malin Beg, County Donegal, Ireland. Quaternary Science Reviews, 12, 35-45.

McCabe, A.M., Clark, P.U. and Clark, J., 2007. Radiocarbon constraints on the history of the western Irish ice sheet prior to the Last Glacial Maximum. Geology, 35 (2), 147-150.

MURPHY, M.E., 1980. Management of sand dune areas in the west of Ireland: a neglected aspect of land reform. Unpublished MSc. Thesis, New University of Ulster.

Ó Cofaigh, C., Benetti S. Dunlop P. and Montey, X. (accepted). Arcuate moraines on the continental shelf offshore of Northwest Ireland. In Dowdeswell et al. (Eds.) Atlas of Submarine Glacial Landforms: Modern, Quaternary and Ancient. Geological Society of London.

O' Cofaigh, C.A., Dunlop, P. and Benetti, S., 2012. Marine geophysical evidence for Late Pleistocene ice sheet extent and recession off northwest Ireland. Quaternary Science Reviews, 44, 147-159.

Ó Cofaigh C., Dunlop P. and Benetti S. (accepted). Submarine drumlins on the Irish continental shelf. In Dowdeswell et al. (Eds.) Atlas of Submarine Glacial Landforms: Modern, Quaternary and Ancient. Geological Society of London.

O'Connor, M. C., Cooper, J. A. G., McKenna, J., and Jackson, D. W. T. 2010. Shoreline management in a policy vacuum: a local authority perspective. Ocean & Coastal Management, 53 (12), 769-778

PRAEGER, R. L. 1895. The Raised Beaches of Inishowen. The Irish Naturalist, 278-285.

Sacchetti, F., Benetti, S., Georgiopoulou, A., Dunlop, P. and Quinn, R., 2011. Geomorphology of the Irish Rockall Trough, North Atlantic Ocean, mapped from multibeam bathymetric and backscatter data. Journal of Maps, 2011, 60-81.

Sacchetti, F., Benetti, S., Georgiopoulou, A., Shannon, P.M., O'Reilly, B.M., Dunlop, P., Quinn, R. and O' Cofaigh, C., 2012. Deep-water geomorphology of the glaciated Irish margin from high-resolution marine geophysical data. Marine Geology, 291-294, 113-131.

Sacchetti, F., Benetti, S., O' Cofaigh, C. and Georgiopoulou, A., 2012. Geophysical evidence of deep-keeled icebergs on the Rockall Bank, Northeast Atlantic Ocean. Geomorphology, 159-160, 63-72.

Sacchetti, F., Benetti, S., Quinn, R. and O' Cofaigh, C., 2013. Glacial and post-glacial sedimentary processes in the Irish Rockall Trough from an integrated acoustic analysis of near-seabed sediments. Geo-Marine Letters, 33, 49-66.

Sacchetti F., Ó Cofaigh C. and Benetti S. (accepted/in publication). Iceberg scours on the Rockall Bank, Northeast Atlantic. In Dowdeswell et al. (Eds.) Atlas of Submarine Glacial Landforms: Modern, Quaternary and Ancient. Geological Society of London

DRAFT

Sejrup, H.P., Hjelstuen, B.O., Torbjorn Dahlgren, K.I., Haflidason, H., Kuijpers, A., Nygård, A., Praeg, D., Stoker, M.S. and Vorren, T.O., 2005. Pleistocene glacial history of the NW European continental margin. Marine and Petroleum Geology, 22 (9-10), 1111-1129.

SELLIER, D., 1995. Derryveigh Mountains – glacial evidence. In: North-West Donegal, Wilson, P. (Ed.), Field Guide No. 19, Irish Association for Quaternary Studies.

SHAW, J., 1985. Holocene coastal evolution, Co. Donegal, Ireland. Unpublished PhD. Thesis, University of Ulster.

SHAW, J. and CARTER, R.W.G., 1994. Coastal peats from northwest Ireland: implications for late-Holocene relative sea-level change and shoreline evolution. Boreas, 23, 74-91.

Stephens, N. and Synge, F.M., 1965. Late-Pleistocene shorelines and drift limits in North Donegal. Proceedings of the Royal Irish Academy 64B, 131-153.

Stephens, N. and Synge, F.M., 1966. Pleistocene shorelines. In: Dury, G.H. (Ed., Essays in Geomorphology: 1-51, London.

TELFORD, M.B., 1977. Glenveagh National Park: the past and present vegetation. Unpublished PhD Thesis, Trinity College Dublin.

Thébaudeau, B., Trenhaile, A.S. and Edwards, R.J., 2013. Modelling the Development of rocky shoreline profiles along the northern coast of Ireland. Geomorphology, 203, 66-78.

WILSON, P., 1989. Nature, origin and age of Holocene Aeolian sand on Muckish Mountain, Co. Donegal, Ireland. Boreas, 18, 71-79.

WILSON, P., 1990a. Coastal dune chronology in the north of Ireland. In: Bakker, Th.W.M., Jungerius, P.D. and Klijn, J.A. (Eds.) Dunes of European Coasts, Catena Supplement, 18, 71-79.

WILSON, P., 1990b. Morphology, sedimentological characteristics and origin of a fossil rock glacier on Muckish Mountain, northwest Ireland. Geografiska Annaler, 72A, 237-247.

WILSON, P., 1990c. Clast variations on talus: some observations from north-west Ireland. Earth Surface Processes and Landforms, 15, 183-188.

WILSON, P., 1990d. Characteristics and significance of protalus ramparts and fossil rock glaciers on Errigal Mountain, County Donegal. Proceedings of the Royal Irish Academy, 90B, 1-21.

WILSON, P., 1993. Description and origin of some talus-foot debris accumulations, Aghla Mountains, Co. Donegal, Ireland. Permafrost and Periglacial Processes, 4, 231-244.

WILSON, P., 1995. North-West Donegal. Field Guide No. 19, Irish Association for Quaternary Studies.

WILSON, P., 2004. Relict rock glaciers, slope failure deposits, or polygenetic features? A re-assessment of some Donegal debris landforms. Irish Geography, 37:1-11.

WILSON, P. and CARTER, R.W.G. (Eds.) 1984. North East Co. Donegal and North West Co. Londonderry. Field Guide No. 7, Irish Association for Quaternary Studies.

WILSON, P. and SELLIER, D., 1995. Active patterned ground and cryoturbation on Muckish Mountain, Co. Donegal, Ireland. Permafrost and Periglacial Processes, 6, 15-25.

WRIGHT, W.B., 1912. The drumlin topography of south Donegal. Geological Magazine, 9:153-159.

DRAFT

QUATERNARY REFERENCES WITH DIRECT REFERENCE TO SOUTH DONEGAL

ANDREWS, J.T. 1998. Abrupt changes (Heinrich events) in late Quaternary North Atlantic marine environments: a history and review of data and concepts. Journal of Quaternary Science, 13, 3-16.

BENNETT, M.R. and BOULTON, G.S., 1993. A Reinterpretation of Scottish 'Hummocky Moraine' and its significance for the Deglaciation of the Scottish Highlands during the Younger Dryas or Loch Lomond Stadial. *Geology Magazine*, 130(3), 301-308.

BURNINGHAM, H., 2002. Meso-scale morphological changes in the Loughros More estuary. Proc. Littoral: The Changing Coast, vol. 3, pp. 265–270.

BURNINGHAM, H., 2005. Morphodynamic behaviour of a high-energy coastal inlet: Loughros Beg, Donegal, Ireland. In: FitzGerald, D.M., Knight, J. (Eds.), High Resolution Morphodynamics and Sedimentary Evolution of Estuaries. Springer, pp. 215–242. Chapter 11.

BURNINGHAM, H., Cooper, J.A.G., 2004. Morphology and historical evolution of northeast Atlantic coastal deposits: the west Donegal estuaries. Journal of Coastal Research. SI 41, 148–159.

BURNINGHAM, H., 2008. Contrasting geomorphic response to structural control: The Loughros estuaries, northwest Ireland. Geomorphology 97. 300–320

CARTER, R.W.G., DEVOY, R.J.N., SHAW, J., 1989. Late Holocene sea levels in Ireland. Journal of Quaternary Science. 4, 7–24.

CHARLESWORTH. J. K. 1921. Thc glacial geology of the northwest of Ireland, Proceedings of the Royal Irish Academy. 36B, 174 - 314.

CHARLESWORTH. J. K. 1951. The Quaternary Era. Edward Arnold. London.

CLOSE. M. H. 1867. Notes on the General Glaciation of Ireland. Journal of the Royal Geographical Society of Ireland, 1. 201-242.

COLHOUN, E.A. 1973. Two Pleistocene sections in south western Donegal and their relation to the last glaciation of the Glengesh Plateau. Irish Geography 6. 594-609.

COOPER, J.A.G., JACKSON, D.W.T., NAVAS, F., McKENNA, J., MALVAREZ, G., 2004. Identifying storm impacts on an embayed, high energy coastline: western Ireland. Marine Geology. 210, 261–280.

EYLES, N. and MCCABE, A.M., 1989. The late Devensian (<22,000 BP) Irish Sea Basin; the sedimentary record of a collapsed ice sheet margin. Quaternary Science Reviews, 8(4), pp. 307-351.

GREENWOOD, S.L. and CLARK, C.D., 2009. Reconstructing the last Irish Ice Sheet 1: changing flow geometries and ice flow dynamics deciphered from the glacial landform record. *Quaternary Science Reviews*, 28(27-28), 3085-3100.

GREENWOOD, S.L. and CLARK, C.D., 2009. Reconstructing the last Irish Ice Sheet 2: a geomorphologically-driven model of ice sheet growth, retreat and dynamics. *Quaternary Science Reviews*, 28(27-28), 3101-3123.

HANVEY, P. 1989. Stratified flow-deposits in a late-Pleistocene drumlin in north-west Ireland. Sedimentary Geology 62, 211-221.

DRAFT

HARTE, C.E. 1867. On the Post-Tertiary Geology (recent and Post-Pleistocene Phenomena) of the County of Donegal and Part of the County of Derry, and its Connexion with that of Scotland. Journal of the Royal Geological Society of Ireland 2. 30-67

HULL. E. 1878. The Physical Geography and Geology of Ireland. Edward Stanford. London.

HUGHES, T.J., 1998. *Ice sheets*. Oxford University Press, New York. 343pp.

JORDAN, C.J., 2002. An holistic approach to mapping the Quaternary Geology and Reconstructing the Last Glaciation of West County Mayo, Ireland, Using Satellite Remote Sensing and 'Conventional' Mapping Techniques. Unpublished PhD thesis, Queen Mary. University of London.

KILROE. J. R. 1888. Direction of ice-flow in the north of Ireland as determined by the observations of the Geological Survey. Quarterly Journal of the Geological Society of London 44, 827-833.

KNIGHT, J. & McCABE, A. M. 1997a. Drumlin evolution and ice sheet oscillations along the NE Atlantic margin. Donegal Bay, western Ireland. Sedimentary Geology, 111. 57-72.

KNIGHT, J. & McCABE, A. M. 1997b. Identification and significance of iceflow transverse subglacial ridges (Rogen moraine) in north central Ireland. Journal of Quaternary Science, 12. 519-524.

KNIGHT, J., MCCARRON, S. G. & McCABE, A. M. 1997. Geologic evidence for controls on late Pleistocene ice activity cycles in Ireland. EOS (Transactions of the American Geophysical Union) Supplement. 78. H31A-04.

KNIGHT, J. 2009: Subglacial erosion forms in northwest Ireland. Boreas, Vol.38, pp. 545–554.

McCABE. A. M. & DARDIS. G. F. 1989. A geological view of drumlins in Ireland. Quaternary Science Reviews. 8. 169-117.

McCABE. A. M., BOWEN, D.O. and PENNEY, D.N., 1993 Glaciomarine facies from the western sector of the last British ice sheet, Malin Beg, County Donegal, Ireland. Quaternary Science Reviews 12. 35-45.

McCABE. A. M. & CLARK, P.U. 2003. Deglacial chronology from County Donegal, Ireland: implications for deglaciation of the British–Irish ice sheet. Journal of the Geological Society, London. 160. 847-855.

MCCARROLL, D., 2001. Deglaciation of the Irish Sea Basin: a critique of the glaciomarine hypothesis. Journal of Quaternary Science 16 (5), 393–404.

MEEHAN, R.T. (2006). Glacial readvances: self-promulgating theories or science-based reality? In: Knight, P.G. (Ed.), Glacier Science and Environmental Change. Blackwell, Oxford, pp. 264–266.

O´COFAIGH, C. and EVANS, D.J.A., 2007. Radiocarbon constraints on the age of the maximum advance of the British-Irish Ice Sheet in the Celtic Sea. Quaternary Science Reviews 26 (9–10), 1197–1203.

RIJSDIJK, K., OWEN, G., WARREN, W.P., MCCARROLL, D. and VAN DER MEER, J.J.M., 1999. Clastic dykes in over-consolidated tills: evidence for subglacial hydrofracturing at Killiney Bay, eastern Ireland. Sedimentary Geology 129 (1), 111-126.

SHAW, J., KVILL, D. and RAINS, B. 1989. Drumlins and catastrophic subglacial floods. Sedimentary Geology 62. 177-202

SMITH, M.J. and KNIGHT, J., 2011. Palaeoglaciology of the last Irish Ice Sheet reconstructed from striae evidence. Quaternary Science Reviews, 30, 147-160.

DRAFT

STEPHENS, N. and SYNGE, F.M. 1965. Late Pleistocene shorelines and drift limits in north Donegal. Proceedings of the Royal Irish Academy 64B. 134 – 179.

WARREN, W.P., 1992. Drumlin orientation and the pattern of glaciation in Ireland. Sveriges Geologiska Underso¨kning 81, 359–366.

WRIGHT. W. B., 1912. The drumlin topography of south Donegal. Geological Magazine. 9. 153-159.

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

AALEN, F.H.A., WHELAN, K. and STOUT, M., 1997. Atlas of the Irish Rural Landscape. Cork University Press, 352pp.

Benn, D.I. and Evans, D.J.A., 1998. Glaciers and Glaciation. London: Arnold.

Bowen, D.Q., Phillips, F.M., McCabe, A.M., Knutz, P.C. and Sykes, G.A., 2002. New data for the Last Glacial Maximum in Great Britain and Ireland. Quaternary Science Reviews 21 (1-3), 89-101.

Bowen, D.Q., Rose, J., McCabe, A.M. and Sutherland, D.G., 1986. Correlation of Quaternary Glaciations in England, Ireland, Scotland and Wales. Quaternary Science Reviews, 5, 299-340.

CARVILLE LEWIS, H., 1894. Papers and notes on the glacial geology of Great Britain and Ireland. Longman, Green and Company, London, 649pp.

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

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

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

COXON, P., 1993. Irish Pleistocence biostratigraphy. Irish Journal of Earth Sciences 12, 83-105.

COXON, P. 2008. Landscapes and environments of the last glacial-interglacial transition: a time of amazingly rapid change in Ireland. The Irish Naturalists' Journal, 45-61.

DAVIES, G.L., 1970. The Enigma of the Irish Tertiary. In Stephens, N. and Glasscock, R.E., Irish Geographical Studies. Queens University of Ireland, Belfast, pp. 1-16.

DOWLING, L.A. AND COXON, P., 2001. Current understanding of Pleistocene stages in Ireland. Quaternary Science Reviews, 20, 1631-1642.

DUNLOP, P., 2004. The characteristics of ribbed moraine and assessment of theories for their genesis. Unpublished PhD Thesis, Department of Geography, Sheffield.

DUNLOP, P. and CLARK, C., 2006. The morphological characteristics of ribbed moraine. Quaternary Science Reviews, 25, 1668-1691.

EDWARDS, K.J. and WARREN, W.P. (Editors), 1985. The Quaternary history of Ireland. Academic Press, London.

DRAFT

EHLERS, J., GIBBARD, P. and ROSE, J. (Editors.), 1991. Glacial Deposits in Great Britain and Ireland. Balkema, Rotterdam.

FEALY, R.M., GREEN, S., LOFTUS, M., MEEHAN, R.T., RADFORD, T., CRONIN, C. and BULFIN, M., 2009. Teagasc EPA Soil and Subsoil Mapping Project –Final Report. Volumes I and II. Teagasc, Kinsealy, Dublin.

FEEHAN, J. and O'DONOVAN, G., 1996. The Bogs of Ireland. The Environmental Institute, University College Dublin.

GALLAGHER, P.H. and WALSH, T., 1943. Characteristics of Irish Soil Types – I. Proceedings of the Royal Irish Academy 42, 205-250.

GARDINER, M. and RADFORD, T., 1980. Soil Associations of Ireland and their land-use potential. Soil Survey Bulletin No. 36, An Foras Taluintais, Dublin, 142 pp.

Greenwood, S. L., 2008. A palaeo-glaciological reconstruction of the last Irish Ice Sheet. Unpublished PhD thesis, Department of Geography, The University of Sheffield.

GREENWOOD, S.L. and CLARK, C.D., 2008. Subglacial bedforms of the Irish ice sheet. Journal of Maps 2008, 332-357.

GREENWOOD, S.L. and CLARK, C.D., 2009a. Reconstructing the last Irish Ice Sheet 1: changing flow geometries and ice flow dynamics deciphered from the glacial landform record. Quaternary Science Reviews 28, 3085-3100.

GREENWOOD, S.L. and CLARK, C.D., 2009b. Reconstructing the last Irish Ice Sheet 2: a geomorphologically-driven model of ice sheet growth, retreat and dynamics. Quaternary Science Reviews 28, 3101-3123.

HAMMOND, R.F., 1981. The Peatlands of Ireland. Soil Survey Bulletin No. 35 (to accompany the Peatland Map of Ireland, 1978). An Foras Taluintais, Dublin, 60pp.

HOLLAND, C.H., 2001. The Geology of Ireland (Second Edition). Edinburgh, Dunedin Academic Press, 532 pp.

HULL, E., 1891. The physical geology and geography of Ireland. London, 328pp.

JESSEN, K., 1949. Studies in the late Quaternary deposits and flora-history of Ireland. Proceedings of the Royal Irish Academy, 52B, 85-290.

KINAHAN, G. H., 1878. Manual of the Geology of Ireland. Dublin. 444pp.

KINAHAN, G.H., 1894. The recent Irish glaciers. Irish Naturalist, 3, 236-240.

KNIGHT, J., 1999. Problems of Irish drumlins and late Devensian ice sheet reconstructions. Proceedings of the Geologists Association, 110, 9-16.

KNIGHT, J. and MCCABE, A.M., 1997. Identification and significance of ice-flow transverse subglacial ridges (Rogen moraines) in north central Ireland. Journal of Quaternary Science, 12: 519-524.

LAMBECK, K., 1996. Glaciation and sea-level change for Ireland and the Irish Sea since late Devensian/Midlandian time. Journal of the Geological Society, London, 153, 853-872.

LEWIS, C.A., 1978. Periglacial features in Ireland: an assessment. Journal of Earth Science, Royal Dublin Society 1, 135-142.

DRAFT

LEWIS, C.A., 1985. Periglacial features. In Edwards, K.J. and Warren, W.P. (Eds.) The Quaternary History of Ireland. Academic Press, London, pp. 95-113.

MCCABE, A.M., 2008. Glacial Geology and geomorphology: The Landscapes of Ireland. Dunedin Academic Press, 274pp.

MCCABE A.M., KNIGHT, J. AND MCCARRON S.G. 1999. Ice-flow stages and glacial bedforms in north central Ireland: a record of rapid environmental change during the last glacial termination. Journal of the Geological Society, London 156, 63-72.

MEEHAN, R.T., 2006. A regional glacial readvance in Ireland: self-promulgating theory, or science based reality? In Knight, P.G., Glacier Science and Environmental Change. Blackwell Scientific Publishing, pp. 264-266.

McCabe, A.M., 1985. Glacial Geomorphology, in Edwards KJ and Warren WP (ed.) The Quaternary History of Ireland. London, Academic Press Inc., 67-93.

McCabe, A.M., 1987. Quaternary Deposits and Glacial Stratigraphy in Ireland, Quaternary Science Reviews 6, 259-299.

McCabe, A.M., 1991. The distribution and stratigraphy of drumlins in Ireland, in Ehlers J, Gibbard PL and Rose J (ed.) Glacial Deposits in Great Britain and Ireland. Rotterdam, Balkema, 421-435.

McCabe, A.M., 1993. The 1992 Farrington Lecture: Drumlin Bedforms and Related Ice-Marginal Depositional Systems in Ireland. Irish Geography, 26 (1), 22-44.

MCCABE, A.M. and DARDIS, G.F., 1989. A geological view of drumlins in Ireland. Quaternary Science Reviews, 8, 169-177.

McCabe, A.M., Knight, J. and McCarron, S.G., 1998. Evidence for Heinrich Event I in the British Isles. Journal of Quaternary Science, 13, 549-568.

McCabe, A.M., Knight, J. and McCarron, S.G., 1999. Ice-flow stages and glacial bedforms in north central Ireland: a record of rapid environmental change during the last glacial termination. Journal of the Geological Society, London 156, 63-72.

MITCHELL, G.F., 1998. The Ice Age. Chapter 2 of Mitchell, G.F. and Ryan, M., Reading the Irish Landscape, Townhouse Press, pp. 35-80.

PRAEGER, R.L., 1937. The Way that I Went. Collins Press, Dublin. 394pp.

Scourse, J.D., Haapaniemi, A.I., Colmenero-Hidalgo, E., Peck, V.L., Hall, I.R., Austin, W.E.N., Knutz, P.C., and Zahn, R., 2009. Growth, dynamics and deglaciation of the last British-Irish Ice Sheet: the deep-sea ice-rafted detritus record. Quaternary Science Reviews, 28, 3066-3084.

SMITH, M.J. and KNIGHT, J., 2011. Palaeoglaciology of the last Irish Ice Sheet reconstructed from striae. Quaternary Science Reviews 30 (1-2), 147-160.

STEVENS, L.A., 1959. Studies in the Pleistocene Deposits of the British Isles. Unpublished PhD Thesis, Cambridge University.

Synge, F.M., 1970. The Irish Quaternary: Current views 1969. In Stephens N and Glasscock RE (ed.) Irish Geographical Studies, in honour of E. Estyn Evans. The Queen's University of Belfast; Belfast.

DRAFT

SYNGE, F.M. and STEPHENS, N., 1960. The Quaternary period in Ireland-an assessment, Irish Geography, 4, 121-130.

WARREN, W.P., 1985. Stratigraphy. In Edwards, K.J. and Warren, W.P. (Editors), The Quaternary history of Ireland. Academic Press, London, pp. 39-65.

Warren, W.P., 1992. Drumlin orientation and the pattern of glaciation in Ireland, Sveriges Geologiska Undersökning 81, 359-366.

WATTS, W. A., 1970. Tertiary and interglacial floras in Ireland. In Stephens, N. and Glasscock, R.E. (Editors), Irish Geographical Studies, Queens University Belfast, pp. 17-33.

WATTS, W.A., 1985. Quaternary vegetation cycles. In Edwards, K. And Warren, W.P. (Eds.), The Quaternary History of Ireland, Academic Press, London, 155-185.

Westley, K., Quinn, R., Forsythe, W., Plets, R., Bell, T., Benetti, S., and Robinson, R. 2011. Mapping submerged landscapes using multibeam bathymetric data: a case study from the north coast of Ireland. International Journal of Nautical Archaeology, 40 (1), 99-112.

WHITTOW, J.B., 1974. Geology and scenery in Ireland. Dublin, Penguin Books, 304 pp.

WOODMAN, P. C., McCARTHY, M. and MONAGHAN, N. T. 1997. The Irish Quaternary fauna project. Quaternary Science Reviews 16, 129-15.

NORTH DONEGAL MINING AND MINERALOGY REFERENCES

Chapman, R.J., Leake, R.C., and Moles, N.R. 2000. The use of microchemical analysis of alluvial gold grains in mineral exploration: experiences in Britain and Ireland, Journal of Geochemical Exploration, 71, 3, 241-268

CLARINGBOLD, K., FLEGG, A., MAGEE, R. and VONHOF, J. 1994. Directory of active quarries, pits and mines in Ireland. Geological Survey Ireland Report Series RS 94/4 (Mineral Resources). 111 pages.

COLE, G.A.J. 1922. Memoir and map of localities of minerals of economic importance and metalliferous mines in Ireland. Memoirs of the Geological Survey Ireland. Mineral Resources. 155 pages.

EARLS, G., HUTTON, D., WILKINSON, J., MOLES, N., PARNELL, J., FALLICK, A. and BOYCE, A. 1996. The gold metallogeny of northwest Northern Ireland. Crowe, Schaffalitzky and Associates (NI) Report No. 049.96. volume 1, vii + 107 pages.

FLEGG, A. 1987. Industrial Minerals in Ireland: their geological setting. Geological Survey Ireland Report Series 87/3. 27pp.

FLEGG, A.M. 1979. Steatite in Ireland. GSI unpublished document. 25 pages

GARDINER, P.R.R., GERAGHTY, C., GARVEY, E., COX, W.R. and LOUGHLIN-LUNT, B. 2008. Bibliography of Irish Mineral Resources, Publications and Selected Reports 1750 – 2007, Exploration and Mining Division, 54 pages.

GEOLOGICAL SURVEY IRELAND. 1987. Industrial Minerals Newsletter No. 1.

Geological Survey Ireland and Environmental Protection Agency. 2009 Historic Mine Sites - Inventory and Risk Classification Volume 1. (Digital Report available online) 170 pages.

DRAFT

LEGG, I.C., PYNE, J.F., NOLAN, C., McARDLE, P., FLEGG A. M. and O'CONNOR, P.J. 1985. Mineral localities in the Dalradian and associated igneous rocks of County Donegal, Republic of Ireland and of Northern Ireland. Geological Survey Ireland Report Series 85/3. 87pp.

LONG, C.B. 1982. Preliminary study of a disused white marble quarry at Dunlewy, Co. Donegal. Geological Survey Ireland, unpublished report, 6 pages, 2 figures.

LONG, C.B. 1983. Tungsten mineralisation in northern Donegal: report on a field meeting with Irish Base Metals geologists at Lough Greenan (P.L. 2115) on 19th and 20th May 1983. Geological Survey Ireland, unpublished report, 9 pages, 5 figures.

LONG, C.B. 1984. Some field observations and thoughts on tungsten mineralisation in Donegal and Connemara. Unpublished Report, Geological Survey Ireland.

McARDLE, P. 1978. The significance of base metal mineralisation in the Dalradian of Donegal, Ireland (abstract). Transactions of Mining and Metallurgy (Section B: Applied Earth Science). 87, B34.

McARDLE, P., REYNOLDS, N., SCHAFFALITZKY, C. and BELL, A.M. 1986. Controls on mineralization in the Dalradian of Ireland. In: C.J. Andrew et al. Geology and Genesis of Mineral Deposits in Ireland. Irish Association for Economic Geology, 31-43.

MOLES, N.R. and SCHAFFALITZKY, C. 1992. Gold exploration methodologies and target definition in the Donegal Dalradian. In: Bowden, A.A., Earls, G., O'Connor, P.G. and Pyne, J.F. (eds), The Irish Minerals Industry 1980-1990. Irish Association for Economic Geology, 119-134.

O'CONNOR, P.J, and LONG, C.B. 1981. Final report to the EEC on the Donegal Uranium Project, Contract PU/3/79. Geological Survey Ireland Unpublished Report 157pp plus figs and maps.

O'CONNOR, P.J. 1986. Uranium mineralization in the Irish Caledonides. In: Andrew, C.J., Crowe, R.W.A., Finlay, S., Pennell, W.M. and Pyne, J.F. (eds), Geology and Genesis of Mineral Deposits in Ireland. Irish Association for Economic Geology 157-175.

O'CONNOR, P.J. and LONG, C.B. 1985. Radioelement abundance data for some Dalradian rocks from Co. Donegal, Ireland. Mineralogical Magazine and Journal of the Mineralogical Society. 49, 643-648.

O'CONNOR, P.J., LONG, C.B., BASHAM, I.R., SWAINBANK, I.G. and BEDDOE-STEPHENS, B. 1984. Age and geological setting of uranium mineralization associated with the Main Donegal Granite, Ireland. Transactions of the Institution of Mining and Metallurgy (Section B: Applied earth sciences) 93, B190-194.

O'CONNOR, P.J., LONG, C.B., BASHAM, I.R., SWAINBANK, I.G. and BEDDOE-STEPHENS, B. 1984. Age and geological setting of uranium mineralization associated with the main Donegal Granite, Ireland. Transactions of the Institution of Mining and Metallurgy B93, 190-194.

DRAFT

Appendix 4. Rejected sites and Renamed Sites

NORTH DONEGAL AUDIT REJECTED AND RENAMED SITES

Based on the authors' expert knowledge of County Donegal's geology, and especially in the main mountain area, a range of sites, previously flagged for consideration in the IGH Master Site list, were assessed as unsuitable for County Geological Site status in this audit. The following sites were investigated as part of the audit on foot of the original recommendations of the IGH expert group. It was known, for example, that some quarry localities had not been adequately considered in the preparation of the IGH Master Site list. Other sites were visited on spec during fieldwork. The rejected sites are listed below with brief notes as to why they were assessed as unsuitable for inclusion.

Bloody Foreland and Knocknafolla sites

The Bloody Foreland and Knocknafolla sites, though listed as two sites, are actually the same locality. The site was listed as important for 'chemical weathering', which is present in a roadside quarry at the north of the ridge, but was not deemed worthy of County Geological Site status.

The 'Bloody Foreland/Knocknafolla' site, which is simply a granite quarry with some weathering in the upper portions of the bedrock.

Note: 'Bloody Foreland' was also listed as important in the Master Site List for 'moraines' and 'raised beaches'. The County Geological Site Reports for Altnapeaste and Altawinny Bay cover these features.

Falcarragh Flat

The 'Falcarragh Flat' feature was included because of 'coarse grained gravels', which have been interpreted as having been deposited by a glacial efflux into standing water. However, the gravels are now very poorly exposed and the majority of the feature has been removed by quarrying; hence is not included as a County Geological Site.

The pit cut into the 'Falcarragh Flat', which is nearing the end of its life, has poor exposure, and has removed the majority of the feature itself.

Fanad Granite

This site was nominated as a County Geological Site for intrusion breccia features. However, these are well covered by better known examples in south Donegal. No breccia was observed at this site when surveyed in summer 2014.

Glencrow Delta

This feature is located approximately 1km WNW of Moville, in the proximity of the Glencrow townland, overlooking Inishowen's Lough Foyle coastline. The IGH Master Site List records Glencrow Delta as a Quaternary (IGH7) theme site for the occurrence of 'flat-topped, ice pushed deltaic gravelly deposits with interbedded red marine muds'. Stephens and Synge (1965) reported on the complexity of the features: the sections of outwash sand and gravel deposits, till deposits, and the red fossiliferous marine clays. However, these specific features are not readily apparent, and are nowhere exposed in easily-observable or accessible locations. Whilst the general moraine topography of the feature is observable remotely, from Moville and from the R238 Moville-Gleneely road, in comparison to other such Quaternary sites in north Donegal, this site is not regarded as being of County Geological Site merit. The site is not deemed under threat of removal or damage, and will most likely continue to serve as productive farmland.

View from Gort South, near Cooly Cross, looking east towards Lough Foyle from the high ground behind Carrownaff, Moville.

View from Glencrow, looking east down Breedagh River valley towards Moville.

Lough Nacung, Dunlewy

The lake was included in the IGH Master Site list as a pater noster lake, along with Dunlewy Lough, and comprising Lough Nacung Upper and Lough Nacung Lower. Pater noster lakes are formed in the upper reaches of glacial valleys, and are generally gouged out of bedrock and are usually dammed by moraines. Neither of the Loughs Nacung were formed in this manner, and Dunlewy Lough is separate from them only because of a man-made road and causeway. From this evidence, the lakes are not pater noster lakes and are rejected as a site.

The man-made causeway and bridge separating Lough Nacung Upper from Dunlewy Lough.

DRAFT

Lough Greenan
Lough Greenan was listed under the IGH6 Mineralogy Theme due to the rare occurrence of the tungsten mineral, scheelite, prompted originally by a 10mm crystal of scheelite in the collections of Ulster Museum, although that may, in fact, have come from a different locality to the one examined in this audit. Tungsten localities around Lough Greenan were reported on by Barry Long of the Geological Survey Ireland. However, most of these were only identified with the aid of industrial ultra violet lamps used at night to detect the blue fluorescence of the scheelite mineral. Others were panned from shallow sediments in the lake shore. The mineral occurs in a variety of associations with the carbonate marble and schist and quartzite, and in veins. Given that this is really an exploration target area, without a clear site with visible mineralisation, and located in the specific mapped mineral localities where there is now no exposure, this site is not suitable for County Geological Site recognition.


A lack of rock exposure is apparent at the two scheelite localities beside Lough Greenan.

Rosepenna
Rosepenna was included in the IGH Master Site list for a 'tombolo' feature. However, it is not certain that the peninsula at Rosepenna is definitively a tombolo and without detailed research into this (confirmation of the three dimensional geometry of the peninsula) Rosepenna should be rejected as a site.

It should be noted that a tombolo is present in the County Geological Site at Inishfree Bay.

Pollan Bay
Pollan Bay was listed under the IGH15 Economic Geology Theme due to the occurrence of stratabound small, accessible, stratiform disseminations and bands of sphalerite, galena, pyrite along the contact of the Dalradian Slieve Tooey Quartzites and Termon Pelites. The green chloritic pelites with thick (<10cm) bands of buff-coloured weathered semipelites and psammites (Termon Formation) dip moderately to the southeast. Exposure is sporadic, with two minor localities near the foreshore showing stratiform sphalerite and pyrite interbanded with the dolomitic marble. Whilst the contact between the Slieve Tooey Quartzites and Termon Pelites is an important zone of deformation, the site is not deemed to be of significance as a County Geological Site. At Annagh, around 2km south of Pollan Bay, occurrences of barite (and haematite and quartz) have also been identified, and the minerals are also associated with the Slieve Tooey Quartzite and Termon Pelites contact zone.

Renamed Sites

- Croaghan Head renamed to Croaghan Hill, as the site is a hill feature.
- Carndonagh (Infiltration Gallery) renamed to Carndonagh Well Field to make the site features easier to understand.
- Quigley's Point (Alluvial Gold) renamed Quigley's Point (Cabry River) as the features of interest occur in the river.
- Moville to Inishowen Head site name updated from its original listing in the IGH Master List to 'Moville to Greencastle' because the features of interest are sufficiently well represented along the 4km coastal section between Moville and Greencastle.

SOUTH DONEGAL AUDIT REJECTED SITES

In addition to the documented sites, the following six sites were investigated on foot of the original compilation of the expert group, but assessed as unsuitable for inclusion, as outlined in the brief notes below.

Barnesmore Gap (IGH 6 Mineralogy)

The Barnesmore Granite is radioelement-rich, i.e. it contains uranium in concentrations greater than 6 ppm and/or thorium in concentrations greater than 25 ppm. Disseminated, fine-grained to microscopic uranium mineralization is dispersed over wide areas. There is a number of showings of secondary uranium minerals (mainly autunite) and these are found mainly within the leucogranite/aplogranite facies (G3) of the granite, either on joint surfaces or at the margins of dolerite dykes. The mineralization has been explored but not exploited and there are no localities that could serve as type sites, as such, for the mineralization.

Sheskinarone Site 1 (IGH6 Mineralogy)

This site is south of the main Sheskinarone beryl location (Sheskinarone Site 2) where large beryl crystals can be seen in quartz-pegmatite veins cutting greisened granite. This site is on a small, low hill covered by thin but extensive blanket bog with numerous granite boulders (float). The beryl in is at the centre of a quartz-feldspar pegmatite zone within a loose boulder of Rosses granite within the blanket bog. Examination of the entire hill area suggests that many of the granite occurrences at this site are also probably float. Field clearance at the eastern end of the hill has thrown up very large boulders (greater than 1 m^3) of granite but further examples of beryl mineralization were not observed. As this is a relatively rare example of this mineral and there have been damaging attempts to collect it from other locations, there is a need to consider conservation and to avoid advertising its location, especially as this is a loose boulder that could be easily carried away. For this reason, it is not recommended to list this site as a CGS. An alternative approach might be to remove the boulder to a county museum or other public exhibition area, thus securing it against future attention from unscrupulous mineral collectors.

General view, Sheskinarone Site 1, looking east with mineralized boulder in foreground.

Beryl (green colour) in quartz-feldspar pegmatite (left) and close-up of beryl in quartz-feldspar pegmatite (coin diameter = 23 mm) (right).

Shalwy moraines (IGH 7 Quaternary)

The ‘Shalwy/Shalweg Moraine’ site was not deemed worthy of inclusion, owing to its local interest only. Such small moraine features are very common across the country, and the majority are important at a local level only. In addition, there is no dated evidence to show that it forms part of the Killard Point readvance, which is what has been interpreted as giving the feature its scientific significance.

Lower Shalwy Valley (left) and Upper Shalwy Valley and Crownarad (right)

Aghlem Bridge (IGH 8 Lower Carboniferous)
Aghlem Bridge, on the southeast side of Lough Eske, was originally listed as a location for evaporate deposits in an incised stream but nothing of interest was observed during the site visit for this report.

Clogheracullion (IGH 15 Economic Geology)
This site, in upland moorland, is within the 9 km-long Main Radiometric Zone (MRZ) of the Main Donegal Granite. The MRZ is spatially associated with the distribution of biotite-rich pegmatites in the granite, although not all pegmatites are mineralized. Exploration in the early 1980s defined a 9m wide uranium-bearing zone with a mean concentration of 0.3 kg/tonne U_3O_8 over a strike length of 500m. Uraninite is the main mineral present, occurring as small (0.1–1.75 mm) crystals in biotite-rich parts of the pegmatite. The disseminated, dispersed and very fine-grained nature of the mineralization means that it is not possible to define a specific site for the purposes of this audit. The site originally described by Legg *et al.* (1985) is now under forest.

Mountcharles (IGH16 Hydrogeology)
The Mountcharles Hand Pump site was originally included as of potential hydrogeological interest but its only local significance appears to have been as the venue for a local bard who told children's stories.

Appendix 5. History of Geological and Geomorphological research in Donegal

In the 1830s the topography of County Donegal was amongst the earliest to be mapped in painstaking detail by the newly established Ordnance Survey of Ireland. At that time geology was a very young science and an arena for many heated disputes. In Antrim, some geologists argued that dolerites in the Portrush Sill were unusual sedimentary rocks, because adjacent layers contained ammonites. Darwin's momentous theory on the *Origin of Species* was published as late as 1859. In Donegal, the controversy about whether granites were igneous or metamorphic rocks would rumble on for another century.

The first geological map of Ireland was published by Griffith in 1839. It showed northeast-southwest trending metamorphic belts in Donegal and proved a stimulus to further research, which soon established that the geology of Donegal was particularly complex. It became apparent that its metamorphic and igneous rocks presented problems that were beyond the grasp of the best existing understanding. Geological Survey Ireland therefore took the wise decision to defer mapping Donegal until the rest of the country was largely complete.

Work on the geological survey of south Donegal by geologists Egan, Kilroe, Kinahan, McHenry, Nolan and Symes began in the 1880s and the results were published between 1888 and 1890 in a series of memoirs with sections and maps on a scale of 1:63,360 (1 inch to a mile) (Hull *et al.* 1891a, 1891b). These publications remain a very useful resource today and are now available for free consultation on the internet at www.geologicalmaps.net/IrishHistMaps/. In this series, the sheet numbers covering South Donegal run as follows:

	15	16	17
22	23	24	25
30	31	32	

where sheet 15 covers the northwestern part (around Dunglow) and sheet 32 the southeastern part (around Pettigoe).

The next advance took place in the 1950s when a remarkable team effort was launched by young geologists based mainly at Imperial College, London. Under the leadership of Professor H. H. Read and lecturer Wallace Pitcher, Donegal was divided up into a series of blocks for thesis mapping by enthusiastic and competitive Ph.D. candidates. The blocks in South Donegal were mapped on a scale of 1:10,560 (6 inches to the mile) by Read, Pitcher, Gindy, Pulvertaft, Cheesman, Mithal, Akaad, Iyengar, French, Walker, Leedal, Elwell, Tozer, Anderson, Kemp, Oswald, George and Wood. These individual projects were integrated by Pitcher and Margaret Spencer into a geological map of Donegal at scale of 1:63,360 which, for the first time illustrated the continuity of the Dalradian stratigraphic succession and the detail of several granite plutons. This map was accompanied by Pitcher and Berger's book *The Geology of Donegal* (1972), which covered every aspect of metamorphic and igneous geology in the county and is still regarded as a classic work.

It shortly became apparent that the Dalradian succession in Donegal could be extended northeast into Islay and onwards through the central highlands of Scotland and, later, southwest into Mayo and Connemara. Thus Donegal became a global keystone in understanding several hundred million years of Earth history. Pitcher's descriptions of the granites in Donegal led to him becoming the leading global

DRAFT

authority in that field also, culminating in his *A Masterclass Guide to the Granites of Donegal* (Pitcher and Hutton, 2003).

Further advances in the understanding of Donegal geology came with descriptions of the key Port Askaig Tillite horizon (Howarth, 1971; Johnston 1993), and with contributions to the understanding of the structural geology by Hutton and Alsop (e.g. Hutton, 1982; Alsop, 1991; Hutton and Alsop, 1996a, 1996b, 2004). The accelerating advance in geological knowledge about Donegal up to the late 1990s was summarised in the Geological Survey Ireland booklet *Geology of South Donegal*, and its accompanying 1:100,000 scale map in the Bedrock Geology Map Series (Long and McConnell, 1999).

Establishing geomorphology as a discipline distinct from geology began only in the 20th century, although its components had been of critical interest to civil engineers in every previous age. The 19th century expansion of canals and railways required contractors to move vast quantities of rock and earth from cuttings to embankments. Additionally, their engineers had to consider the effects of flooding and erosion on their designs for bridges and viaducts. They soon found that structures developed in friable gravel and drift had a totally different character from those in solid rock. They realized that the superficial sediments had erosion and deposition characteristics that could not be explained by present day processes. These observations eventually led geologists to conclude that these deposits were evidence that thick glaciers had covered the country in the not very distant past.

The Swiss geologist, Louis Agassiz was amongst the first to recognize the extensive role of ice in shaping the landscape throughout northern Europe. He visited Britain and Ireland in 1840 and confirmed that similar structures to those he had observed in Switzerland were present in Scotland, northern England and in the north, centre, west and southwest of Ireland. However, the glaciological theories of Agassiz and Buckland had hardly entered the scientific repertoire in 1843 when Portlock published his comprehensive *Geological study of Londonderry and parts of Tyrone and Fermanagh*. In this book Portlock treated boulder clay and gravel in a short and tentative chapter entitled *Detritus*.

The Finn Valley Railway between Strabane and Stranorlar opened in September 1863. Four years later, in June 1867, William Harte, County Surveyor of Donegal, read a paper to the Royal Geological Society of Ireland entitled *On the post-Tertiary Geology (Recent and Post Pliocene Phenomena) of the County of Donegal, and part of the County of Derry, and its Connexion with that of Scotland.* Harte was a careful observer whose career he said, ‘had brought him in contact with the contents of every quarry and gravel pit in the county’.

Harte became interested in the glaciological theories being put forward by Jamieson, Geikie and others to explain the boulder clays and gravels found in Scotland and Ireland and sought to contribute his own understanding to the debate. He suggested that ice accumulations in Donegal had been thickest on an old ‘Central Range’ extending from the Bluestacks through Derryveagh and Errigal to the Bloody Foreland. Valleys everywhere were initially filled with boulder clay, establishing a smooth plane for the ice to slide down. As the ice thawed, drainage sifted boulders and gravel from those valley deposits and a major proportion was dispersed eastwards towards Derry. As meltwater descended from the mountains it first produced boulder-clay ridges followed by crag and tail hills. Farther east the small hills accumulated valley gravels and all sediment components became finer as the Foyle was approached.

Although mostly concerned with North Donegal phenomena, Harte used Lough Eske to illustrate his theory of rock basin formation. He noted that rocks excavated there by ice are strewn in all directions westward, but not eastward of his 'Central Range'.

After brief chapters in Geological Survey Ireland memoirs mentioned above, the next significant description of Ice Age phenomena in south Donegal was a paper by W.B. Wright, entitled *The Drumlins of South Donegal* (Wright, 1912). This account discussed the shape of drumlins along the eastern shore of Donegal Bay and contrasts them with those near Pettigoe, concluding that their form was a function of fluctuations in the direction of ice movement.

Stephens and Synge (1965) mapped raised shorelines on Inishowen and Fanad peninsula that indicated post-glacial uplift of 15 to 25 m. Colhoun (1973) mapped the most important glaciological features of the Slieve League Peninsula (Fig 5) and gave an interpretation of the wider area that has not been superceded. Later, McCabe *et al.* (1993) implied that the western end of the Slieve League Peninsula had experienced an isostatic rebound of about 45 m.

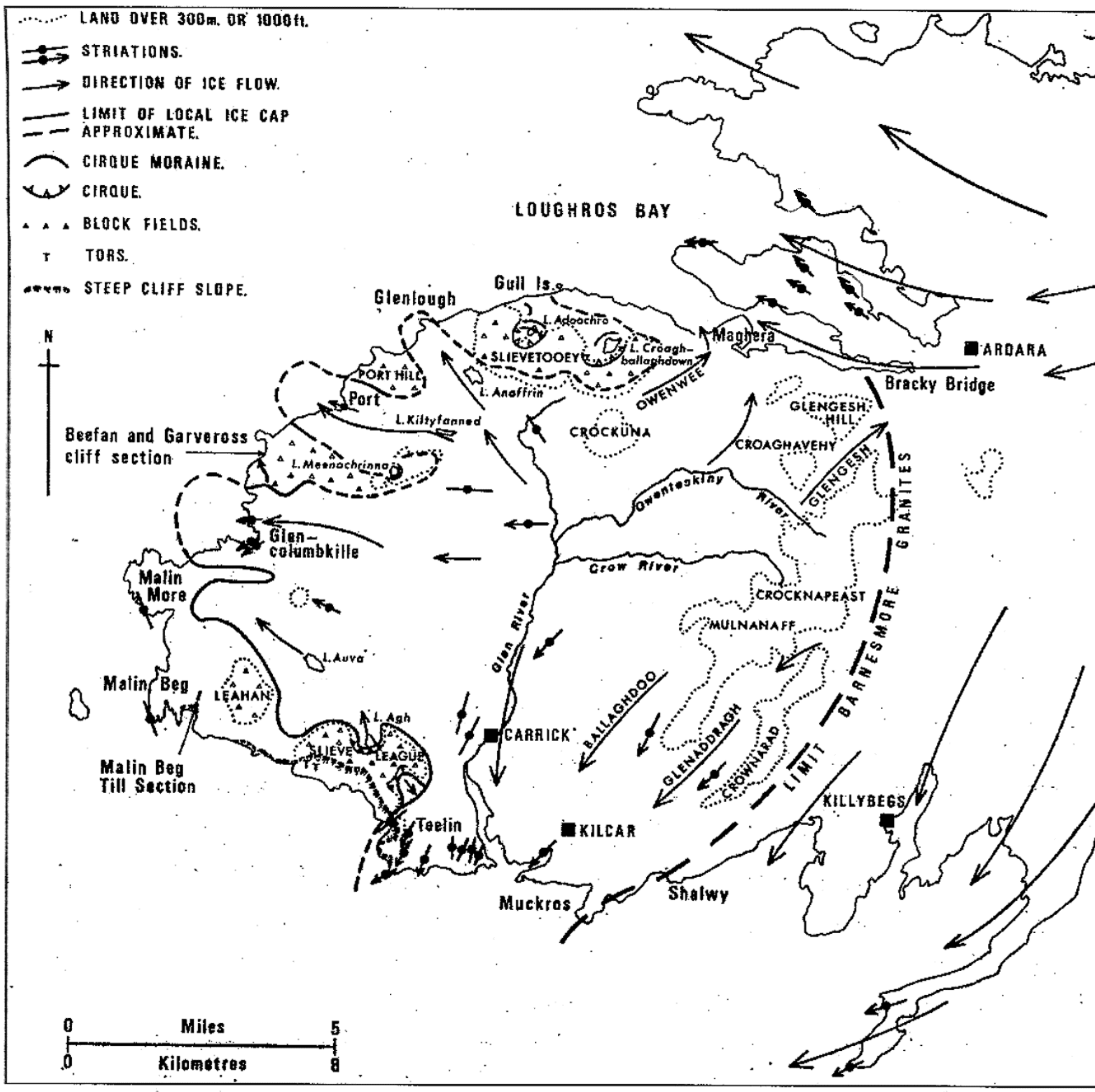


Fig. 5 Extent of ice cover and direction of ice flow to the coast in south Donegal during Late Midlandian glaciation (courtesy of Irish Geography)

There have been several studies of drainage patterns along the northwest coast of Ireland (Pitcher and Berger, 1972). Others have written about Holocene sea levels and aeolian deposits. However the contemporary coastal geomorphology of the region remained relatively neglected until recent decades when geomorphologists from the University of Ulster at Coleraine studied Donegal's beaches, dunes, wave erosion and associated tidal and saltmarsh processes. As a result, Donegal's coastline, with the highest average wind speeds in Europe, has become a benchmark for international comparison. Burningham and Cooper (2004) examined west Donegal coastal morphology to evaluate historical change in this environment and to appraise the factors controlling coastal behaviour. These studies culminated with Burningham's study (2008) of Loughros Bay, which considers the interaction between all the causes that contribute to its rapidly changing shape.

DRAFT

Appendix 6. Geoschol leaflet on the geology of Donegal

DONEGAL

AREA OF COUNTY: 4,841 square kilometres or 1,869 square miles

COUNTY TOWN: Lifford

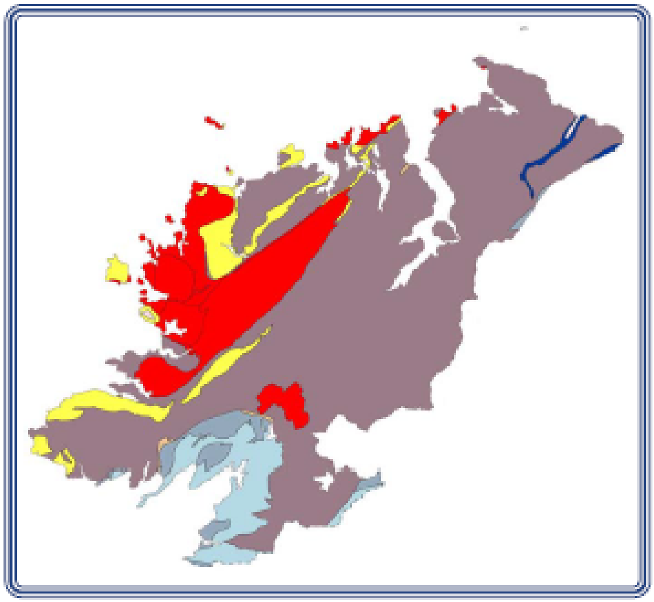
OTHER TOWNS: Bundoran, Donegal, Letterkenny, Stranorlar

GEOLOGY HIGHLIGHTS: Precambrian metamorphic rocks, granites, Lower Carboniferous sandstones and limestones, building materials

AGE OF ROCKS: Precambrian; Devonian to Carboniferous

Malin Head

Precambrian metamorphic schists and quartzite at Malin Head.
In the distance is Inishtrahull, composed of the oldest rocks in Ireland.



Geological Map of County Donegal

Pale Purple: Precambrian Dalradian rocks; **Bright blue:** Precambrian Gneiss and Schists; **Pale yellow:** Precambrian Quartzite; **Red:** Granite; **Beige:** Devonian sandstones; **Dark blue:** Lower Carboniferous sandstones; **Light blue:** Lower Carboniferous limestone.

Geological history

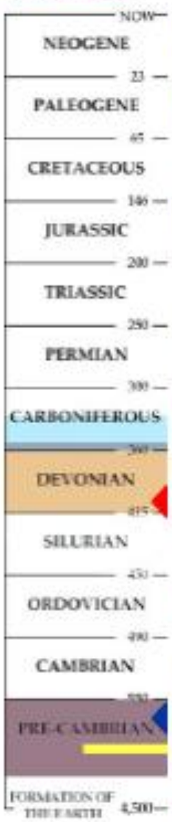
The geology of Co. Donegal most closely resembles that of Co. Mayo, and the county contains the oldest rocks in Ireland, around 1780 million years old, exposed on the offshore island of Inishtrahull. 1000 million years ago [Ma] sediments were deposited in an ocean and an Ice Age that affected the Earth at this time produced glacial till of cobbles of rock set in a matrix of crushed rock. Between 470 and 395 Ma the whole area was subjected to a mountain-building event called the Caledonian Orogeny and the rocks were metamorphosed or altered into gneiss, schists and quartzites now known as the Dalradian Group. Errigal Mountain is composed of this quartzite which weathers to a 'sugarloaf' shape. The metamorphosed glacial deposits are called Tillites. In the late phase of the orogeny two continents collided and the north-east to south-west trend of the rocks in Donegal was produced. At the same time around 405 Ma a series of six granite masses were injected

Granites, Bluestacks Mountains

into the older rocks of which the Main Donegal Granite is the largest. Granite is an igneous rock which crystallised as it cooled down, and its constituent minerals - quartz (glassy), feldspar (white or pink) and mica (black or silvery) interlocked.

There are no Ordovician or Silurian rocks in Donegal and only a small patch of Devonian sandstones along the northern shore of Donegal Bay. In the Lower Carboniferous (350 Ma) a warm shallow ocean migrated northwards very slowly. When it reached Donegal it resulted, firstly, in the deposition of sands and muds carried south by rivers that drained the old continent. This material was laid down close to the shoreline and now forms the sandstones and mud stones at Doorin Point (pictured below). These gave way to limestones that often contain corals and other fossils. The sea level fluctuated at this time and a shallowing of the sea saw further sandstones (such as the Mountcharles Sandstone) being deposited. Later limestones were deposited in the deepening ocean in which some reefs rich in organisms such as corals, cephalopods (squids) and bryozoans also grew. The Carboniferous rocks are found in a semicircle around Donegal Bay.

Doorin Point. Layers of Lower Carboniferous mudstone and sandstone on the north shore of Donegal Bay



Geological timescale showing age of rocks in Donegal.

Inishtrahull

Inishtrahull is a small island off the northern coast of Donegal. It once supported a reasonable population which had its own National School. It is also the site for a Lighthouse. Geologically the island is fascinating as it contains the oldest rocks in Ireland. These are igneous rocks called syenite and have been dated using radiometric minerals. They are 1,779 million years old.

Dimension stones: Granites and the Mountcharles Sandstone

Stone is a most useful building material. In the past many small quarries exploited the diverse rock types of Donegal. Slates were quarried for roofing, weathered quartzite sands were used for glass-making, and talc was mined for lubricants and talcum powder. Several quarries still work some of the marble bands for agricultural lime and for decorative stone chippings or roadstone. The Donegal Granites were once cut into setts at Barnesmore Gap and transported from the quarries by rail for use as paving in Victorian cities. Now granite boulders are often used for headstones or commemorative stones. The Mountcharles Sandstone is a Lower Carboniferous yellow sandstone that was popular in the 1890s. It was used for the National Library and National Museum in Dublin but due to acid rain falling in the city between 1890 and 1930 it began to disintegrate. However elsewhere in Ireland where the air was clean it proved to be a hard-wearing stone and it continues to be quarried and used today. The photograph to the right shows one of the stone mine workings.

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

www.geoschol.com

Text by Patrick Wyse Jackson & Mike Simms

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 Donegal. These have been specially prepared for this report in order to make the information accessible to planners and other staff without geological training. For most sites more detailed reports and information files are held in the IGH Programme in Geological Survey Ireland. These are available for consultation if required. Further sites may become relevant as Geoheritage (IGH) Programme work develops.

Due to the large number of geological heritage sites in Donegal, the county has been divided into 'north' and 'south' areas for audit purposes. The northern extent of the south Donegal report area has been taken to roughly coincide with the Geological Survey Ireland 1:100K Bedrock Sheet 3/4 boundary, and runs approximately from Burtonport in the west to just south of Newtown Cunningham in the east.

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

Coordinate Projection System – IRENET95 ITM

Irish Transverse Mercator (ITM) is the geographic projection co-ordinate system now in use for Ireland, and has been applied to all site localities in the site reports. It is the standard co-ordinate system for OSi maps, including the new Discovery map series, but a coordinate conversion tool is available on the OSi website at: http://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 typically 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 recommended or will be recommended for NHA designation, detailed site boundary maps will become available to the Local Authority, through NPWS, as the designation process is undertaken. Some areal extents 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

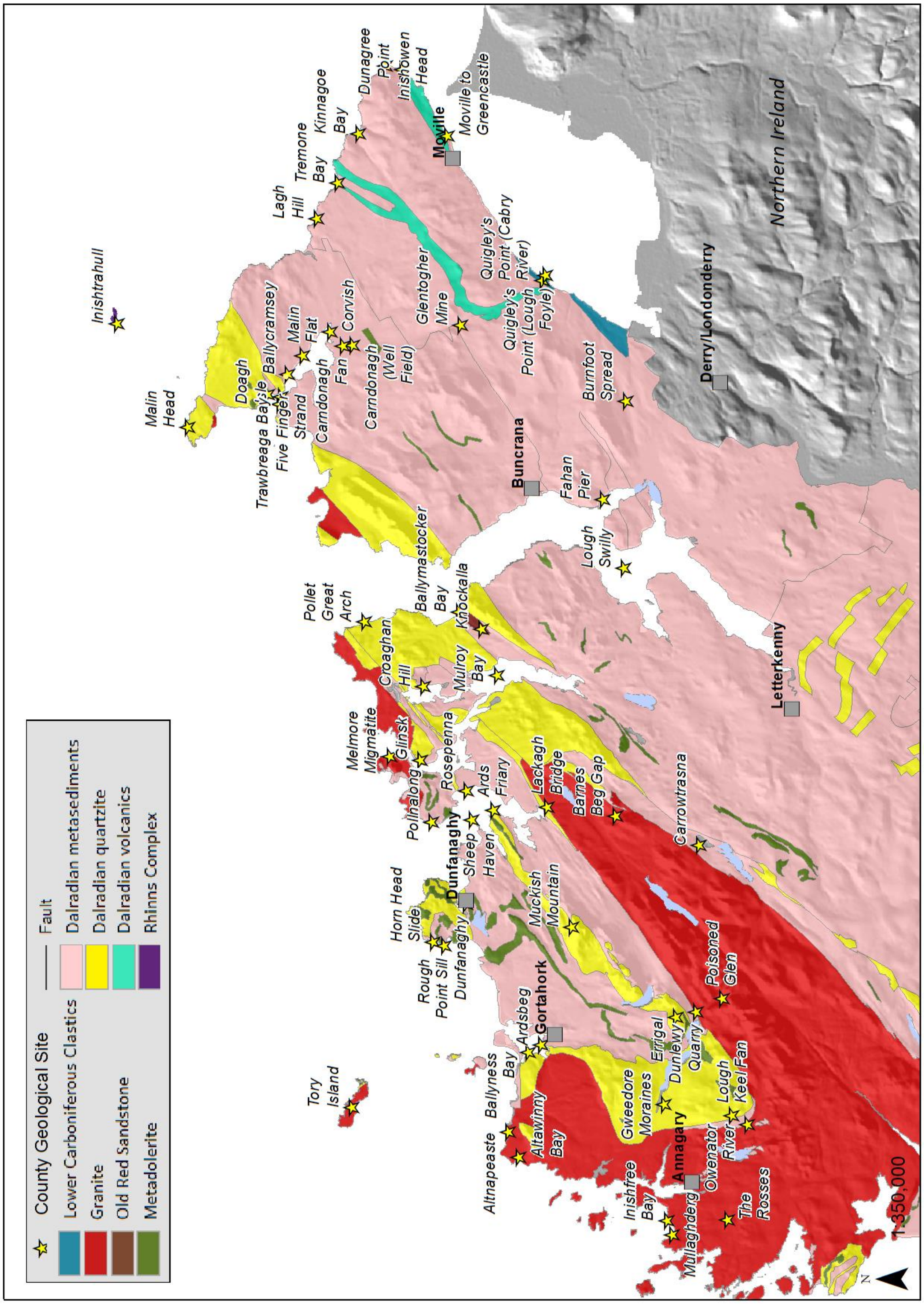
DRAFT

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 with NPWS on the most important sites to be designated. Any landowner within areas or sites identified in this report with concerns over any aspect of this project is encouraged to contact Clare Glanville, Head of the Geoheritage and Planning Programme, in Geological Survey Ireland, Beggars Bush Haddington Road Dublin D04 K7X4. Phone 01-6782837. Email: clare.glanville@gsi.ie

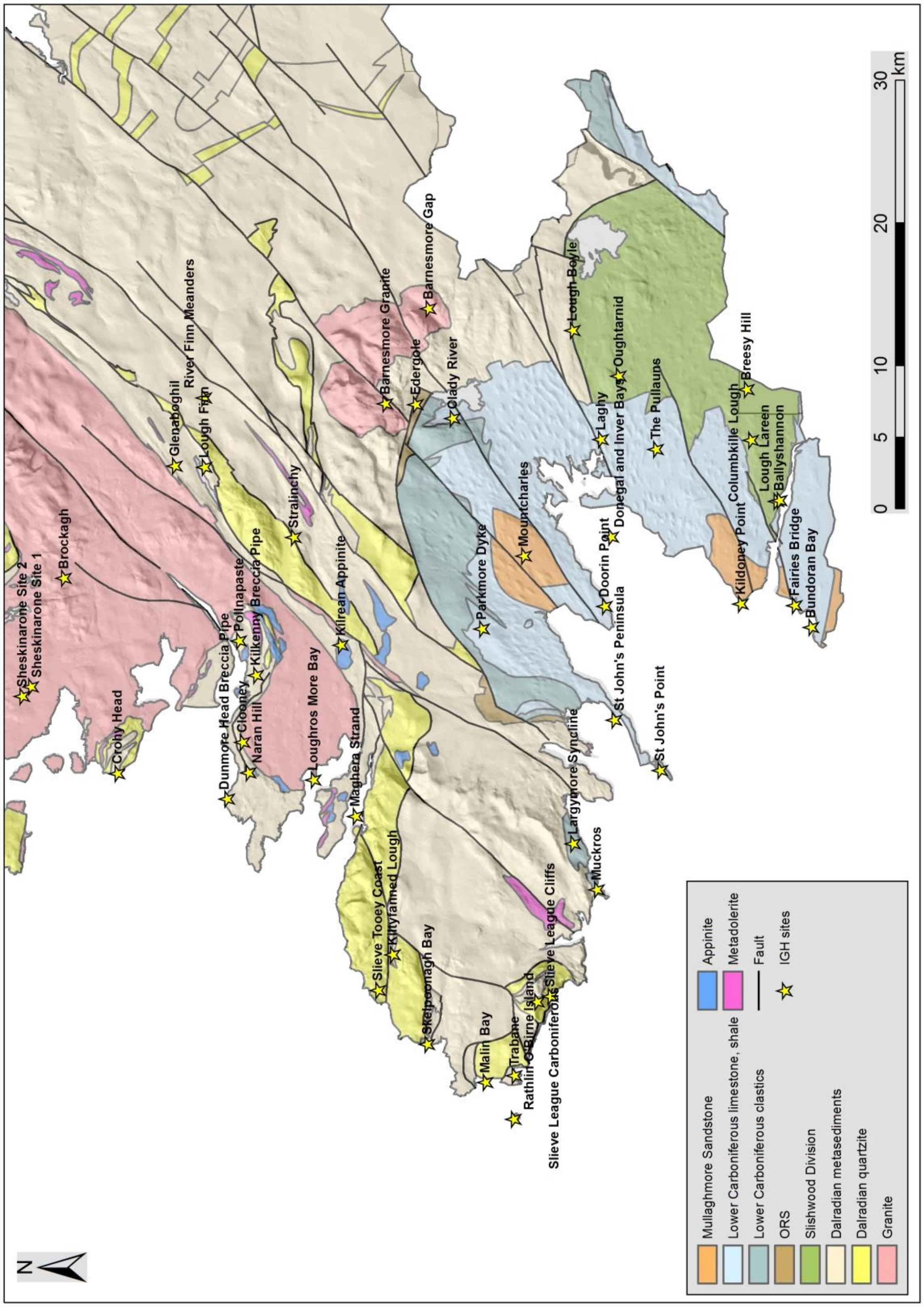
DRAFT

Site Reports – Location Map North Donegal



Simplified Geological Map of North Donegal with site locations indicated.

Site Reports – Location Map South Donegal Audit



Simplified Geological Map of South Donegal with site locations indicated.