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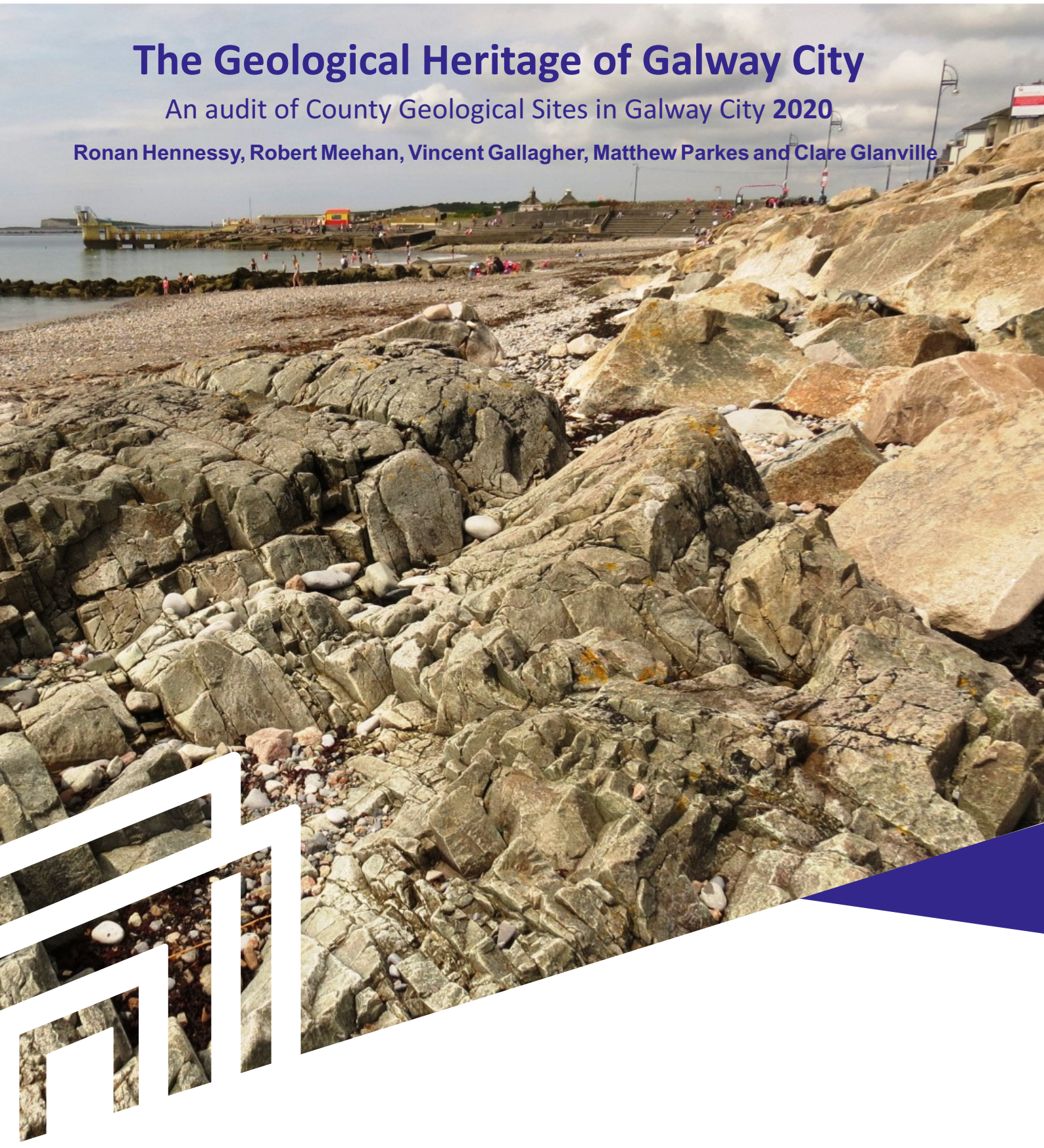
The Geological Heritage of Galway City

An audit of County Geological Sites in Galway City **2020**

Ronan Hennessy, Robert Meehan, Vincent Gallagher, Matthew Parkes and Clare Glanville



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

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2020

The Galway City Geological Heritage Audit was completed on behalf of

This report is a contribution to the programme of work supported by Geological Survey Ireland in establishing a national dataset of sites of geological significance (known as County Geological Sites)

For the:
Geoheritage Programme
Geological Survey Ireland
Beggars Bush
Haddington Road
Dublin 4
D04 K7X4
01-6782837

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Not represented in Galway City

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Executive Summary

Galway City is situated at the junction between the lowland east and upland west County Galway, on a narrow stretch of land (5 km north-to-south) between the great expanse of Lough Corrib to the north and inner Galway Bay to the south. The River Corrib flows southward through the city, draining the northern limestone lake via the 'upper' river, before rapidly racing to the sea after descending over the Salmon Weir. The high banks of the tidal 'lower' river expose metamorphic rock. At the Claddagh, the river empties into inner Galway Bay, where the island and headland topography varies from bare exposed bedrock (Mutton Island) to thick deposits of glacial till (Ballyloughaun, Hare Island; Rusheen Bay). The Salthill coastline, fringed by a revetement constructed of granite boulders that protect against coastal erosion, is also underlain by Galway Granite bedrock.

Whilst bedrock surface exposure may be limited in this urban/suburban setting, Galway City exhibits a diverse geological foundation. The city hosts the three main rock types: igneous rock at the west, metamorphic rock in the centre and sedimentary rock at the east. In addition to this trinity of geological bedrock types, the bedrock surface is blanketed with glacial sediments (tills) that were deposited during the last ice age, around 18,000 years ago. Furthermore, the karst limestone underlying the east side of the city ensures that freshwater is transported seaward via subterranean conduits, as well as by the city's river and canals.

Awareness of Galway City's rich geodiversity is not common. This report aims to record and bring attention to the diverse range of geological heritage sites that occur within the city. The sites represent the accessible examples of the city's bedrock foundation (Blackrock, Fairland's Park), sites with historical connections (Shantalla Sliding Rock), karst landforms (Merlin Park Cave), and iconic landforms on the Galway City seascape (Rusheen Bay Drumlins).

This report documents what are currently understood by the Geoheritage Programme at Geological Survey Ireland to be the most important representative geoheritage sites in Galway City. The report proposes the sites as County Geological Sites, for inclusion in future City Development Plans (CDP). The audit provides a reliable summary record of County Geological Sites to replace a provisional listing dating from the 1990s which was based on desk studies, and subsequently adopted in the past and current CDPs.

County Geological Sites do not receive statutory protection like Natural Heritage Areas (NHA), but they do receive an effective protection from their inclusion in the planning system. Some of the sites described in this report are considered to be of national importance as a best representative example of a particular geological feature. These sites are provisionally notified to the National Parks and Wildlife Service (NPWS) by Geological Survey Ireland, as recommended for designation as a Natural Heritage Area (NHA). NHA designation would only occur following further surveying and consultation with landowners where relevant. Some County Geological Sites fall within existing pNHAs and SACs where the ecological interest is founded upon the underlying geodiversity.

The adoption of sites identified in this audit within future CDPs would ensure that Galway City follows an established and effective methodology for documenting geological heritage and

ensuring that geoheritage is not overlooked in the general absence of allocated resources for progress at national level.

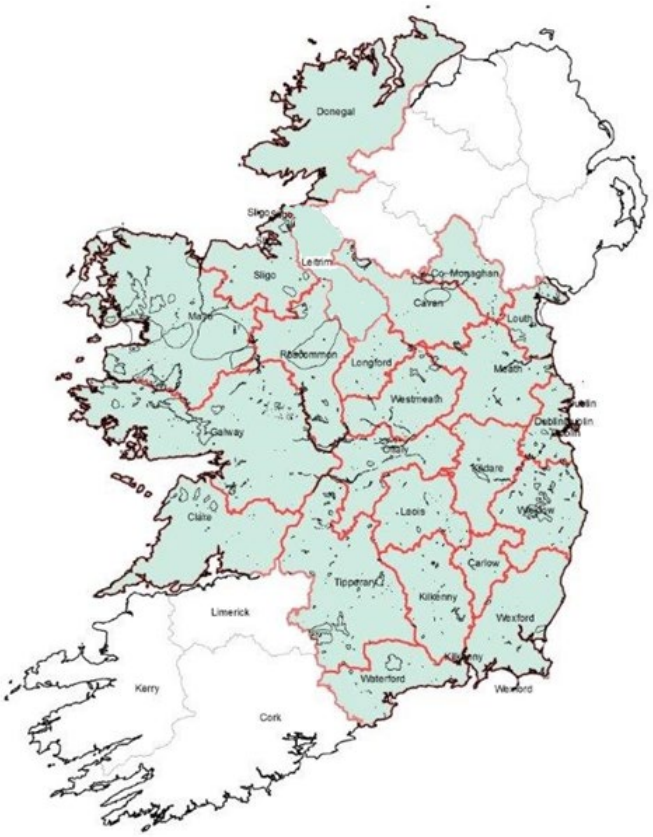
This report is compiled in non-technical language (with a glossary for unavoidable geological terminology) and will serve to inform the work of Geological Survey Ireland's Geoheritage Programme and is available on Geological Survey Ireland's website (www.gsi.ie). The report will also serve as a working document for use by the Heritage Officer and the Planning Department of Galway City Council. The report can be made publicly available via the Council website. A section of the report includes recommendations on how to best present and promote the geological heritage of Galway City to the people of the region.

The preliminary sections, summary geological history and accompanying map, and timescale column particularly may be used to preface a booklet or as website information in the development of this work, and for information, as seen fit by the Heritage Officer, and as funding permits. The main report and individual County Geological Sites reports content provide essential information for a general interest publication communicating the geological heritage of Galway City. Adequate recognition of the geological heritage of Galway City may add value to sustainable tourism and education initiatives into the future.

1. Galway City in the context of Irish Geological Heritage

This report brings Galway City to the forefront of geological heritage within Ireland, as a geological heritage audit has been completed for most of the country, including Galway County. 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), local authority-level geological heritage audits play a significant role in defining and safeguarding Ireland's geological heritage. County Geological Site audits (county and city) are the only effective means of geological conservation at present in Ireland, albeit with only an advisory role within the context of City and County Development Plans. County Geological Site audits in themselves confer no statutory protection on geological sites, although City and County Development Plans can provide such protection as required. Similar geological audits have been completed in urban and suburban regions including Dublin City, South Dublin, Dún Laoghaire-Rathdown and Fingal.

This audit report will also serve to support commitments 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, as a very important element of its strategy on geological heritage (see Appendix 1).



County Geological Audits completed up to end 2020 (shown in green).

The Geoheritage (Irish Geological Heritage; IGH) Programme in Geological Survey Ireland complements other nature conservation efforts of the last two decades, by assessing Ireland's geodiversity. Geodiversity is the foundation of the biodiversity addressed under European Directives on habitats and species by the designations of Special Areas of Conservation (SAC) and on a national scale by the introduction of Natural Heritage Areas (NHA) as the national nature conservation method. As a targeted conservation measure, to protect the very best of Irish geology and geomorphology, the Geoheritage Programme fills a void that has existed since the end of the *Areas of Scientific Interest* scheme, listed by An Foras Forbartha in 1981.

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

IGH THEMES

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

A fundamental approach for NHA selection is that only a minimum number of sites necessary to demonstrate a particular geological theme are 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, identifying any sites of international importance, is nearly always covered by the other two.

Designation of geological NHAs is the remit of Geological Survey Ireland's partner in the geoheritage/natural heritage programme, the National Parks and Wildlife Service (NPWS). Once designated, any geological NHAs will be subject to normal statutory process within the Galway City Council 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 which 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 a City or County Development Plan.

Currently, in 2020, a Master List of candidate CGS and NHA sites is used in Geological Survey Ireland, originally compiled with the help of Expert Panels for all 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. The inclusion of all sites as County Geological Sites (CGS) in Galway City's planning system will ensure that they are not inadvertently damaged or destroyed through lack of awareness of them outside of the Geoheritage Programme in Geological Survey Ireland.

The sites proposed here as County Geological Sites (CGS) in Galway City have been visited and assessed specifically for this project, and represent the current state of knowledge. It does not exclude other sites being identified later, or directly promoted by the Galway City Council or Geological Survey Ireland, 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 is emphasised that CGS listing is not a statutory designation, and carries no specific implications or responsibilities for landowners. CGS listing is primarily a planning tool, designed to record the scientific importance of specific features, and to provide awareness of them in any decision on any proposed development that might affect them. It thus also has an educational role for the wider public in raising awareness of this often undervalued component of our shared natural heritage.

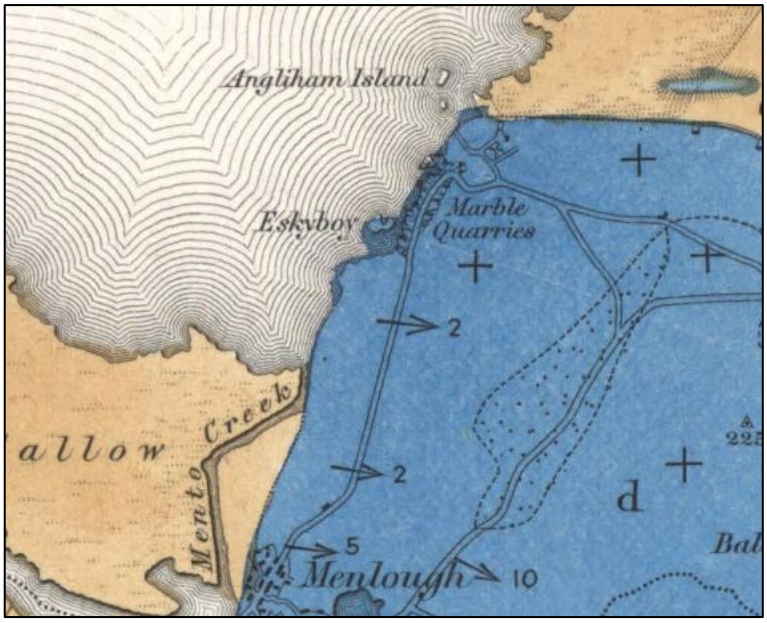
1.1 Galway City County Geological Sites

Site Name	Designation	IGH Primary	IGH Secondary	GIS Code
Doughiska N6 Road Cut	County Geological Site	IGH8		GC001
Fairlands Park	County Geological Site	IGH11		GC002
Menlough Mushroom Rocks	County Geological Site	IGH1		GC003
Menlough Quarry	County Geological Site	IGH8	IGH15	GC004
Merlin Park Cave	County Geological Site	IGH1		GC005
Merlin Park Quarry	County Geological Site	IGH15	IGH8	GC006
Rusheen Bay Drumlins	County Geological Site	IGH7		GC007
Salthill Promenade	County Geological Site	IGH11		GC008
Shantalla Sliding Rock	County Geological Site	IGH11		GC009
St. Augustines Well	County Geological Site	IGH16	IGH1	GC010
Terryland River	County Geological Site; recommended for Geological NHA	IGH1		GC011
Westside Sports Grounds	County Geological Site	IGH11		GC012

1.2 Rejected, Combined and Renamed Sites

The Geoheritage (IGH) Master Site list for Galway City was limited, with only five sites listed. All sites were assessed as suitable County Geological Site candidates in this audit. An additional selection of sites were assessed based on aspects of geological heritage that may have been initially overlooked by the Geoheritage (IGH) expert panel when compiling the Master Site List for Galway City. The geological or geomorphological characteristics at several sites were no longer visible, built over, inaccessible, or were not deemed suitable for CGS status. The rejected, or otherwise modified sites are listed below with brief notes as to why they were deemed unsuitable for inclusion.

Anglingham Quarry
Historically, Anglingham Quarry and Menlough Quarry occupied the same area that straddled the Anglingham townland and Menlough townland boundary. Early edition 25 inch to 1 mile scale Ordnance Survey Ireland maps indicate a 'Lime Kiln' at the Anglingham quarry, and Anglingham Quay on the lakeshore, where stone was taken by boat to Galway City via the River Corrib. Menlough Quarry remains in existence, and therefore the Anglingham Quarry record in the IGH Master List is referenced in the Menlough Quarry CGS report. William Wilde's *Loch Coirib – It's Shores and Islands* (published 1867) makes note of "black limestone, that will take a fine polish, and form good marble, occurs at Menlough and Anglingham, which quarries are at present worked." Today, the quarry area in Anglingham townland is a farm pasture site, with no noticeable trace of past quarrying activities, and is therefore rejected as a County Geological Site.



'Marble' quarries at Anglingham and Menlough townlands shown on Geological Survey Ireland 1st Edition Map Sheet 105, published in 1869.

Forthill Drumlin

The topography of the eastern side of 'old' Galway City, from the Docks to Moneenageisha, is dominated by a NE-SW trending hill of thick glacial deposits (drumlin). This NE-SW orientation is seen elsewhere in Roscam, Renmore/Ballyloughan, and in the Rusheen Bay drumlins. Lough Atalia occupies a NE-SW trough between these drumlin features. The till sediments at Forthill, which could be easily dug into, were such that the hill proved to be a suitable site for a cemetery, close to the city from late-Medieval times. However, much of the hill is built on or is inaccessible, and therefore is not considered a suitable County Geological Site.

Extract of Map of Galway City showing 'West Fort Hill' and St. Augustine's Wells (Hardiman 1820).

Lackagh Quarry (Coolagh Quarry)
A large limestone quarry situated at Coolagh on the northeast side of Galway City, ceased operation in 2010. The proposed route of the N6 Galway City Ring Road (GCRR) around Galway City is through the quarry site. The proposed route includes a tunnel at the quarry to enable the road to follow a route beneath a large area of limestone pavement (a protected habitat) situated between the quarry site and Menlough to the west. The site was not deemed a suitable County Geological Site at the time of this audit.

Gated entrance to Lackagh Quarry.

Barna Drumlins
This site has been renamed Rusheen Bay Drumlins. The IGH Master List named this site as the Barna Drumlin Swarm. However, the drumlins are neither located in the townland of Barna (situated NW of Rusheen Bay), nor is Bearna village located with the boundary of Galway City. The drumlins are situated in the townlands of Derryloney and Knocknacarragh. The westernmost drumlin is locally referred to as the Silver Strand drumlin, however this does not represent the entire group of landforms. Rusheen Bay Drumlins is considered a more accurate geographical attribution to the drumlin swarm.

Shantalla Quarry
Located at the T-junction of Old Seamus Quirke Road and Shantalla Road, little remains of this granite quarry, which was situated roughly between Shantalla Place and Maunsells Park. The quarry was initially operated by Galway Marble and Granite Works, and later by the Galway Granite Quarry and Marble Works (established 1900). A branch from the Galway - Clifden Midland Great Western Railway was constructed in 1911 leading from the present site of the Chapel of St. Columbanus in NUIG, west to the quarry along a route that later became Seamus Quirke Road. Stone was transported to Galway Station via the line, and subsequently to the stone works at Fisheries Field. The green space at New Avenue is the site of the railway line terminus. Granite from Shantalla Quarry was used locally in the Dominican Church, Claddagh. The granite was also used in the construction of Charles Stuart Parnell Monument in Dublin. Pink-coloured, fined grained stone was used for the top of the monument, whilst dark-grey, medium-grained

stone was used for the base. Shantalla Granite is also reported to have been used in the base of the Fontenoy Memorial, a 6 m high Celtic Cross erected around 1906, which stands in the *Esplanade d'Irlande,* in the village of Fontenoy, Belgium. Polished granite used in the old Post Office building on Exhibition Road, South Kensington, London has also been reported to be from Shantalla Granite. This site was visited as part of this audit. However, as no remnant of the quarry site is visible today, the site was not considered a suitable County Geological Site.

Location of Shantalla Quarry railway branch terminus at New Avenue.

Location of Shantalla Quarry railway branch terminus as viewed from Shantalla Road.

2. Galway City Council Policies regarding geology and geological heritage

Geological heritage is an integral part of Galway City's natural and cultural heritage and the Galway City Development Plan (CDP 2017-2023) includes policies to protect geological heritage from inappropriate development. Appendix 1 (Glossary and Acronyms) of CDP 2017-2023 provides a definition for 'Geodiversity'*:*

> *Geodiversity (and Geological Heritage) refers to the variety of rocks, minerals, natural processes, landforms, fossils and soils that underlie and determine the character of our landscape and environment. Geology is the science that comprises the study of the Earth, the rocks of which it is composed and the processes by which it evolves. It is, in effect, the story of our planet and every rock holds clues to understanding its evolution.*

Galway City CDP 2017-2023 Strategic Environmental Assessment provides a list of twelve Local Biodiversity Areas, seven of which are associated with County Geological Sites (in bold):

- ***Rusheen Bay – Barna Woods – Illaunafamona***
- *Cappagh – Ballymoneen*
- *Ballagh – Barnacranny Hill*
- *Mutton Island and nearby shoreline*
- ***Lough Atalia and Renmore Lagoon***
- ***River Corrib and adjoining wetlands***
- ***Menlough to Coolagh Hill***
- ***Ballindooley – Castlegar***
- *Ballybrit Racecourse*
- *Merlin Park Woods*
- ***Doughiska***
- ***Roscam***

CDP 2017-2023 also includes a list of six 'other areas of Local Importance in the City', four of which are directly associated with County Geological Sites (in bold):

- ***Terryland Forest Park***
- *City canal system*
- *Lake*
- ***Cave, Merlin Park***
- ***Terryland Glenanail***
- ***Cooper's Cave, Terryland***

However, references to the significance of geology and geological heritage tend to be limited to its association with ecology, habitats and biodiversity. The CDP 2017-2023 SEA notes that, '*there are sites of local geological and geomorphological interest within the city such as caves and sea cliffs, which are in themselves important nature habitats and landscape features'.* The report further states that '*geological heritage is part of Galway City's heritage… The Plan should include*

policy to protect geological heritage from inappropriate development. The distribution and diversity of habitats in the city reflects to a large extent the underlying geology (as well as climate and land-use history), this includes habitats protected under the Habitats Directive. The NIR (Natura Impact Report) of the Galway City Development Plan 2017-2023 highlights the potential for contamination of water resources as a result of the karst geology in the city area. The WRBD River Basin Management Plan (2009-2015) and future WRBD plan provide a mechanism for addressing potential water contamination and the Plan should support its implementation.' The importance of geology and geoheritage in terms of industrial heritage, landscape morphology, settlement patterns, and landscape character is overlooked, as too is the importance of the geological heritage itself.

Of the Key Environmental Issues considered in the CDP 2017-2023 Strategic Environmental Assessment report, the following are included:

Key Environmental Indicator: Soil (CDP 2017-2023 SEA P.6)

> *Geological heritage is part of Galway City's heritage and the Plan includes policy to protect geological heritage from inappropriate development. The distribution and diversity of habitats in the city reflects to a large extent the underlying geology (as well as climate and land-use history), this includes habitats protected under the Habitats Directive. The NIR of the Galway City Development Plan 2017-2023 highlights the potential for contamination of water resources as a result of the karst geology in the city area. The WRBD River Basin Management Plan and future WRBD plan provide a mechanism for addressing potential water contamination and the Plan supports its implementation.*
>
> *The DEHLG Quarry Guidelines (2004) identifies potential environmental effects of quarrying, including impacts on air quality, water supplies, groundwater, noise and vibration, traffic, heritage and landscape and on waste management.*
>
> *Soil erosion can be caused by construction activities. Erosion results in a loss of nutrients in the upper layers of the soils and also leads to reduced water-holding capacity. Erosion can also impact on surface water quality. Climate change is likely to increase soil erosion, as a result of higher rainfall intensity and possible loss of organic matter, which will result in reduced structural stability and the Plan includes policy on climate change.*

Key Environmental Indicator: Water (CDP 2017-2023 SEA P.7)

> *Key challenges for Galway City include balancing growth with preventing the deterioration of water quality and delivering physical infrastructure to meet population projection targets... The continued development and enhancement of wastewater and drainage infrastructure within the city is essential to its future growth and in order to maintain and enhance water quality. Water quality is also a key environmental condition supporting the integrity of European sites and areas identified on the WFD Registers of Protected Areas. The Plan promotes the*

protection of surface water, groundwater and coastal/estuarine resources and their associated habitats and species including fisheries.

The Terryland River is used as one of the city's water resources and feeds from Lough Corrib and the Corrib basin, the bulk of which lies outside the city's boundary. While the issue of water quality in the Bay and the Western River Basin District (WRBD) concerns Galway City, Local Authority areas in the district upstream also contribute to impacts on water quality in the River Corrib and Galway Bay.

CDP 2017-2023 Strategic Environmental Report sets out Strategic Environmental Objectives (SEO). These were identified based on a current understanding of the key environmental issues and informed policy formulation, and include:

SEO Soil including Geology:

- *Maintain the quality of soils*
- *Minimise the consumption of non-renewable sand, gravel and rock deposits*
- *Protect and conserve important County geological heritage sites*

CDP 2017-2023 SEA Report includes statements of direct or loose relevance to geoheritage:

Section 4.4.1 Soils including Geology (CDP 2017-2023 SEA) states:

'(t)he Natura Impact Report highlights the potential for contamination of water resources as a result of the limestone/karst geology. In some parts of the city there are substantial glacial deposits, mainly boulder clay. This is most evident along the coast between Silverstrand and Blackrock and around Renmore. The soils which overlie the rocks and glacial deposits are predominantly in the category of shallow brown earths and rendzinas, associated with grey-brown podzolics, gleys and peat'.

Section 4.4.2 County Geological Sites (CDP 2017-2023 SEA) states:

Local Biodiversity Areas identified in Section 4.2 Biodiversity, Flora and Fauna include a number of sites of geological heritage importance. These include mushroom stones at Menlough, the Barna Drumlin Swarm, the site of Merlin Park Quarry, Angliham and Menlough Quarries…. These are categorised as County Geological Sites and are currently being considered by the GSI and NPWS for designation as Natural Heritage Areas (NHAs).

Section 4.4.3 Quarrying (CDP 2017-2023 SEA) states:

Quarrying results in the depletion of soils or the materials being quarried. Within the city, two quarries were qualified to submit to An Bord Pleanála for 'substitute consent' in accordance with Section 261(a) of the Planning and Development Act

2010 relating to the control of quarries. The EU (Environmental Impact Assessment and Habitats) Regulations 2015 introduced changes to legislation relating to applications for substitute consent and for prospective development applications to An Bord Pleanála. These regulations aim to facilitate An Bord Pleanála in considering both past development and proposed future development of quarries in a holistic manner.

Section 4.4.3 Soil Contamination (CDP 2017-2023 SEA) states:

Soil can be contaminated by a wide range of pollutants, as a result of leakages and accidental spillages or by activities that use the soil for support or space, such as landfills and historic landfills. There is one registered closed historic landfill within the City Council functional area, located at South Park. A revised risk assessment carried out for this site in 2014 concluded that based on its current use, South Park does not pose an environmental risk. An application has been made to the EPA for a Certificate of Authorisation for this site in accordance with the Waste Management (Certification of Historic Unlicensed Waste Disposal and Recovery Activity) Regulations 2008. Given the range of land use activities which have taken place historically, contamination may be uncovered during development works at brownfield sites such as at Ceannt Station or the Inner Harbour area. Such contamination would have the potential to affect water quality, biodiversity, flora and fauna and human health. The Development Plans waste management policy contains policy to ensure that proposals on contaminated lands include appropriate remediation measures and that construction and demolition waste is subject to appropriate environmental considerations.

Section 4.5.3 Groundwater (CDP 2017-2023 SEA) states:

Groundwater is an important natural resource, a source of drinking water and makes an important contribution to lake levels and river flows. The city is divided into two aquifer classifications. To the east of the River Corrib is a regionally important aquifer, which is hosted by the Lower Carboniferous Burren Karst limestone, the most important aquifer in County Galway. To the west of the river is what is classified by the GSI as poor aquifer bedrock, which is moderately productive only in local zones. The Geological Survey of Ireland (GSI) classifies much of the plan areas as having high to extreme groundwater vulnerability. The NIR of the Galway City Development Plan 2017-2023 identified European sites potentially at risk from contamination of groundwater though underground pathways within the karst landscape to the east of Galway City. It is an objective of the WRBD Management Plan 2009-2015 to protect groundwater quality of this area and all practicable steps should be taken to prevent any further deterioration of the status of the waters.

Section 4.5.5 Flooding (CDP 2017-2023 SEA) states:

Flooding is a natural process that can happen at any time in a wide variety of locations. Galway City, due to its landscape setting, is vulnerable to three key

sources of flooding, fluvial, groundwater and coastal. Flooding is closely linked to the structure and function of Annex I habitats and the habitats of Annex II species in SACs, and of Annex I and other regularly occurring migratory bird species in the case of SPAs. The frequency, pattern and severity of flooding is expected to increase as a result of climate change. The DEHLG's Planning System and Flood Risk Management Guidelines for Planning Authorities (2009) acknowledges that flooding can impact on water quality by reason of pollutants carried by floodwater. Further details on flood risk are set out in Section 4.6, Air and Climatic Factors and the SFRA of the Galway City Development Plan 2017-2023.

The completion of this geological heritage audit will ensure that the listing of Galway City's County Geological Sites is provided for inclusion in the future City Development Plans (CDP) with a robust selection of sites that are genuinely important in Galway City. Whilst some are candidates for NHA designation in the future if the geological NHAs are realised, many new sites that are of local importance have been added to original Geoheritage Master List of five IGH sites.

Groundwater

CDP 2017-2023 puts groundwater and source protection firmly in frame with relation to the Water Framework Directive 2000, with one objective of particular geological relevance:

> Policy 9.6 Water Quality
> *Protect the city's groundwater resource in accordance with the Groundwater Directive 2006/118/EC and the European Communities Environmental Objectives (Groundwater) Regulations, 2010 (S.I. No. 9 of 2010) or any updated legislation and ensure that any development, which threatens the quality of the city's groundwater is restricted Minimise and control discharges to inland surface water bodies, groundwater and coastal waters to prevent water pollution.*

Mineral Extraction

CDP 2017-2023 includes policies relating to mineral extraction and quarries in Chapter 6, and makes reference to the GSI/ICF Guidelines (Gatley and Parkes 2008) in *DM Standard 37: Extractive Development* - regarding guidelines for use:

> a) Guidelines
> Compliance with the provisions and guidance, as appropriate, contained within Section 261 of the *Planning and Development Act, 2000* (as amended), by Section 74 and Section 75 of the *Planning and Development (Amendment) Act 2010*, the DoEHLG *Quarries and Ancillary Facilities Guidelines* 2004 and the *EPA Guidelines for Environmental Management in the Extractive Sector* 2006. Where extractive developments may impact on archaeological or architectural heritage, regard shall be had to the D*AHG Architectural Conservation Guidelines 2011 and the Archaeological Code of Practice 2002* (including any updated/superseding documents) in the assessment of planning applications. Reference should also be made to the *Geological Heritage Guidelines for the Extractive Industry 2008* (including any updated/superseding documents).

It is herein suggested that the inclusion of 'County Geological Sites' in Objective EQ1 – Protection of Natural Assets of the CDP would be valuable in the protection of geoheritage. The objective could be amended to read (additional text in bold):

> Objective EQ1 Protection of Natural Assets
> *Protect areas of geo-morphological interest, groundwater and important aquifers, important archaeological features, Natural Heritage Areas and European Sites,* ***and County Geological Sites*** *from inappropriate development.*

Natural Heritage

CDP 2017-2023 has extensive objectives relating to natural heritage and biodiversity, under which geological heritage is included:

> Policy 4.2 Protected Spaces: Sites of European, National and Local Ecological Importance
> - *Protect from inappropriate development the County Geological Sites in the city.*
> - *Commission an audit of County Geological Sites in partnership with GSI.*
> - *Protect, conserve and promote the nationally designated sites of ecological importance, including existing and proposed Natural Heritage Areas (NHAs and pNHAs) in the city.*

CDP 2017-2023 also registers geological heritage in Development Standards in Chapter 13:

> l) Heritage and Biodiversity
> *Proposals in relation to heritage and biodiversity would include any recommendations for the site to be considered as part of the geological heritage of the County and any proposed measures with regard to the protection and promotion of the environment and biodiversity, including any proposals for rehabilitation. The Council will require an Ecological Impact Assessment for all proposals within or in the vicinity of an SPA, SAC or NHA. Where a quarry development falls within a conservation designation, the developer is advised to consult with the DECLG prior to making an application. Evidence of such consultation should be submitted to the Planning Authority at application stage. It shall also be a requirement that all new proposals that are likely to have an impact on SAC or SPA shall be screened for the need to undertake a Habitats Directive. The Council will require that the operator of the quarry shall put in place an Environmental Monitoring System, to monitor all environmental standards (noise, dust, blasting etc.) on an on-going basis.*

With this geological audit report, future CDPs should be able to include additional specific objectives relating to geological heritage and County Geological Sites, and to include a listing of the sites in any appendices or maps accompanying CDP documents.

The Galway City Biodiveristy Plan 2014-2024 states:

> '*The distribution and diversity of habitats in the city reflects to a large extent the underlying geology and soils, as well as climate and land-use history. In the west*

of the city there is acid peat-land and heath, which overlies granite rocks. The northern and eastern parts of the city are underlain by limestone which outcrops in places. The water bodies and wetlands associated with the Corrib system dominate the centre and northern fringe of the city. Several areas of woodland occur in the city, as well as patches of scrub and there are extensive networks of hedgerows and stone walls within the city's agricultural zone. The coastal zone of Galway City consists of a diverse range of habitats including sea cliffs, salt marsh, shingle banks, and sandy, muddy and rocky shores'.

N6 Galway City Transport Project and N6 Galway City Ring Road

In its submission to An Bord Pleanála (*Statement of Evidence: Responses to Soils and Geology Objections/Submissions 19th February 2020*), Geological Survey Ireland made the following submission, which demonstrates the priority of geoheritage in transport infrastructure development.

> 4.6.2 S_030.1 "*Recommendations: Should the development go ahead, all other factors considered, Geological Survey Ireland would much appreciate a copy of reports detailing any site investigations carried out. Should any significant bedrock cuttings be created, we would ask that they will be designed to remain visible as rock exposure rather than covered with soil and vegetated, in accordance with safety guidelines and engineering constraints. In areas where natural exposures are few, or deeply weathered, this measure would permit on-going improvement of geological knowledge of the subsurface and could be included as additional sites of the geoheritage (programme), if appropriate. Alternatively, we ask that a digital photographic record of significant new excavations could be provided. Potential visits from Geological Survey Ireland to personally document exposures could also be arranged."*

The N6 Galway City Ring Road Environmental Impact Assessment Report (Volume 1, September 2018) Section 9.9 (Soils and Geology) reports on the *'evaluation of potential likely significant impacts on the soils and geology environment'* resulting from the proposed N6 Galway city Ring Road development. Section 9.10 reports on hydrogeological studies and investigations conducted to determine a comprehensive assessment of the hydrogeological impacts of the proposed route.

NRA guidelines provide useful criteria for ranking importance of identified soils and geological constraints, which include (extract):

Importance	Criteria	Typical Example
Very High	Attribute has high quality, significance, or value on a regional or national scale.	Geological feature rare on a regional or national scale (NHA) Large existing quarry or pit proven economically extractable mineral resource.
High	Attribute has high quality, significance, or value on a local scale.	Geological feature of high value on local scale (County Geological Site).

3. Geological conservation issues and site management

Geodiversity is often overlooked as the foundation for much of the biodiversity that has been identified for conservation through SAC or NHA designation. It is therefore unsurprising that many of the most important geological sites are actually in the same areas as SAC and pNHA sites. In such formally designated areas for nature conservation, geological heritage more often than not enhances and cements the value of the sites. Therefore, a recognition and acknowledgment of geological heritage value 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. Examples include disused quarries, natural bedrock or quaternary exposures on hilly ground, coastal cliff sections, or other natural cuttings into the subsurface, such as stream sections. These discrete sites typically host a feature or features of specific interest such as fossils, minerals, springs, or they are a representative (type) section of a particular stratigraphical sequence of rocks. **The second type of site is a larger area of geomorphological interest, i.e. a landscape that incorporates features that illustrates the processes that formed it**. The Quaternary theme (IGH 7) and the Karst theme (IGH 1) often include such large sites. In Galway City, the Rusheen Bay Drumlins site is a large area of interest owing to the Quaternary and Holocene features that overlie a major fault (Barna Fault) separating the central and eastern blocks of the Galway Granite Batholith.

It is also important from a geological conservation perspective that planners are cognisant of the landscape importance of geomorphological features which may not in themselves warrant any formal site designation, but which form an integral part of the character of Galway City. For example, the Rusheen Bay Drumlin swarm, and Blake's (Gentian) Hill in particular, are familiar landmarks on the western Galway Bay backdrop when viewed from Salthill. Additionally, few cities can claim to have a foundation composed of the three rock types: sedimentary, metamorphic and igneous rock. Awareness of the city's geological heritage can enable planners to maintain the unique character of the city, and consider this heritage when planning for coastal protection works, new road infrastructure and public amenity and green space planning. The Strategic Environmental Assessment within the City Development Plan can support the conservation and promotion of geological heritage. In addition, the now routine pattern of consultations with Geological Survey Ireland, either by the City Council's planning department or by consultants conducting Environmental Impact Assessment (EIA) and Strategic Environmental Assessment (SEA), can greatly improve the representation of the geodiversity and geoheritage in planning and development.

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 development is proposed for a site deemed of geological interest. In this way, geologists may be afforded the opportunity to learn more about a site or area by recording and sample collection of temporary exposures, or to influence the design outcome so that access to

exposures of rock is maintained for the future, or occasionally to prevent a completely inappropriate development through the presentation of a strong scientific case.

In many counties, working quarries are included as County Geological Sites because the quarries host the best representative sections available of specific rock sequences in areas where exposure may otherwise be poor. No restriction is sought on the legitimate operation of these quarries. However, maintenance of exposure after quarry closure is sometimes sought in agreement with the operator and planning authority in such a case. The disused quarry at Menlough (Menlough Quarry) is included as County Geological Site for Galway City. Issues relating to quarries are explored in a set of Geological Heritage Guidelines for the Extractive Industry, published jointly by Geological Survey Ireland and the Irish Concrete Federation in 2008 (Gatley and Parkes, 2008).

A new quarry may open up a window into the rocks below and reveal significant or particularly interesting features such as pockets of fossils or minerals, or perhaps a karstic depression or cave. Equally, a quarry that has finished working may become more relevant as a geological heritage site at that stage in its life. Operations at the limestone quarry at Coolagh (Lackagh Quarry) ceased in 2010. However, the condition of quarry into the future remains uncertain, and therefore the site was not included as a County Geological Site at the time of this audit.

It may need occasional maintenance to prevent overgrowth of vegetation obscuring the scientific interest, or may be promoted to the public by means of a viewing platform and information panel. When considered on a nationwide scale, some sites may require restrictions and a typical case might be at an important fossil or rare mineral locality, where a permit system may be required for genuine research, but the opportunity for general collecting may need to be controlled.

Waste dumping

Illegal waste dumping is a problem throughout the country. Not only is waste unsightly and messy, waste material dumped in areas where rock is exposed (e.g. quarries or disused gravel pits) may leach into groundwater as the waste degrades. 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.

New exposures in development

Local authorities 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 Council 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). A successful example of this in Galway City is at the N6 Doughiska Road Cut. Traditionally, the grading and grassing over of slopes in cuttings is largely a civil engineering convenience. 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 can improve the character and interest of the route, by showcasing the geology and landscape of the locality. Tree or shrub planting, when done in unison with rock exposure, especially where they show interesting features, not only assists the geological profession, but

also creates new local landmarks. This can also potentially save money on the construction costs. It may also contribute to road safety by providing diversity of surroundings to maintain drivers' attention. Works on roads around Galway City occasionally require bedrock excavation and cuttings, included here as a County Geological Site. The proposed N6 Galway City Ring Road route would see the excavation of road cuttings, road tunnels, and the construction of a bridges and viaduct. The preservation of rock exposures along the roadside would be a welcome feature in showcasing the geological foundation.

Geoparks

An extremely interesting development in geological heritage, not just in Ireland but internationally, has been the rapid recent growth and adoption of the UNESCO 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 is fully assisted by the United Nations Educational, Scientific and Cultural Organisation (UNESCO). See www.globalgeopark.org and www.europeangeoparks.org. A fundamental basis of the Geopark concept 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. UNESCO Geopark branding therefore helps promote the geological heritage resource so that the community can benefit from it. However, significant management support from local authorities has proven to be essential across the network.

There are three UNESCO Global Geoparks on the island of Ireland: the cross-border Marble Arch Caves UNESCO Global Geopark (www.marblearchcavesgeopark.com); the Copper Coast UNESCO Global Geopark (www.coppercoastgeopark.com) and the Burren and Cliffs of Moher UNESCO Global Geopark (www.burrengeopark.ie). The Joyce Country and Western Lakes Aspirant Geopark Project in north County Galway and south County Mayo is progressing and will hopefully be successful in its bid for UNESCO Geopark status in late 2021 (www.joycecountrygeoparkproject.ie).

3.1 James Mitchell Geology Museum, NUI Galway

The James Mitchell Geology Museum is located in NUI Galway's ashlar limestone Gothic Revival Quadrangle Building. The museum is curated by Earth and Ocean Sciences staff at the School of Natural Sciences. Established in 1852, three years after the opening of Queen's College Galway, the museum has remained in the same room for over 165 years. In 1977, the museum was named the James Mitchell Museum in honour of Professor James Mitchell, Chair of Geology and Mineralogy at University College Galway from 1921 to 1966. A three-year FÁS programme in the 1990s saw the curation, conservation and logging of collections as well as refurbishment of the museum itself to restore a 19th century theme. More recent conservation works were carried out in 2013 when the Museum was officially relaunched and opened to the public and for outreach activities at various levels. The rock, mineral and fossil collections serve as excellent teaching and research resource for students of all ages, primary to third level, as well as the wider community and visitors alike.

NUI Galway Quadrangle.

Gemstone and mineral collection.

The museum fossil collection ranges in age from Cambrian to recent times. Rock and mineral specimens from all over the world, spanning from Palaeoproterozoic times to the present-day, are included among the collections. The museum's collection consists of over 1700 mineral specimens and over 1500 rock specimens. The collection also includes over 5000 fossil specimens sourced from around the globe, many of which are on display, or stored in drawers below the varnished oak display cabinets. Additionally, in 2013 a very significant gemstone collection donated by Mr. Adrian Ryder, an avid gemstone collector and a graduate of the NUIG's Diploma in Gemmology, was added to the Museum. The collection includes over 400 rough and faceted gemstones. Remarkable pieces in the collection include a square ruby of 1590 ct (318 grams), a baguette emerald of 4300 ct (860 grams) and 21 diamonds both rough and cut for a total of over 26 ct. Wall-mounted frames hold large specimens of Jurassic marine reptiles (Ichthyosaurus and Plesiosaurus), as well as replicas of Cretaceous dinosaurs, and the skulls of Megalosaurus and Iguanodon, and a complete Hypsilophodon replica.

Mineral collection in original 19th century display cabinets.

4. Summary and Recommendations

4.1 Proposals and ideas for promotion of geological heritage in Galway City

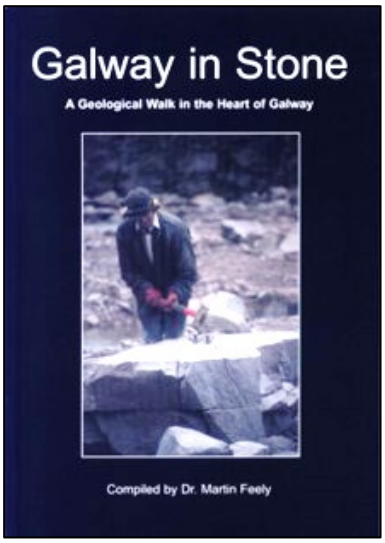
This section briefly examines the existing objectives in the Galway City Biodiversity Plan (2014-2024) relating to geological heritage and provides specific suggestions as to how these may be implemented, supported or enhanced by the audit of geological heritage sites in the county. There are many aspirational objectives in the plan that could very loosely be related in some way to this audit, but only two are specific about geology:

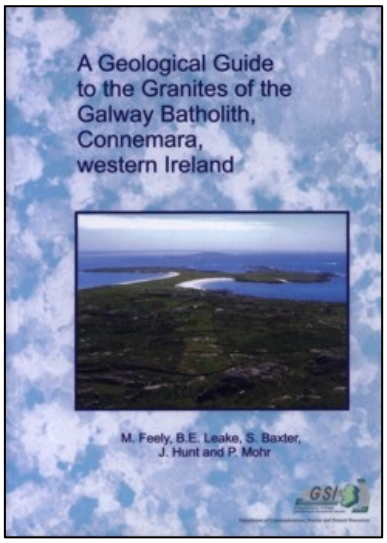
> ***2. Education and Training***
> *NH 2.4 Assist the business and industry sector with biodiversity and natural heritage education and training e.g. in the areas of ecotourism,* ***geotourism****, sustainable resource management, natural capital.*
>
> ***3. Research and Information***
> *NH 3.4 Promote and develop biodiversity and natural heritage mapping* ***e.g. geological heritage sites*** *and freshwater and marine heritage sites.*

Whilst the latter objective is fulfilled by this geological heritage audit, which includes field mapping to define the site and GIS definition of site boundaries, the audit can only assist in the first objective by providing information. For many of the publicly accessible sites, this audit may help to communicate the geological interest in an amenity site which is undervalued, unexploited or simply not well understood.

4.2 Ideas for projects

Books
Several publications provide information on the geology of Galway City. These include the excellent *Galway in Stone - A Geological Walk in the Heart of Galway* (Feely et al., 2002, plus a revised version] and *A Geological Guide to the Granites of the Galway Batholith, Connemara, Western Ireland* (Feely et al., 2006).





The 1:100,000 Geological Survey Ireland map report for Sheet 14 Geology of Connemara covers Galway City and is an essential resource.

It is suggested that much of the content in this audit report and accompanying site reports could be edited to produce a geological heritage of Galway City, similar to publications produced for Counties Mayo, Clare, Roscommon, Longford, Sligo, Fingal, and Waterford following geological audits in those counties.

Signboards

Simple explanatory or interpretive signboards may be considered at key geological heritage locations but their location and individual siting should be selective. Galway City Council should have a controlling input, in conjunction with the Geoheritage Programme at Geological Survey Ireland. It is suggested that a single panel communicating various heritage interests at a location is preferable to multiple topic-specific panels.

The collation of appropriate text and graphics on information panels requires both geoscientific and graphic design skills. The Geological Survey Ireland Geoheritage Programme can provide advice on appropriate content if signboards are considered.

Information panels at Whitestrand, Salthill Promenade.

'Beaches' Information panel at Whitestrand, Salthill Promenade.

The extensive promotion of the Wild Atlantic Way (WAW) by Fáilte Ireland has resulted in the erection of information panels at WAW Discovery Points along the route. The role of geology and geomorphology in the origin of the coastal landscape features along this route should be included at these scenic locations.

Museum exhibitions

The James Mitchell Museum at the National University of Ireland Galway currently hosts a selection of fossils, minerals and rock samples from Ireland and the world. The museum is included as a County Geological Site. With some extra research covering human dependence on geology and resources, an interesting exhibition could be put together for display in the Galway City Council Offices, City Library branches or other public spaces based on the resources compiled in the audit. Similar exhibitions have been showcased following the completion of audits in counties Carlow, Dun Laoghaire-Rathdown, Waterford, Wicklow, and Longford.

James Mitchell Geology Museum, NUI Galway.

DVD projects
Two digital media resource development projects funded by Galway County Heritage Forum, Galway County Council and The Heritage Council saw the production of DVDs between 2004 and 2008. These DVDs focused on 3D animations and interactive of aspects of Connemara geological landscape, and in particular the Twelve Bens and the Dog's Bay area. More of such resources could be added.

Leaflets
Publicly available leaflets on the geology or geological heritage of Galway City would serve as a useful resource to visitors, schools and the local community. Leaflets with guided trails and 'points-of-interest' could be made available as PDF downloads on the City Council website or via local community heritage, tourism and education programmes.

New media
There are increasing numbers of examples of new methods of promoting Earth Sciences, via mobile phone applications and other electronic media. Self-guiding apps on specific sites would be one of these, such as those produced by Ingenious Ireland for Dublin city geology, and the app for tourists in the Burren and Cliffs of Moher UNESCO Geopark.

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 summary of the geology of County Galway (including Galway City) is available for download (see Appendix 8).

Maps
The inclusion of County Geological Sites and geological heritage information in the future Ordnance Survey Ireland paper map editions of the 1:50,000 Discovery Series would be a welcome venture. The EastWest Mapping maps of County Wicklow and County Mayo currently include Geological Survey Ireland data.

5. A summary of the geology of Galway City

5.1 Concise simple summary of the geology of Galway City

In terms of the geological bedrock upon which it has developed, Galway City is Ireland's most geodiverse city, being underlain by varieties of the three rock types (sedimentary, igneous, metamorphic). In addition, the land surface is variable and includes glacial deposits in the form of drumlins, an exposed karst limestone landscape (Mionlach, Coolagh), a major river and tidal estuary (River Corrib), an extensive coastline of sand and cobble beaches (Salthill, Ballyloughan), lagoons (Lough Atalia, Rusheen Bay), and cliffs in soft sediment (Silver Strand, Derryloney, Hare Island, Ballyloughan). Whilst built ground covers extensive areas of the city, stone walls often reflect the underlying bedrock, with a prevalence of granite walls in the newly developed western suburbs and limestone in the eastern suburbs.

5.2 More detailed summary of the geology of Galway City

The physical landscape of Galway City is controlled by the bedrock geology. The eastern part of Galway City, east of the River Corrib, is almost entirely underlain by Carboniferous Limestone, with the exception of a wedge of metamorphic bedrock extending from the 'old' city centre east to Renmore Army Barracks. In contrast, the western part of the city, west of the River Corrib, is almost entirely underlain by igneous and metamorphic bedrock, with the exception of an area of limestone along the low-lying west bank of River Corrib from the NUIG Dangan Sports Fields to Bushypark.

The eastern limestone bedrock comprises Lower Carboniferous (Mississippian) Visean limestone, which formed around 330 million years ago. The coarse- to medium-grained limestone is pale grey, bedded, bioclastic and fossiliferous. The limestone is karstified and displays a variety of karst features including limestone pavement, springs, swallow holes, turloughs, epikarst, estavelles, conduits, karst enclosed depressions and mushroom rocks. Over 200 karst and limestone pavement features are listed in the N6 Galway City Transport Project Route Selection Report (Table 4.4.4 therein). Groundwater is also important in this limestone area, having an influence on the flow direction of the Terryland River, and local turlough levels.

To the west of the River Corrib, the topography rises from the low metamorphic and limestone terrain to the hummocky upland granite terrain that extends from Ballagh south to Rahoon and Rusheen Bay. This granite landscape is part of the Galway Granite Batholith. The batholith is a c. 600 km^2 area of granite that extends westwards from Galway City to Slyne Head, and is made up of multiple granite bodies that were intruded over a period of some 40 million years in the late Silurian and Devonian periods, between c. 423 and c. 380 million years ago. The granite batholith comprises a western, central and eastern block. The granites of Galway City are almost entirely of the eastern block, comprising the Murvey Granite and Errisbeg Townland Granite. The Murvey Graniteis a fine grained, aphyric, felsic granite. In contrast, the coarse grained Errisbeg Townland Granite is pink, phenocrystic K-feldspar granite. A major fault, the Barna Fault, delineates the boundary between the central and eastern blocks of the batholith. This north northwest – south southeast oriented fault zone is a clearly identifiable feature of the landscape around Barna Woods. Bearna Stream flows along the fault line, and there is a noticeable 'dip' in the R336 Barna

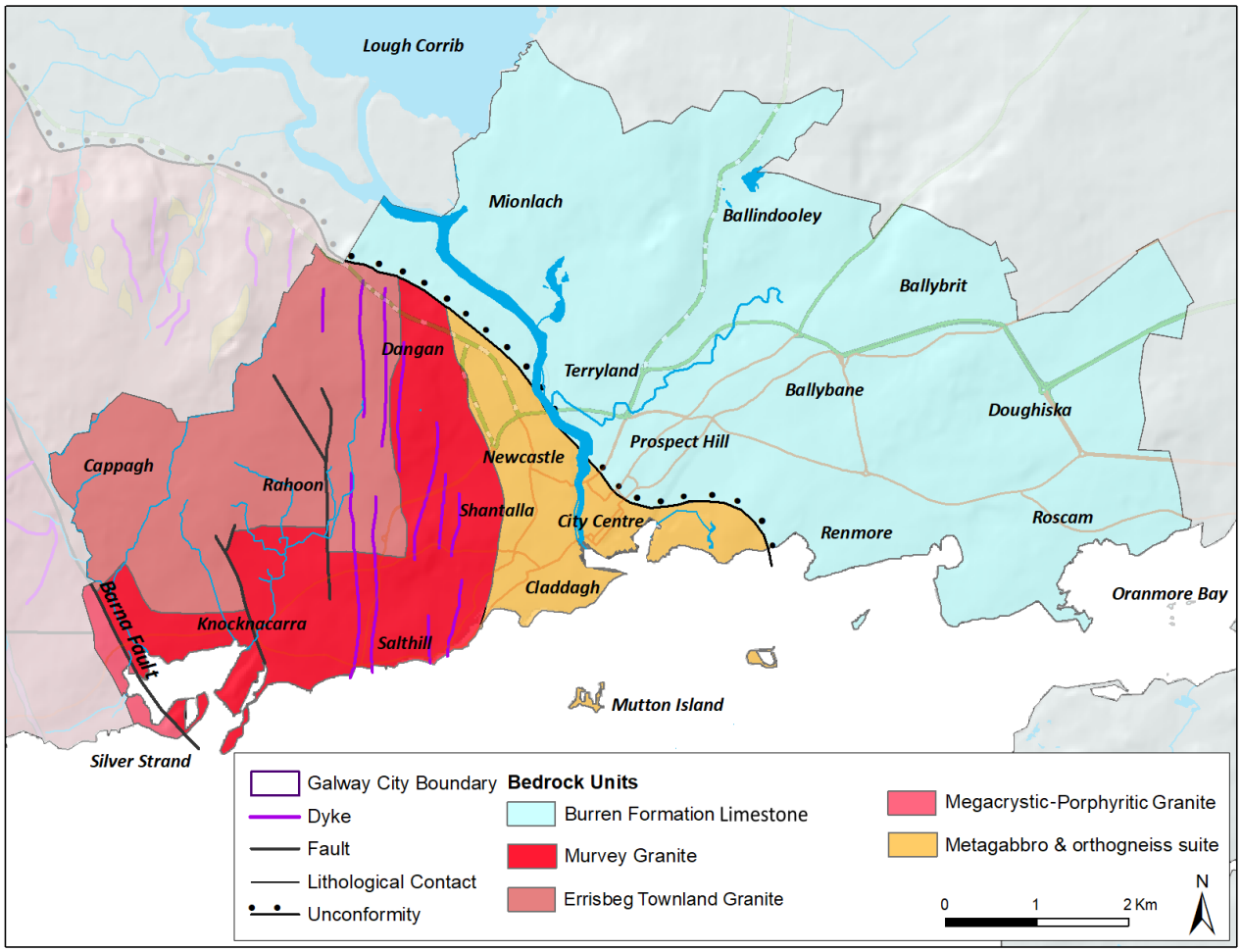
road at Barna Woods. Central block Megacrystic-Porphyritic granite occurs on the west side of the fault. Granite is best seen along the coast in Galway City, from Silver Strand to Seapoint in Salthill.

A northward-tapering wedge of metamorphic rock underlies the central portion of Galway City. The intrusive contact with the granites is approximately along a line extending from Dangan south to Grattan Beach. The eastern contact (unconformity) with the Carboniferous Limestone runs south from Dangan, via Woodquay and Lough Atalia, to Ballyloughan. These metamorphic rocks are the oldest rocks in Galway City. They formed originally as igneous rocks (granite and gabbro) around 470 million years ago and were subsequently metamorphosed deep in the earth's crust, under conditions of high pressure and temperature, into amphibolite and granite gneiss, to form part of the Connemara Metagabbro and Orthogneiss Suite. This group of metamorphic rocks is found across central Connemara. Surface exposure of these dark grey rocks in Galway City is limited but they are exposed downstream of the Salmon Weir in the high banks of the River Corrib. Accessible outcrops occur at Fairlands Park and Shantalla Sliding Rock, both included as County Geological sites. The bedrock cropping out around the edge of Mutton Island also comprises these metamorphic rocks.

During the last 2.6 million years, glaciation had a major effect on the Irish landscape. Glacial erosion shaped the mountains and surrounding terrain, and glacial deposits such as drumlins and eskers blanketed the lower ground. The landscape topography in the city reflects the influence of glacial activity in the region during the last glaciations. Drumlins throughout the area of the city were deposited at the base of the ice sheet that moved northeast to southwest during the maximum period of the last Ice Age, around 18,000 years ago. Drumlin sediment is predominantly sourced from limestone areas to the northeast, but boulders of Galway Granite, metamorphic rock and clastic sedimentary rock occur within the till deposits. Geological Survey Ireland's Quaternary map data notes over a dozen drumlins in Galway City, all near the coast, at Roscam, Renmore, Lough Atalia, City Centre, Claddagh, St. Mary's College, Knocknacarragh and Rusheen Bay. These are part of more extensive field of drumlins, some of which occur further west between Moycullen and An Spidéal. More recent Quaternary deposits, accumulated since glaciation, alluvium and fen peat occur along the River Corrib and the Terryland River. Along the coastline, the relentless energy of the sea and the varied resistance of different rocks and sedimentary cover has been a major influence on city's coastal geomorphology.

AGE (Million Years Ago)	*ERA*	*PERIOD*	*EVENTS IN GALWAY CITY (non-italics)*	*IF THIS TIMESCALE WAS A DAY LONG...*
2.58	Cenozoic	Quaternary	Several ice ages smothering Galway City, followed in the last 10,000 years by the spread of vegetation, growth of bogs and fens and arrival of humans. Sea-level rise drowned peats along coast. Deposition of (till) boulder clay in drumlins. Dissolution of limestone beneath Quaternary sediments creating karst features.	Ice ages would begin 38 seconds before midnight
23		Neogene	Erosion, especially limestone. Caves, swallow holes, cavities, underground streams develop in limestones on east side of Galway City.	Neogene period begins at 11.52 pm
66		Palaeogene		Palaeogene period begins at 11.40 pm
145	Mesozoic	*Cretaceous*	*Erosion. No record of rocks of this age in Galway City.*	11.15 pm
201		*Jurassic*	*Uplift and erosion. No record of rocks of this age in Galway City.*	Age of the dinosaurs, starting at 10.55 pm
252		*Triassic*	*Desert conditions on land. No record of rocks of this age in Galway City.*	10.42 pm
299	Palaeozoic	*Permian*	*No record of rocks of this age in Galway City.*	10.30 pm
359		Carboniferous	Land submerged. Limestones deposited in tropical seas around much of Galway City.	Inundation of land by sea around 10.10 pm
419		Devonian	Caledonian mountain building. Galway Granite intruded.	Granite intruded at 9.52 pm
443		*Silurian*	*Shallow seas following closure of Iapetus Ocean. No record of rocks of this age in Galway City.*	Starts at 9.42 pm
485		Ordovician	Iapetus Ocean divides Ireland into two. Igneous rocks intruded and later metamorphosed forming MetaGabbro and Orthogneiss Suite rocks in central bedrock wedge of Galway City.	Begins at 9.28 pm
541		*Cambrian*	*Opening of the Iapetus Ocean. No record of rocks of this age in Galway City.*	Starts at 9.11 pm
2500	Proterozoic	Precambrian	Some of Irelands oldest rocks deposited in northwest Ireland. *No record of rocks of this age in Galway City*	Beginning 11.00 am
4000	Archaean		*Oldest known rocks on Earth.*	Beginning 3.00 am
4600			*Age of the Earth.*	Beginning 1 second after midnight

The Geological Timescale and Galway City.



Geology map of Galway City outlining the main geological units.

6. Acknowledgements

Funding from Geological Survey Ireland and is acknowledged. The authors also acknowledge the many members of the IGH Programme Expert Panels who helped define the sites that were considered for County Geological Site status. The following people are also acknowledged for their assistance to the completion of this audit:

- Alessandra Constanzo, Earth and Ocean Sciences, National University of Ireland Galway
- Martin Feely, Earth and Ocean Sciences, National University of Ireland Galway

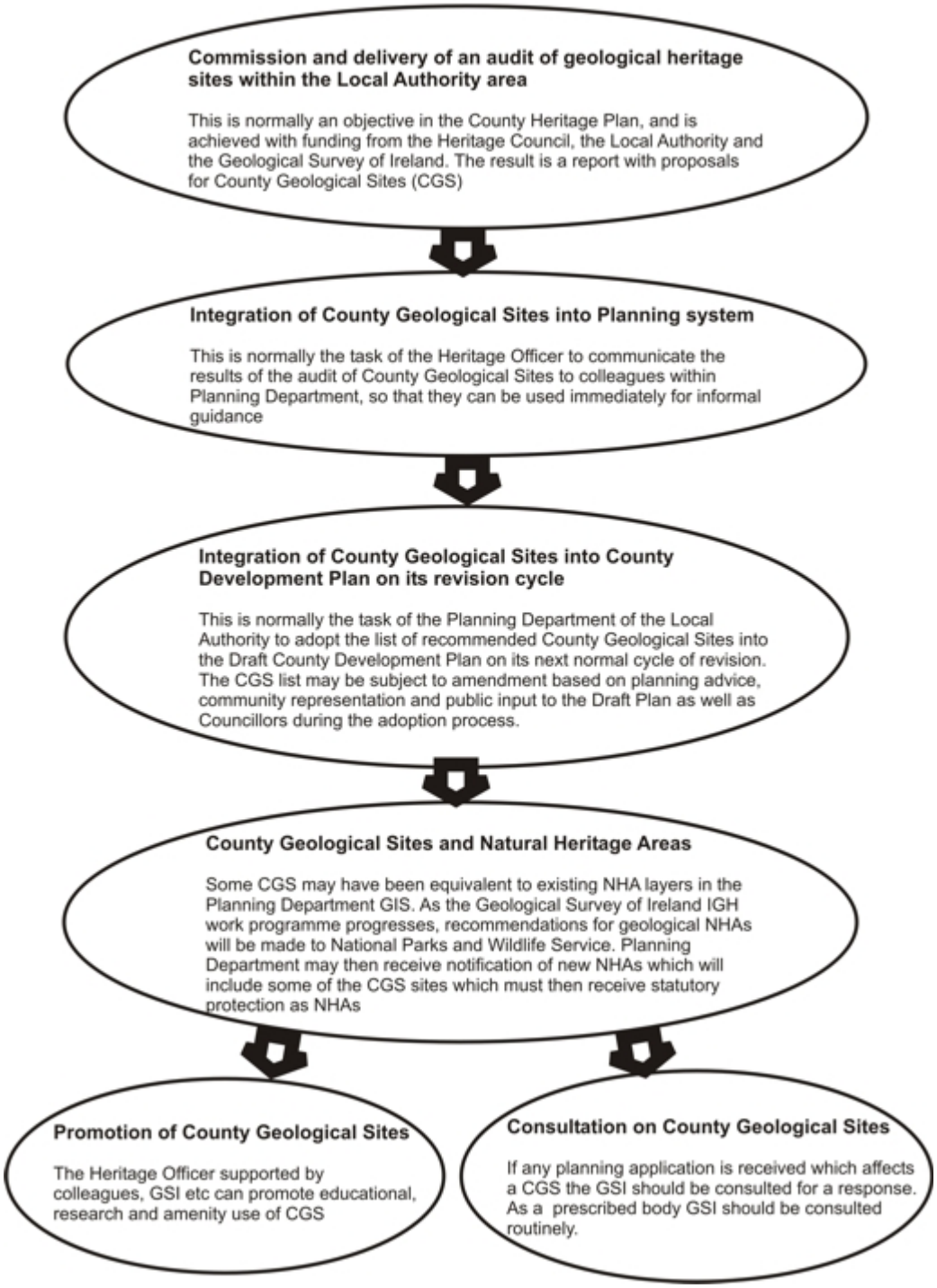
Appendix 1 – Geological heritage audits and the planning process

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

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

The chart below illustrates the essential process, established by the Geoheritage Programme (formerly IGH) in Geological Survey Ireland, over the course of numerous county audits since 2004. Due to timing and external factors, on this occasion, the Audit was carried out on behalf of Geological Survey Ireland without the involvement of Galway City Council. However, the overall process and principles remain the same.

County Geological Sites - a step by step guide



Appendix 2 - Bibliography – Geology of Galway

Appendix 2 provides a reference list of papers, books, articles and unpublished reports relating to the geology and geomorphology of Galway City and surrounding areas. Due to the very extensive influence of glaciation on the Irish landscape, and the relative accessibility for study there is an enormous body of literature on the Quaternary, or Ice Age geology of Ireland, and Galway. Appendix 3 includes Quaternary references.

Shortlist of Key Geological References

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

FEELY, M., and CONSTANZO, A. 2014. *Galway City Walks: Buildings in Stone*. Galway Civic Trust. 48pp.

FEELY, M., LEAKE, B.E., BAXTER, S., HUNT, J. AND MOHR, P., 2006. A geological guide to the Granites of the Galway Batholith, Connemara, western Ireland. Geological Survey of Ireland.

GATLEY, S. and PARKES, M.A. 2008. *Geological heritage guidelines for the extractive industry.* Irish Concrete Federation and the Geological Survey of Ireland. 16pp. Available online at https://www.gsi.ie/en-ie/publications/Pages/Geological-Heritage-Guidelines-for-the-Extractive-Industry.aspx

HOLLAND, C.H. (editor) 1981. A Geology of Ireland. *Scottish Academic Press*, 335pp.

LEAKE, B.E. and TANNER, P.W.G. 1994. The geology of the Dalradian and associated rocks of Connemara, western Ireland. *Royal Irish Academy*, 96pp.

LONG, C.B., McCONNELL, B., ARCHER, J.B and others. 1995. A geological description of southwest Mayo and adjoining parts of northwest Galway to accompany Bedrock Geology 1:100,000 scale map series, Sheet 10, Connemara. The Geology of Connemara and South Mayo. *Geological Survey of Ireland*.

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

PRACHT, M., LEES, A., LEAKE, B., FEELY, M., LONG, B., MORRIS, J. AND MCCONNELL, B. 2004. Geology of Galway Bay: a geological description to accompany the bedrock geology 1: 100,000 map series, Sheet 14, Galway Bay. Geological Survey of Ireland. Geological Survey of Ireland.

REYNOLDS, N., McARDLE, P., PYNE, J.F., FARRELL, L.P.C. and FLEGG, A.M. 1990. Mineral localities in the Dalradian and associated igneous rocks of Connemara, County Galway. *Geological Survey of Ireland Report Series*, RS 90/2, 89pp plus map.

GEOLOGICAL REFERENCES WITH DIRECT REFERENCE TO GALWAY CITY

BAXTER, S. 2000. The geology of part of the Galway Granite near Barna, Co. Galway, Ireland. Unpublished PhD Thesis, National University of Ireland, Galway.

BELL, A. 1992. The Galway Granites: dimension stone potential. *Geological Survey of Ireland Report Series* RS92/1, 113pp.

COATS, J.S. and WILSON, J.R. 1971. The eastern end of the Galway Granite. *Mineralogical Magazine* 38, 138-151.

CRUISE R.J., TRAILL W.A., LEONARD H., LEONARD W.B., NOLAN J., SYMES R.G., WILKINSON S.B., KINAHAN G.H., WARREN J.L., O'KELLY J., and MCHENRY A. 1869 Explanation to accompany sheet 105, with that portion of sheet 114 that lies on the north of Galway Bay. Memoirs of the Geological Survey of Ireland, Dublin.

DOLAN, M.J., McCABE, B.A., MOLLOY, K., MURRAY, J., HENRY, T., DALY, E., and O'LEARY, D. 2020 A Pleistocene deposit preserved in deep karst at Coolough, County Galway, western Ireland. *Geological Journal*. 1-14pp.

McCABE, A.M. and DARDIS, G.F., 1989. Sedimentology and depositional setting of late Pleistocene drumlins, Galway Bay, western Ireland. *Journal of Sedimentary Petrology*, 59, 944-959.

PRAEGER, R.L. 1906 Notes of a Western Ramble. *The Irish Naturalist*, Vol. 15, No. 12, 257-266.

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

COLE, G.A.J. 1922. *Memoir and Map of Localities of Minerals of Economic Importance and Metalliferous Mines in Ireland.* Geological Survey of lreland, 155pp. [Re-printed 1998 as: *Memoir of Localities of Minerals of Economic importance and Metalliferous Mines in Ireland.* Mining Heritage Society of Ireland, 39pp + 155pp]

COXON, P. 200I. Cenozoic: Tertiary and Quaternary (until 10,000 years before present). *In: The Geology of Ireland* (ed Holland, C. H.). Dunedin Academic Press, Edinburgh, 387 - 427.

DOYLE, E., HINCH, C. and COX, W. 2001. *Directory of Active Quarries, Pits and Mines in Ireland (3rd Edition).* Geological Survey of lreland Report Series, RS 0111, 465pp.

ELSDON and KENNAN, P. 1979. Geochemistry of lrish granites. *In: The Caledonides of the British Isles Reviewed* (eds Harris, A.L., Holland, C.H., and Leake, B.E.). Geological Society of London Special Publication, 8, 513-516.

FARRELL, L. 1972. *A Preliminary Report on Areas of Scientific Interest in County Galway.* Unpublished report, Dúchas - The Heritage Service, Dublin.

FEELY, M., GAYNOR, S., VENUGOPAL, N., HUNT, J. and COLEMAN, D.S. 2018. New U-Pb Zircon Ages for the Inish Granite Pluton, Galway Granite Complex, Connemara, Western Ireland. *Irish Journal of Earth Sciences, 36*, 17-23.

HOLLAND, C. H. (editor) 2001. *The Geology of Ireland.* Dunedin Academic Press, Edinburgh 531 pp.

KENNAN, P.S. 1979. Irish Caledonides Plutonic Rocks. *In: The Caledonides of the British Isles-Reviewed* (eds Harris, A.L., Holland, C.H. and Leake, B.E.). Geological Society of London Special Publication, 8, 705-711.

KENNAN, P.S. 1995. *Written in Stone.* Geological Survey of lreland, 50pp.

KINAHAN, G.H. 1889. *Economic Geology of Ireland.* Journal of the Royal Geological Society of lreland, 8, 514pp.

MARCHANT, T.R. and SEVASTOPULO, G.D. 1980. The Calp of the Dublin district. *Irish Journal of Earth Sciences* 3, 195-203.

MITCHELL, F. 1986. *The Shell Guide to Reading the Irish Landscape.* Michael Joseph/Country House, 228pp.

PHILCOX, M.E. 1984. *Lower Carboniferous lithostratigraphy of the Irish Midlands.* Irish Association for Economic Geology, 89pp.

SEVASTOPULO, G. D. and WYSE-JACKSON, P.N. 2001. Lower Carboniferous. *In: The Geology of Ireland* (ed Holland, C. H.). Dundee Press, Edinburgh, 241-288.

Appendix 3 - Bibliography – Galway City Quaternary References

QUATERNARY REFERENCES WITH DIRECT REFERENCE TO GALWAY CITY AND REGION

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

CHARLESWORTH, J.K., 1929. The glacial retreat in Iar Connaught. *Proceedings of the Royal Irish Academy*, 39B, 95-106.

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

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

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

COXON, C.E., 1994. Carbonate deposition in turloughs (seasonal lakes) on the western limestone lowlands of Ireland, I: present day processes. *Irish Geography*, 27, 14-27.

COXON, C.E. and DREW, D., 1986. Groundwater flow in the lowland limestone aquifer of eastern Co. Galway and eastern Co. Mayo, western Ireland. In: Paterson, K. and Sweeting, M.M. (Editors) *New Directions in Karst*, Norwich, GeoBooks, pp. 259-279.

COXON, C.E. and DREW, D., 1998. Interaction of surface water and groundwater in Irish karst areas: implications for water resource management. In: Brahana, J.V., Eckstein, Y., Ongley, L.K., Scneider, R. and Moore, J.E. (Editors) *Gambling with groundwater – Physical, Chemical and Biological Aspects of Aquifer- Stream Relations*. American Institute of Hydrology, St. Paul, Minnesota, pp. 161-168.

COXON, P., 1996. The Gortian Temperate Stage. *Quaternary Science Reviews*, 15, 425-436.

COXON, P., 2001a. Cenozoic: Tertiary and Quaternary (until 10,000 years before present). In: Holland, C.H. *The Geology of Ireland*. Dunedin Academic Press, Edinburgh, pp. 387-427.

COXON, P., 2005. The Quaternary of Central Western Ireland. QRA / IQUA Field Guide, Quaternary Research Association, London, 220pp.

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

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

DEWEY, J.F., 2000. Cenozoic tectonics of western Ireland. *Proceedings of the Geologists' Association,* 111, 291-306.

DOLAN, M.J., McCABE, B.A., MOLLOY, K., MURRAY, J., HENRY, T., DALY, E., and O'LEARY, D. 2020. A Pleistocene deposit preserved in deep karst at Coolough, County Galway, western Ireland. *Geological Journal*. 1-14pp.

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

DREW, D.P. 1974 Caves of the Kinvarra Area, Co. Galway Irish Speleology 2, 3, 28-31pp.

DREW, D.P. and DALY, D., 1993. Groundwater and karstification in mid Galway, south Mayo and north Clare. *Geological Survey of Ireland, Report Series*, 93/3, 86pp.

DUNNE, L. and FEEHAN, J., 2003a. *Irelands Mushroom Stones: Relics of a vanished Lakeland*. Environmental Institute, UCD, Dublin. 28pp.

DUNNE, L. and FEEHAN, J., 2003b. The origin and significance of Mushroom Stones in Ireland. *Irish Journal of Earth Sciences*, 20, 33-40.

FINCH, T.F. (Editor), 1977. *Guidebook for INQUA Excursion C16: Western Ireland*. GeoAbstracts, Norwich, 39pp.

FLOOD, P. and EISING, J. 1987. The use of Vertical Band Drains in the Construction of the Galway Eastern Approach Road. *Proceedings of 9th European Conference on Soil Mechanics*, Dublin, 1, 417–529.

JONES, G. LL., 2000. Ancient karst or palaeokarst in Ireland. In: Daly, D., Drew, D., Deakin, J., Ball, D., Parkes, M. and Wright, G. (Ed.). *The Karst of Ireland*. Geological Survey of Ireland, Dublin, pp.4-7.

KEARY, R., 1964. A note on the beach sands of the Cois Fharraige coast. *Irish Naturalists Journal*, 15(2), 40-43.

KINAHAN, G.H. and CLOSE, M.H., 1872. *The general glaciations of Iar-Connaught and its neighbourhood in the counties of Galway and Mayo*. Hodges, Foster and Co., Dublin, 20pp.

LEWIS, C.A., 1975. *Guidebook for INQUA Excursion C16: Western Ireland*. GeoAbstracts, Norwich, 39pp.

McCABE, A.M., 1991. The distribution and stratigraphy of drumlins in Ireland. In: Ehlers J, Gibbard PL, Rose J. (Editors), *Glacial deposits in Great Britain and Ireland*. Balkema, Rotterdam, 421-435.

McCABE, A.M., 1993. The 1992 Farrington lecture: Drumlin bedforms and related marginal depositional systems in Ireland. *Irish Geography*, 26(1), 22-44.

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

McCABE, A.M., DARDIS, G.F. and HANVEY, P.M., 1992. *Glacial sedimentology in northern and western Ireland.* Field Excursion Guidebook, University of Ulster, Coleraine, 236 pp.

MITCHELL, F.J.G., 2009. The Holocene. In: Holland, C.H. and Sanders, I.H. (Editors). *The Geology of Ireland*. Second Edition, 397-404.

MITCHELL, G.F., 1981. The Quaternary– until 10,000 BP. In: Holland, C.H. (Editor) *A geology of Ireland*. Scottish Academic Press, Edinburgh, pp. 235-258.

MITCHELL, G.F., 1998. The Ice Age. Chapter 2 of Mitchell, G.F. and Ryan, M., *Reading the Irish Landscape*, Townhouse Press, pp. 35-80.

O'CONNELL, M. and WARREN, W.P., 1988. *Connemara*. IQUA Field Guide Number 11, Irish Quaternary Association, Dublin, 75pp.

ORME, A.R., 1967. Drumlins and the Weichsel Glaciation of Connemara. *Irish Geography*, 5, 262-274.

WARREN, W.P., 1992. Drumlin orientation and the pattern of glaciation in Ireland. *Sveriges Geologiska Undersokning, Research Papers*, Series Ca 81, 359-366.

WILLIAMS, D., and O'CONNELL, M., 1996. Cave-Like Tunnels within Boulder Clay in Galway City, Western Ireland. *Irish Naturalists' Journal*, 25, 7, 263-266.

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

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

ASHLEY, G.M. and WARREN, W.P., 1995. *Irish Eskers; Origin of ice contact stratified deposits. INQUA Commission on Formation and properties of Glacial Deposits Symposium and field excursion handbook*. Geological Survey of Ireland, Dublin. 59pp.

BELLAMY, D., 1986. *The Wild Boglands: Bellamy's Ireland*. Country House Publishers, Dublin, 178pp.

BOWEN, D.Q. and SYKES, G.A., 1988. Correlations of marine events and glaciations on the northeast Atlantic margin. *Philosophical Transactions of the Royal Society*, B318, 619-635.

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

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

COLE, G.A.J., 1901. The topography and geology of Ireland. In: Coyne, W.P. (Editor) *Ireland Industrial and Agricultural*. Department of Agriculture, Dublin, 450 pp.

DREW, D.P. and JONES, G.LL., 2000. Post-Carboniferous pre-Quaternary karstification in Ireland. *Proceedings of the Geologists' Association*, 111, 345-353.

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

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.

FLINT, R.F., 1930. The origin of the Irish 'eskers'. *Geographical Review* 20, 615-620.

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

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.

HOLLAND, C.H., 2001. *The Geology of Ireland* (Second Edition). Edinburgh, Dunedin Academic Press, 532pp.

HULL, E., 1878. *The physical geology and geography of Ireland*. London, 328pp.

KINAHAN, G.H, 1887b. Irish marbles and limestones. *Scientific Proceedings of the Royal Dublin Society*, 5, 372-444.

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

MITCHELL, G.F., 1976. *The Irish landscape*. Collins, London, 240pp.

MITCHELL, G.F., 1980. The search for Tertiary Ireland. *Journal of Earth Sciences of the Royal Dublin Society*, 3, 13-33.

PRAEGER, R.L., 1937. *The Way that I Went*. Collins Press, Dublin. 394pp.

REYNOLDS, J.D., 2005. Fauna of turloughs and other wetlands. In: Otte, M.L. (Editor) *Wetlands of Ireland*. University College Dublin Press, 144-156.

SIMMS, M.J., 2004. Tortoises and hares: dissolution, erosion and isostasy in landscape evolution. *Earth Surface Processes and Landforms*, 29, 477-494.

SMITH, M.J. and KNIGHT, J., 2011. Palaeoglaciology of the last Irish Ice Sheet reconstructed from striae. *Quaternary Science Reviews* 30 (1-2), 147-160.

SYNGE, F.M., 1970. The Irish Quaternary: current views 1969. In: Stephens, N. and Glasscock, R.E. (Editors) *Irish Geographical Studies in honour of E. Estyn Evans*. Geographical Society of Ireland, Dublin.

WHITTOW, J.B., 1974. *Geology and scenery in Ireland*. Dublin, Penguin Books, 304pp.

WILLIAMS, P.W., 1970. Limestone morphology in Ireland. In: Stephens, N. and Glasscock, R.E. (Editors), *Irish Geographical Studies in honour of E. Estyn Evans*, Geographical Society of Ireland, Dublin. 105-124.

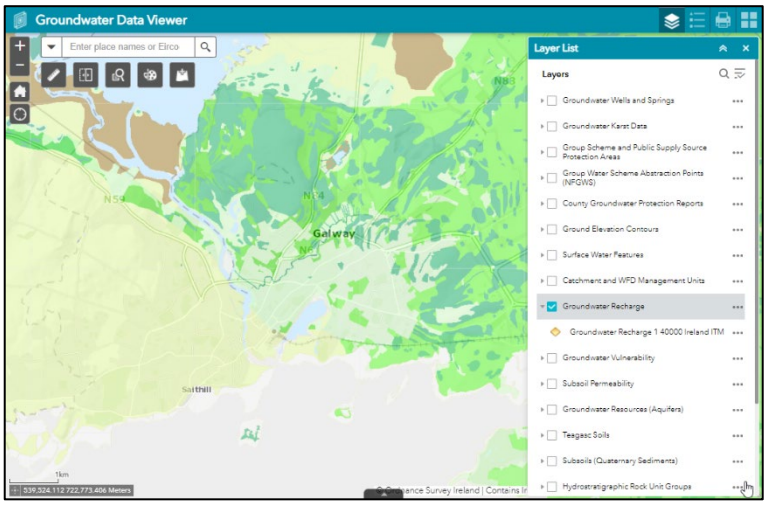
Appendix 4 – Geological heritage versus geological hazards

Ireland is considered low risk in terms of major geological hazards. There are no active volcanoes in Ireland. Ireland's location on a stable tectonic plate, distant from the closest active plate boundary (c. 2,500 km) means that earthquakes are rare. From the annals of recorded history, Ireland has not experienced disastrous landslides, mudflows or other geological catastrophes that occur in other parts of the world. Aside from being spared from cataclysmic natural disasters, the risk of one-off events always remains, such as a potential tsunami which could occur in the aftermath of the collapse of seamounts in the Canary Islands. This section briefly explores the record and nature of geological hazards in Galway City 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 prolonged quiet periods in between. The County Geological Sites in Galway City represent evidence of past geological environments and processes, such as the tropical marine environments with abundant Carboniferous sea-life (limestone), crustal igneous-activity associated with great mountain-building events (Galway Granite), and arctic environmental conditions when ice sheets covered the land surface. A few County Geological Sites represent active geomorphological or land-forming processes, such as at Rusheen Bay.

Flooding

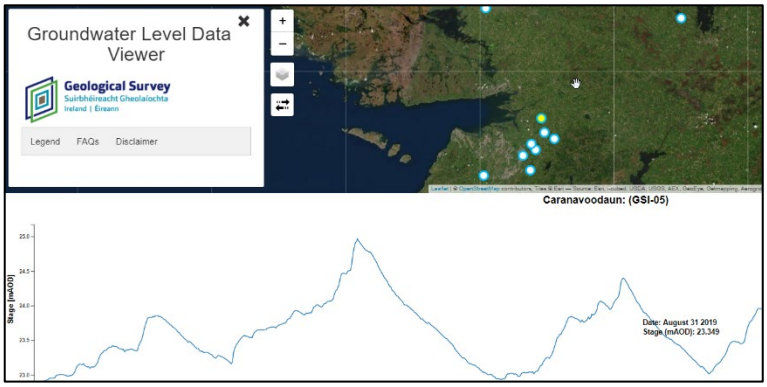
There are two types of flooding which need consideration. River flooding occurs inland when the rainfall exceeds the capacity of the ground to absorb moisture, and the river channels cannot adequately discharge it to the sea.



Screengrab of Geological Survey Ireland Groundwater Data Viewer.

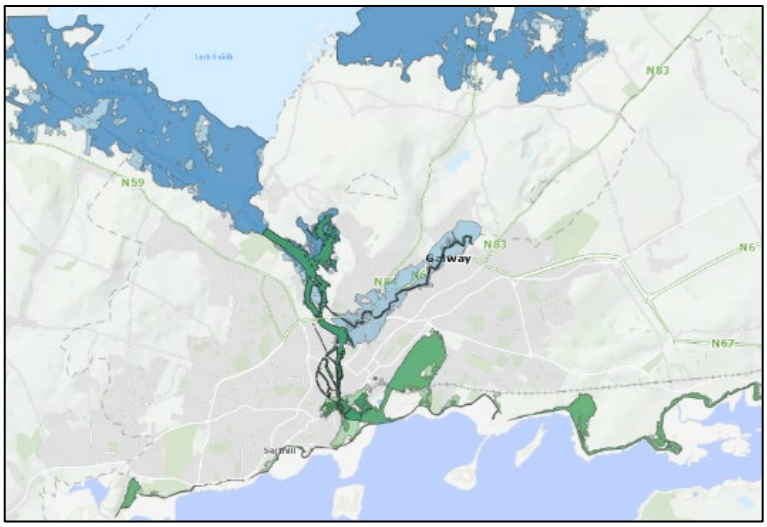
Groundwater flooding maps (historic & predictive) are available through Geological Survey Ireland web map viewers, such as the Groundwater Level Data Viewer. The historic flood maps provide information of historic flooding, both surface water and groundwater. The predictive groundwater flood map provides information on the probability of future karst groundwater flooding (where

available). For information on the development and limitations of these flood maps, please check the associated user guidance notes.



Screengrab of Geological Survey Ireland Groundwater Level Data Viewer.

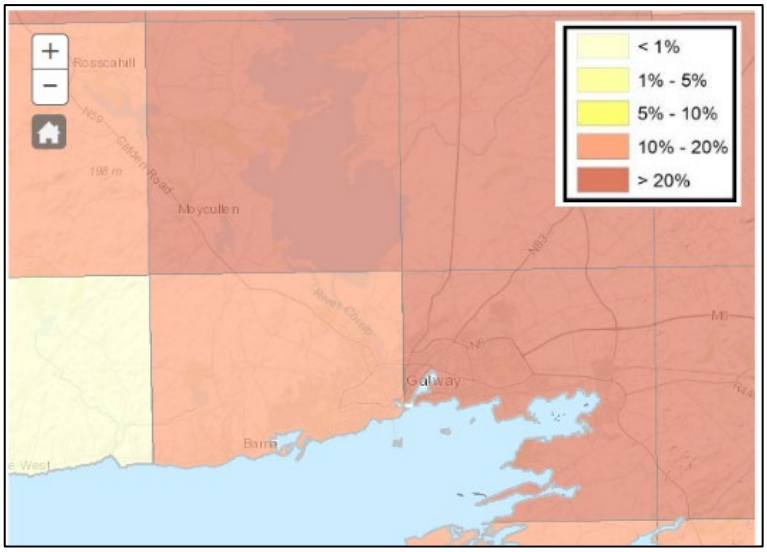
The OPW website (www.floodinfo.ie) can be consulted for details of individual flood events in and around Galway City. Karstic flooding can occur when underground passages are unable to absorb high rainfall events. The Carboniferous Limestone bedrock underlying the east side of Galway City is prone to karstic flooding in places such as Ballindooley, where flooding is a recurring event. Coastal flooding is a recurring event in Salthill, where storm surge can overtop the promenade and lead to localised flooding. The city centre area around the Spanish Arch is also subject to recurring flooding events.



Screengrab of OPW Flooding Probability Map showing Galway City. Green areas indicate potential coastal flooding events. Blue areas indicate potential fluvial flooding events.

Radon

Radioactive minerals and gases at high 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 viewed on the Environmental Protection Agency (EPA) website (see EPA High Radon Areas map).



Screengrab of EPA Radon Map showing Galway City and environs. See www.epa.ie

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. As the groundwater is largely contained within limestone, it should be noted that karstic springs are especially vulnerable to pollution since the flow is mainly within fissure conduits allowing rapid transmission of pollution from source to water supply. The opportunity for microbial attenuation of pollutants is far less in limestone fissures (as there are no natural barriers to stop pollutants) than it would be in granular deposits, which act as natural filters.

Landslides

Geological Survey Ireland has been compiling national data on landslides in the past decade. Galway City is deemed to have a low level of landslide susceptibility, and no major landslide events have occurred in recent decades.
See http://www.gsi.ie/Programmes/Quaternary+Geotechnical/Landslides/

Coastal Vulnerability

Geological Survey Ireland is undertaking a coastal vulnerability mapping initiative to gain an insight into the relative susceptibility of the Irish coast to adverse impacts of sea-level rise through the use of a Coastal Vulnerability Index (CVI). The main areas of vulnerability will be identified by both CVI and the analysis of individual variables, also called coastal indicators: geomorphology, cliff type, coastline orientation, regional coastal slope, tidal range, significant wave height, relative sea-level rise, and long-term shoreline erosion and accretion rates. The first phase of CVI mapping (2019-2021) is focused on the Irish Sea coast.
https://www.gsi.ie/en-ie/programmes-and-projects/marine-and-coastal-unit/projects/Pages/Coastal-Vulnerability-Index.aspx

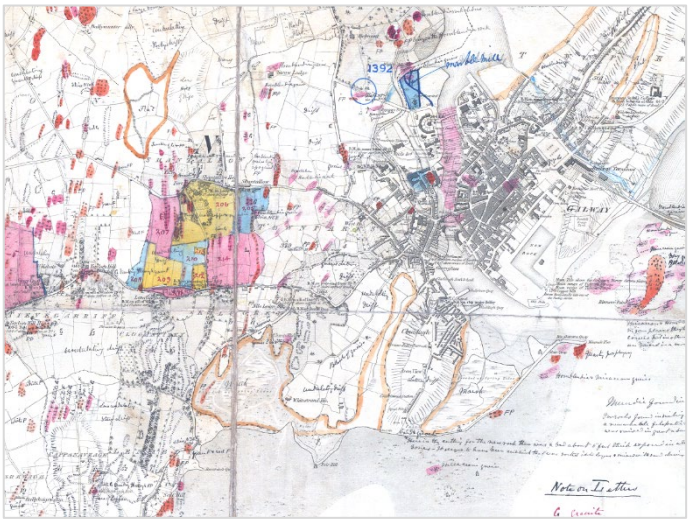
Appendix 5 - Data sources on the geology of Galway City

This section is a brief summary of various data resources that may be of assistance for queries relating to geology, groundwater and mapping. Geological Survey Ireland has accumulated an abundance of disparate data 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. Data is available free of charge. Key datasets include:

GOLDMINE
Goldmine (**G**SI **O**n**L**ine **D**ocument **M**aps and **I**nformatio**N** **E**xplorer) is the Geological Survey Ireland online digital archive database. The service provides public access to reports, publications and maps in PDF or high resolution TIFF image format. The library consists of scanned documents and maps which include Geological Survey Ireland principal datasets, Mineral Exploration Reports, Geotechnical Reports, boreholes and test data, historic 6 inch to 1 mile (6") and 1 inch to 1 mile (1") scale geological maps, official Geological Survey Ireland publications, bulletins, published and unpublished reports, groundwater well hydrographs, airborne geophysical maps, mineral locality reports and mine records. https://secure.dccae.gov.ie/goldmine/index.html (or search online for Geological Survey Ireland Goldmine).

1:100,000 Map Report Series
All historical, modern and other mapping deliverables have been compiled into colourful maps and detailed reports that describe the geology of the entire country. Geological Survey Ireland Sheet 14 covers all of Galway City.

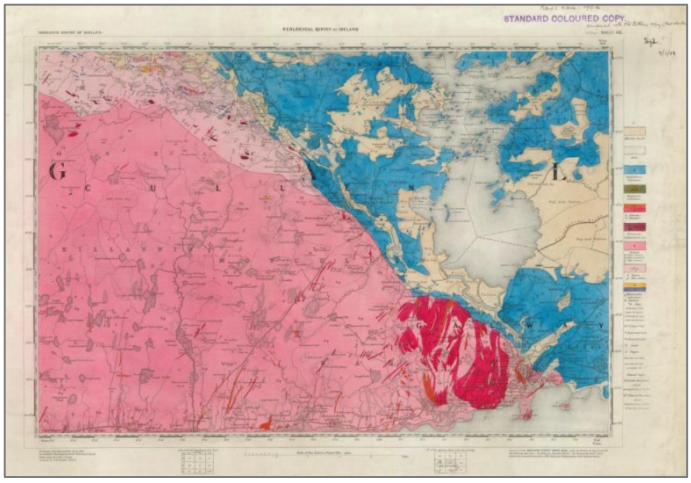
19th century 6 Inch to the Mile Fieldsheets
The 6" scale field sheet series provides an important historical and current resource with very detailed observations of the geology of the entire country. Produced in the mid-18th century, these sheets are digitally available the public via the Interactive Web Data Delivery System (IWDDS). https://jetstream.gsi.ie/iwdds/map.jsp



Excerpt from Geological Survey Ireland 6 inch to 1 Mile Field Sheet 94.

19th century One Inch to the Mile Maps and Memoirs

Information from the detailed 19th century mapping was distilled into one inch to the mile maps, of which parts of parts of Sheets 105 and 106 cover Galway City. Each sheet is accompanied by a memoir detailing the geology of that area in detail. The memoirs continue to provide valuable records of observations even though interpretations may have changed with better geological understanding. Memoirs are publicly available in scanned PDF format on the GSI GOLDMINE website. https://secure.dccae.gov.ie/goldmine/index.html



Geological Survey Ireland 1 Inch to 1 Mile Map Sheet 105.

Maps and memoirs are publicly available in on the BGS/GSNI/GSI Irish Historical Geological Maps website. http://www.geologicalmaps.net/irishhistmaps/history.cfm

MinLocs Data

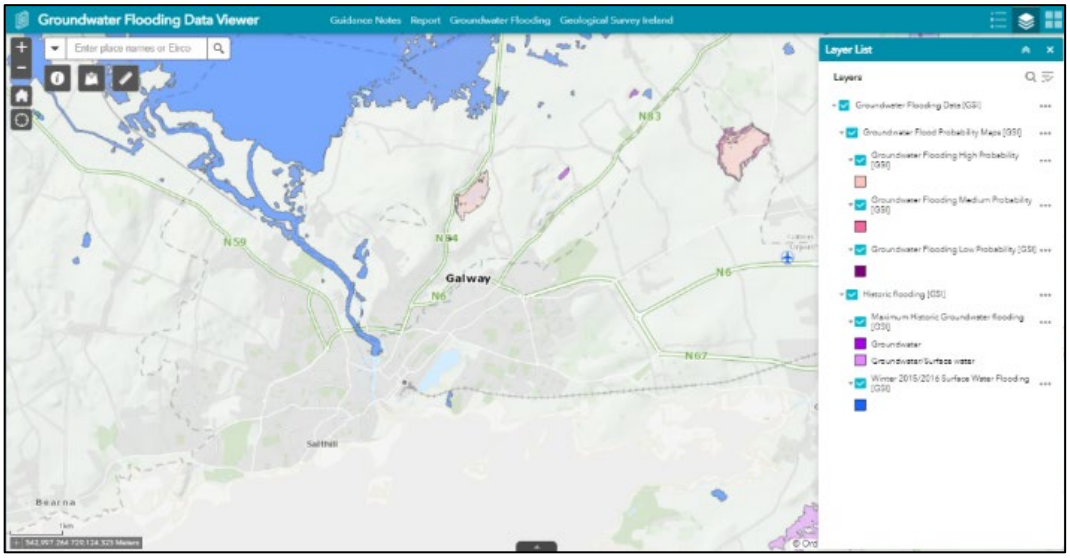
The MinLocs Database records all known mineral occurrences, however small, from GSI records, such as 19th century field sheets and Open File data.

Subsoils Mapping

In 2012, Geological Survey Ireland completed Groundwater Protection Schemes (GWPSs) in partnership with Local Authorities, and there is now national coverage of GWPS mapping. Subsoil and bedrock mapping provides a significant resource for groundwater protection, as well as other purposes. Detailed compilation of glacial geology and geomorphology datasets, including a revision published by Geological Survey Ireland in 2014 has amplified data pertaining to groundwater and quaternary mapping. Digital mapping of many different datasets is now available via the Geological Survey Ireland public data viewer (see www.gsi.ie).

Groundwater Flooding

The winter of 2015/2016 saw extensive groundwater flooding in Ireland. The lack of data on groundwater flooding and groundwater flood hazard maps were identified as serious impediments to managing groundwater flood risk. Geological Survey Ireland in collaboration with Trinity College Dublin and Institute of Technology Carlow initiated a groundwater flood project (GWFlood) to address the deficits, and subsequently published (1) a Groundwater Flood Maps Viewer showing historic and predictive groundwater flood maps, (2) a Groundwater Level Data Viewer showing live groundwater hydrometric data and (3) a comprehensive project report (see www.gsi.ie).

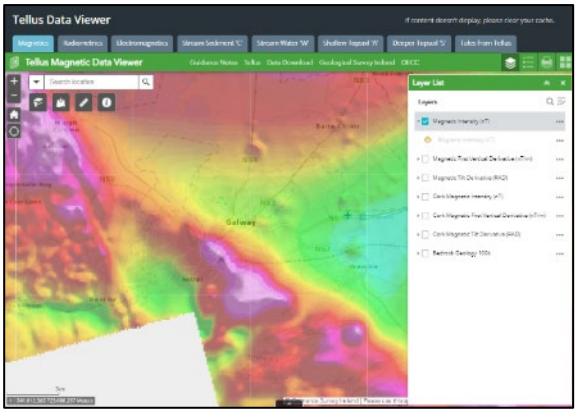


GSI Groundwater Flooding Data Viewer.

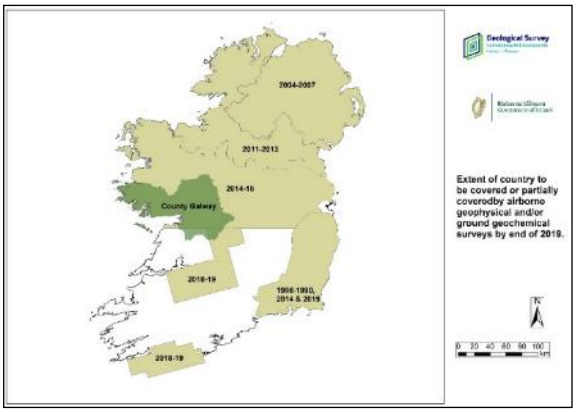
Tellus Mapping

Tellus is an island-wide mapping project, combining airborne geophysical and geochemical surveys to provide geoscientific information for the island of Ireland. Tellus surveying was completed in County Galway, including the city area, in 2019. All Tellus geochemical and geophysical data is available online free of charge. As of 2019, the Tellus airborne geophysical survey has mapped 75% and the geochemical programme 50% of the country. The Tellus surveys support mineral exploration, environmental management, agriculture and research activity.

Data are freely available at [https://www.gsi.ie/en-ie/programmes-and-projects/tellus/Pages/Data-and-Maps.aspx.](https://www.gsi.ie/en-ie/programmes-and-projects/tellus/Pages/Data-and-Maps.aspx)



GSI Tellus Data Viewer displaying Magnetic Intensity in Galway City.



Coverage of Tellus Survey up to 2020.

Historic Mine Records in Geological Survey Ireland

Abandonment plans and varied other material exist for the various mining ventures in the country and are stored in Geological Survey Ireland. The range of data varies from single items for some historical mine sites in Leitrim, to immensely detailed series of plans for more modern mine sites such as those of the Connacht Coalfield, which straddled Counties Leitrim, Roscommon and

Sligo. Virtually all of these are scanned and available on GOLDMINE (see above) but additional material, e.g. photographs, may be stored in the paper records, held in Geological Survey Ireland archives. Additionally, scanned material does not include some very historic or rare plans and documents that are stored in a separate Geological Survey Ireland archive, part of the National Archive. The EPA, Geological Survey Ireland and the former Exploration & Mining Division undertook a joint project entitled "Historic Mine Site - Inventory and Risk Characterisation (HMS - IRC)". This project carried out detailed site investigations and characterisation on priority historic mine sites in the country. A risk ranking methodology was developed which categorised the sites according to the risks posed to human and animal health and the environment. The project commenced in January 2006 and was completed in December 2008. A final report and a GIS geodatabase was produced on completion of the project. Reports and maps available at https://www.epa.ie/enforcement/mines/. The project provides an understanding of the impacts of historic mining sites in Ireland and their status at the time of the study.

Ordnance Survey Ireland Geohive

The Ordnance Survey Ireland online mapping website Geohive offers a superb resource with Ordnance Survey Ireland maps at different scales, colour and black & white air photos, and a varied range of datasets available to view online. Geological Survey Ireland data (e.g. bedrock geology, Quaternary geology, minerals, groundwater and county geological heritage sites) is available on the map service, along with NPWS and other protected site data. Boundary data for County Geological Sites are available as a data layer on the online mapping service. http://map.geohive.ie/

Heritage Council Heritage Viewer

HeritageMaps.ie is a web-based spatial data viewer, co-ordinated by the Heritage Council, and working with the Local Authority Heritage Officer network, which focuses on the built, cultural and natural heritage around Ireland and off shore. The map viewer allows users to look at a wide range of built and natural heritage data sets online. Boundary data for County Geological Sites are available as a data layer on the online mapping service. http://heritagemaps.ie/

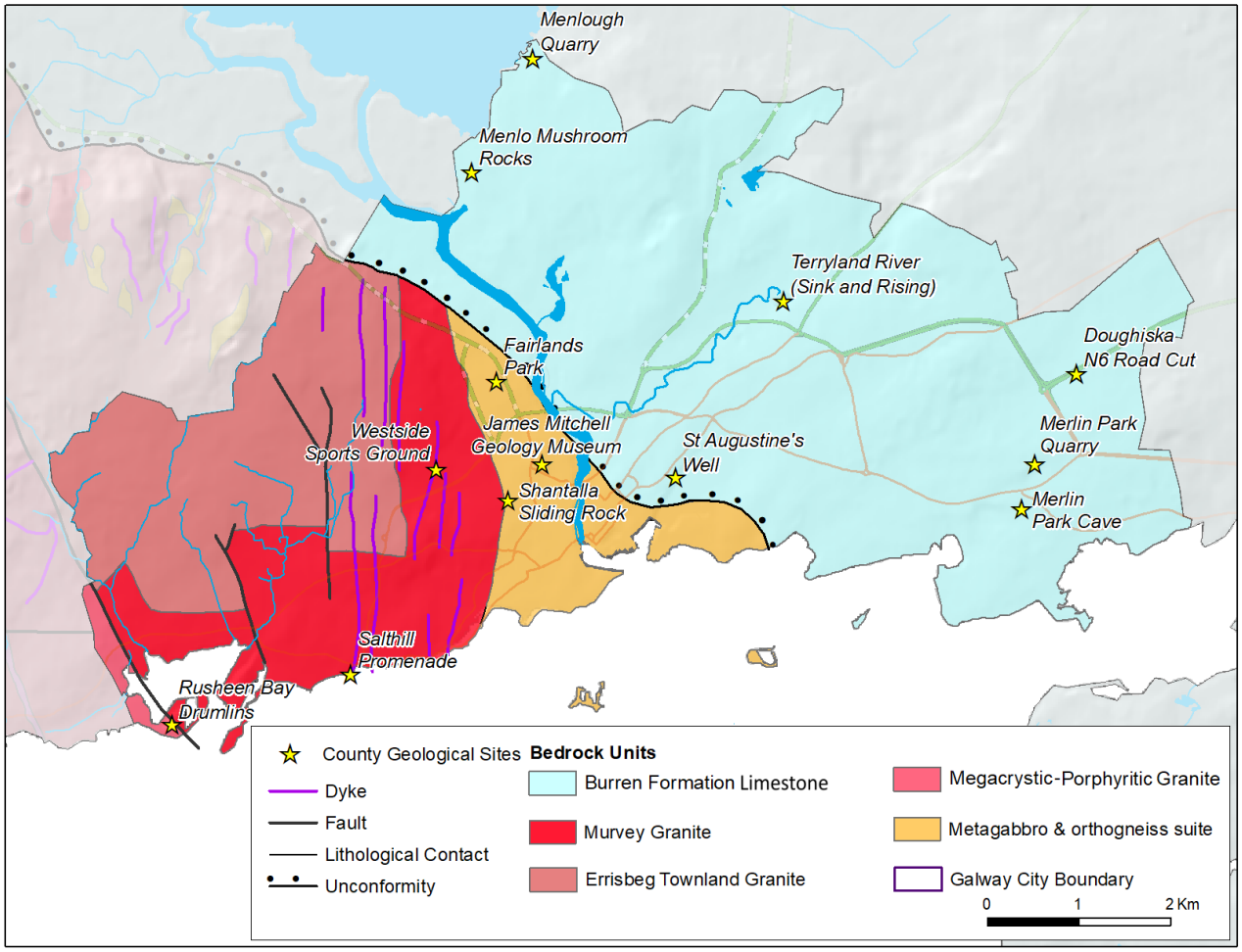
Appendix 6 – Further sources of information and contacts

Geoheritage Programme staff at Geological Survey of Ireland can be contacted in relation to any aspect of this report. The Galway City Heritage Officer is the primary local contact for further information in relation to County Geological Sites in Galway City. Other contacts include Conservation Rangers of the National Parks and Wildlife Service, currently in the Department of Culture, Heritage and the Gaeltacht.

Web sites of interest

www.gsi.ie	Geological Survey Ireland
www.npws.ie	National Parks and Wildlife Service
www.heritagecouncil.ie	The Heritage Council
www.galwaygeology.net	Galway Geological Association
www.galwaycity.ie	Galway City Council
www.geologicalmaps.net	Historical Geological Maps
www.geology.ie	Irish Geological Association
www.iqua.ie	Irish Quaternary Association
www.progeo.ngo	ProGEO - The European Association for the Conservation of Geological Heritage
www.floodinfo.ie	Office of Public Works Flood Plans and Flood Maps
www.joycecountrygeoparkproject.ie	Joyce Country and Western Lakes Geopark Project

Appendix 7 – Detailed geological map of Galway City



Geological Map of Galway City with County Geological Site locations indicated.

Appendix 8 – Geoschol leaflet on the geology of County Galway

GALWAY

AREA OF COUNTY: 6,148 square kilometres or 2,373 square miles

COUNTY TOWN: Galway

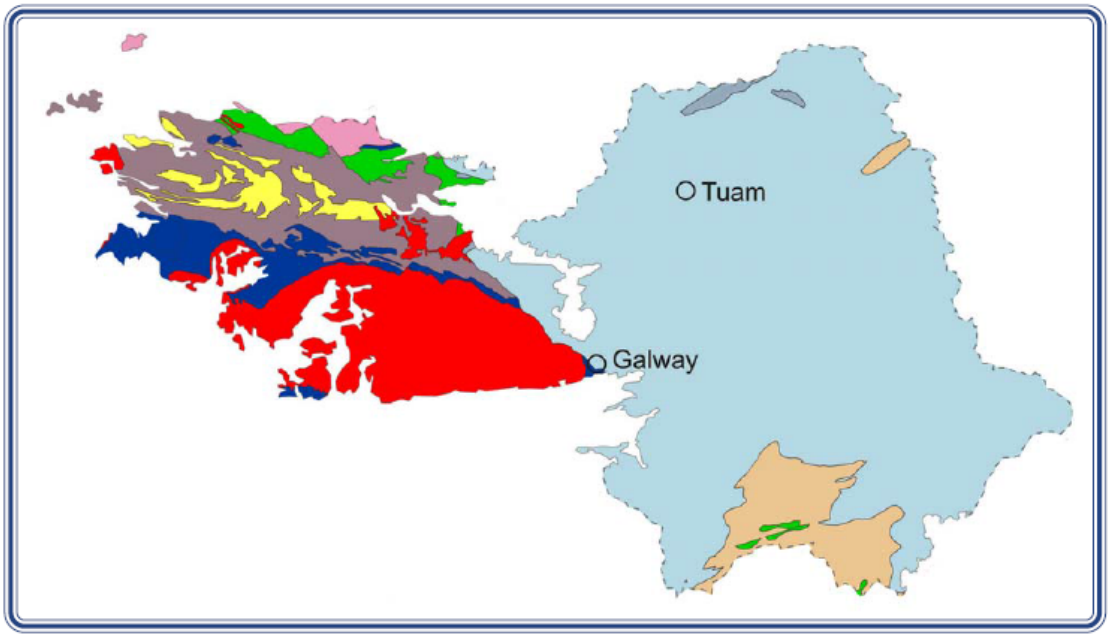
OTHER TOWNS: Athenry, Ballinasloe, Clifden, Gort, Loughrea, Oughterard, Portumna, Tuam.

GEOLOGY HIGHLIGHTS: Galway Granite, Connemara metamorphic rocks and mountains, Connemara marble, Glengowla Mine, Aran Islands

AGE OF ROCKS: Precambrian; Cambrian-Carboniferous; Tertiary

Bencollaghduff, Twelve Bens, Co. Galway

The ancient quartzite peaks of the Twelve Bens, deeply eroded by glaciers during the last Ice Age.



Geological Map of County Galway

Pale purple: Precambrian Dalradian rocks; **Pale Yellow:** Precambrian quartzites; **Pink:** Ordovician; **Dark blue:** Ordovician igneous & volcanic rocks; **Green:** Silurian; **Red:** Granite; **Beige:** Devonian sandstones and conglomerates; **Blue grey:** Lower Carboniferous sandstones; **Light blue:** Lower Carboniferous limestone.

Geological history

Galway has some of the most complex geology in the whole of Ireland. Ancient metamorphic rocks such as schist and gneiss (pronounced as 'nice') occur through Connemara from Galway City to Inishbofin. The whole of Connemara is a very big structure with massive folds. It is part of the Dalradian sequence that also occurs in North Mayo, Donegal and through into western Scotland. There are even older Precambrian rocks in a very few places exposed by massive faults. Many large areas, such as Connemara, are defined as terranes. These are sequences of rocks that were formed in one place and are now alongside other sequences that were originally formed a long way apart. Major faults in the Earth's crust have brought them together over millions of years.

The Twelve Bens of Connemara are made of metamorphosed sandstone, which is quartzite. They form hills because they are more resistant to erosion over long periods than the other rocks. Running along the base of the hills are areas of metamorphosed limestone, which is marble. Marble is white if the

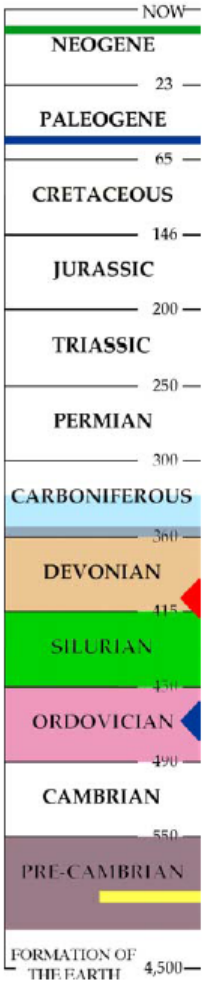
Drumlin at Salthill - this is a good place to see a cross-section through such a structure.

limestone was pure, but the addition of a few impurities means that the Connemara marble has green bands through it.

The Galway Granite is found in south Connemara from Galway City through to Roundstone. It is not one single rock type, but was formed by the intrusion of nine or so large granite masses (called batholiths or plutons) about 400 million years ago. It was formed underground and the molten igneous rock cooled slowly. The rocks that covered it have since been eroded away.

At the same time as the granite was injected below ground, Devonian age rivers were eroding hills and depositing sands and gravels in lower lying areas. Some of these sandstones and conglomerates are seen in Slieve Aughty in the south of the county. Appearing as small inliers, or 'windows' to see below these rocks, are Silurian age slaty rocks. Virtually all of Galway east of the city is covered by limestone, deposited in a shallow tropical sea around 330 Ma ago. This has been eroded down over millions of years, since it was formed and then raised to become land. Although it has some caves in it and some karstic features it has not become like the Burren in Clare because in the Ice Ages a thin veneer of sediment was deposited on most of it. So the limestone terrain of east Galway has good soils for grazing with neat fields and limestone walls. In the Aran Islands, the terrain is more like the Burren, with the only evidence of glaciations being some odd boulders of Galway Granite on the bare limestone pavement.

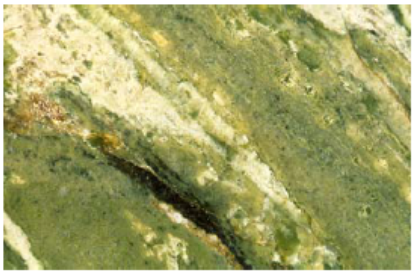
Rocks younger than the Carboniferous are found in only a few tiny patches in Co Galway (not shown on map). A few dolerite dykes, fractures up which volcanic lava moved around 60 Ma ago in the Paleogene (blue on timescale), have been found in the extreme west. Near Headford, pockets of sand and lignite (brown coal) around 3 Ma are preserved in deeply weathered limestone (green on timescale).



Geological timescale showing age of rocks in Galway.

Galway fossils

The metamorphic and igneous rocks of Connemara do not contain fossils, but the limestone plains of east Galway include many fossils, as the limestone represents a former tropical sea, teeming with life. Some of the Ordovician and Silurian rocks between Killary harbour and the Connemara mountains do contain fossils of shells, trilobites, graptolites and nautiloids for example but only in certain places.



Quarry at Streamstown, Clifden (left) where Connemara Marble (right) is extracted

Mining & Building Stones

Historical mining of lead, zinc and other minerals took place in many small mines in the 1800s, but especially around Oughterard and Maam. The tourist show mine at Glengowla is the best place to see how these mines operated. Stone extraction has been a feature of Galway for centuries with such diversity of rock types. Most notable are the Connemara marble quarries around Clifden and Recess. This marble has the mineral serpentine giving it a streaky green appearance, well known for ornamental uses. Limestone quarries near Galway City also produced Galway Black Marble – really a very dark polished limestone. In the 1950s revival of Irish mining, Tynagh Mine took special place as the first of the big new mines that produced metal ores in Ireland. Near Headford, some wind-blown pure sands collected in hollows and caves and have been quarried for glassmaking in recent decades.

Suggested reading

• Martin Feely, 2002. *Galway in Stone. A Geological Walk in the Heart of Galway*. Geoscapes, Dublin.

Map adapted with permission from Geological Survey of Ireland 1:1,000,000 map 2003.
Image credits: Mike Simms 1; Matthew Parkes 3, 4 (left); Patrick Wyse Jackson 4 (right).

Text by Matthew Parkes & Mike Simms

Appendix 9 – Glossary of Geological Terms

Geological term	Definition
Bedrock	a general term for the rock, usually solid, that underlies soil or other unconsolidated, superficial material.
Boulder Clay	unconsolidated, unsorted glacial deposits consisting of boulders and cobbles mixed with very finely ground-up rock or silt. Also known as till.
Channel	a landform consisting of the outline of a path of relatively shallow and narrow body of fluid, most commonly the confine of a river, river delta or strait.
Diamict	lithified, poorly-sorted deposits comprising clasts of various sizes in a mud matrix
Drumlin	a streamlined mound of glacial drift, rounded or elongated in the direction of the original flow of ice.
Dyke	a sub-vertical sheet-like igneous intrusion that cuts across the bedding or foliation of the country rock.
Erratic	a large rock fragment that has been transported, usually by ice, and deposited some distance from its source. It therefore generally differs from the underlying bedrock, the name "erratic" referring to the errant location of such boulders. Tracing their source can yield important information about glacial movements.
Estavelle	opening in karstic terrane. May act alternatively as a swallow hole and as a rising according to ground-water conditions.
Fault	planar fracture in rocks across which there has been some displacement or movement.
Gabbro	a dark coarsely crystalline intrusive (plutonic) igneous rock composed mostly of plagioclase feldspar, olivine, pyroxene and amphibole.
Glacial	of or relating to the presence and activities of ice or glaciers.
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.
Hornblende	hydrous (OH-bearing) silicate mineral containing Ca, Fe and Mg as major components
Hummock	a small hill or knoll in the landscape, which may be formed by many different processes.
Igneous	a rock or mineral solidified from molten or partially molten material i.e. from magma.
Joint	a fracture in a rock, which shows no evidence of displacement.
Limestone	a sedimentary rock consisting chiefly of calcium carbonate ($CaCO_3$), primarily in the form of the mineral calcite.
Lithology	the description of rocks on the basis of such characteristics as colour, composition and grain size.
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.
Moraine	any glacially formed accumulation of unconsolidated debris, in glaciated regions, such as during an ice age.
Outcrop	part of a geologic formation or structure that appears at the surface of the Earth.
Spring	the point where an underground stream reaches the surface.
Stratigraphy	the study of stratified (layered) sedimentary and volcanic rocks, especially their sequence in time and correlation between localities.
Till	unconsolidated, unsorted glacial deposits consisting of boulders and cobbles mixed with very finely ground-up rock as sand, silt or clay.
Volcanic Rock	any rock produced from volcanic material, e.g. ash, lava.

Section 2 - Site Reports

Site reports – general points

The following site reports are non-technical summaries of the proposed County Geological Sites for Galway City. These have been specially prepared for this report in order to make the information accessible to planners and readers without geological training. For most County Geological Sites more detailed information is held in the Geoheritage Programme at Geological Survey Ireland and are available for consultation. Further sites may become relevant as Geoheritage Programme work develops.

Each site report has primary location information, a summary of the main rock types and age, and a short description of the key aspects of scientific interest. A brief section outlining any particular management or other issues specific to the site is included, along with low-resolution photographs exemplifying the site. Additional photographs may be made available from the Geoheritage Programme should they be required for an information booklet or leaflet for the public. Site location grid references (Irish Transverse Mercator IRENET95) are given for a central point within the site boundary, as well as the townland in which the County Geological Site is located. Grid references are only indicative of the location, but the site extent is best shown on the included maps. Irish Transverse Mercator (ITM) is the geographic projection co-ordinate system currently used in Ireland (superseding Irish Grid TM65), and has been applied to all site localities in the site reports. Irish Transverse Mercator (ITM) is the standard co-ordinate system for OSI maps.

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. The boundaries are only indicative of the limits of exposure, or area of geological interest, and not based on detailed field and boundary surveys, which are outside the scope of this audit. Boundaries are drawn to include the geological or geomorphological interest of the site, and are generally extended to the nearest mappable boundary, such as a field boundary, path, road or edge of built-up area. On a few sites, such as along coastal sections, it is impractical to find an offshore boundary within a reasonable distance and an arbitrary line may be defined. County Geological Sites are non-statutory and so this should not prove problematic. If any sites are assessed for Natural Heritage Area (NHA) status in the future, boundaries may require small revisions.

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

In terms of any geological heritage site designation as NHA, due process of site reporting, boundary survey and very importantly, consultation with landowners where they can be readily identified, will take place before Geological Survey Ireland finalises recommendations with NPWS on the most important sites to be designated. Any landowner within areas or sites identified in

this report with concerns over any aspect of this project is encouraged to contact the Head of the Geoheritage Programme, in the Geological Survey of Ireland, Beggars Bush, Haddington Road, Dublin 4, D04 K7X4. Phone 01-6782837. Email: clare.glanville@gsi.ie