The Geological Heritage of Wicklow

An audit of County Geological Sites in Wicklow

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

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Report Summary

County Wicklow is widely known for its geological heritage, mainly in the context of iconic landscapes such as the Wicklow Mountains and glacial valleys such as Glendalough, yet it also has some very fine but underappreciated geological sites. The historic mining landscape at Avoca, for example, is rich part of the county's geological heritage, but is not always readily appreciated as such. The County Council’s support for this audit is critical in raising the profile of geological heritage in Wicklow. The geology of the county is not representative of all the time periods but the geological heritage interest extends widely throughout the county.

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

County Geological Sites do not receive statutory protection like Natural Heritage Areas (NHA) but receive an effective protection from their recognition in the planning system by inclusion in the CDP. Some of the sites described in this report are considered to be of national importance as best representative examples of particular geological formations or features. They have been provisionally notified to the National Parks and Wildlife Service (NPWS) by the GSI and recommended for designation as Natural Heritage Areas (NHAs) once due survey and consultation with landowners is complete. Many of the other sites fall within existing pNHAs and SACs where the ecological interest is actually founded upon the underlying geodiversity. The commission of this audit and inclusion of the geological sites within the CDP ensures that County Wicklow follows a now established and effective methodology for ensuring that geological heritage is not overlooked in the general absence of allocated resources for progress at national level. It ensures that Wicklow remains at the forefront of geological conservation in Ireland.

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This report is written in non-technical language (with a glossary for unavoidable geological terminology) as a working document for use by officials of Wicklow County Council. It will also be made available to the wider public via the local authority website and the Wicklow online community heritage archive. A chapter of the report includes recommendations on how to best present and promote the geological heritage of Wicklow to the people of the county. It will also inform the work of the IGH Programme and be made available through the GSI website.

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

Wicklow in the context of Irish Geological Heritage

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

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

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

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

IGH THEMES

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

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

Designation of geological NHAs will be by the GSI's partners in the Programme, the National Parks and Wildlife Service (NPWS). Once designated, any geological NHAs will be subject to normal statutory process within the Wicklow 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 the County Development Plan, along with any clear NHA selections.

Currently, in 2014, a Master List of candidate CGS and NHA sites is in use, having been established in GSI with the help of Expert Panels for all the 16 IGH themes. For several themes, the entire process has been largely completed and detailed site reports and boundary surveys have been done along with a Theme Report. Due to various factors, none have yet been formally designated. However, some sites in Wicklow were considered to be of national importance and have been put forward as Natural Heritage Areas (NHA) for those few themes. These include Bray Head, Slieveroe and Rocky Valley, below the Sugarloaf, all within the IGH2 Theme. No progress has yet been made with their designation as geological NHAs although Rocky Valley and Bray Head are already pNHAs for the ecological importance. Therefore, inclusion of all sites as County Geological Sites (CGS) in Wicklow's CDP will ensure that they are not inadvertently damaged or destroyed through lack of awareness of them outside of the IGH Programme in GSI.

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

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

Geological conservation issues and site management

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

Broadly speaking, there are two types of site identified by the IGH Programme. The first, and most common, includes small and discrete sites. These may be old quarries, natural exposures on hilly ground, coastal cliff sections, or other natural cuttings into the subsurface, such as stream sections. They typically have a feature or features of specific interest such as fossils or minerals or they are a representative section of a particular stratigraphical sequence of rocks. **The second type of site is a larger area of geomorphological interest, *i.e*. a landscape that incorporates features that illustrates the processes that formed it**. The Quaternary theme and the Karst theme often include such sites. In Wicklow, the glaciated terrain, riddled with channels cut by glacial meltwater, that dominates the county is characteristic of the larger sites encompassed under the IGH 7 Quaternary theme. Large areas of Wicklow's landscape could present a problem for definition of geoheritage as, although impressive, they can be too extensive to consider as 'sites'.

It is also important from a geological conservation perspective that planners understand the landscape importance of geomorphological features which may not in themselves warrant any formal site designation, but which are an integral part of the character of Wicklow. A lack of awareness in the past, has led to the loss of important geological sites and local character throughout the country. In Wicklow, if a full Landscape Characterisation Assessment was completed it would provide a tool for planners to help maintain the character of the County. The Strategic Environmental Assessment within the County Development Plan also provides tools. In addition, the now routine pattern of consultations with GSI, either by the planning department or by consultants carrying out Environmental Impact Assessment, plus strategic environmental assessment (SEA), has greatly improved the situation.

There are large differences in the management requirements for geological sites in comparison to biological sites. Geological features are typically quite robust and generally few restrictions are required in order to protect the scientific interest. In some cases, paradoxically, the geological interest may even be served better by a development exposing more rock. **The important thing is that the relevant planning department is aware of the sites and, more generally, that consultation can take place if some development is proposed for a site**. In this way, geologists may get the opportunity to learn more about a site or area by recording and sample collection of temporary exposures, or to influence the design so that access to exposures of rock is maintained for the future, or occasionally to prevent a completely inappropriate development through presentation of a strong scientific case.

In many counties, working quarries may have been listed because they are the best representative sections available of specific rock sequences, in areas where exposure is otherwise poor. No restriction is sought on the legitimate operation of these quarries.

However, maintenance of exposure after quarry closure is generally sought in agreement with the operator and planning authority in such a case. At present, working quarries like those at Blessington are now included as County Geological Sites in Wicklow. These issues are briefly explored in a set of Geological Heritage Guidelines for the Extractive Industry, published jointly by the GSI and the Irish Concrete Federation in 2008.

A new quarry may open up a window into the rocks below and reveal significant or particularly interesting features such as pockets of fossils or minerals, or perhaps a karstic depression or cave. Equally a quarry that has finished working may become more relevant as a geological heritage site at that stage in its life. It may need 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.

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

Waste dumping
An occasional problem throughout the country, including in County Wicklow, is the dumping of rubbish in the countryside. The dumping of waste is not only unsightly and messy, but when waste materials are dumped in areas where rock is exposed, such as in quarries, they may leach into the groundwater table as they degrade. This can cause groundwater pollution and can affect nearby drinking water supplies in wells or springs. Groundwater Protection Schemes (DELG 1999) help to combat pollution risks to groundwater by zoning the entire land surface within counties into different levels of groundwater vulnerability. Such a scheme was previously completed for Wicklow County Council by the GSI and was incorporated into a full national scheme in 2012, thus ranking the county land surface into vulnerability categories of 'Extreme', 'High', 'Moderate' and 'Low', and helping planners to assess which developments are suitable or not in some areas of Wicklow. Without any Carboniferous Limestone in the geology of the county, groundwater is less important as a public supply, but many shallow wells in glacial gravels are highly vulnerable to pollution.
http://spatial.dcenr.gov.ie/GeologicalSurvey/Groundwater/index.html

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

In the case of the N11 through the stretch between the Glen of the Downs and Ashford, there were new exposures created during road improvements in the last decade. However none of these were selected as sites because even in a few years they have become very degraded and vegetated. The combination of rock types and the angles of slope created in the cuttings mean that there is little chance of maintaining good accessible rock exposures without a regular routine of cleaning and vegetation removal. An alternative site at the new Wicklow Service Area has been selected which is similar to the N11 road cuttings but is much steeper and liable to retain faces for much longer.

Geoparks

An extremely interesting development in geological heritage, not just in Europe but internationally, has been the rapid recent growth and adoption of the Geopark concept. A **Geopark is a territory** with a well-defined management structure in place (such as Local Authority support), **where the geological heritage is of outstanding significance and is used to develop sustainable tourism opportunities**. Initially it was largely a European Geoparks Network (EGN) but since 2004 has expanded worldwide as the Global Geoparks Network (GGN) and is fully assisted by the United Nations Educational, Scientific and Cultural Organisation (UNESCO) [see www.globalgeopark.org and www.europeangeoparks.org]. A fundamental theoretical basis of the Geopark is that it is driven from the bottom up – the communities in the Geopark are the drivers of the project and are the main beneficiaries. The Geopark branding therefore helps promote the geological heritage resource so that the community can benefit from it.

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

At present, despite very interesting geological heritage in the county, it is not likely that any area would meet the criteria for a Geopark application, without extensive community development and the proactive support of Wicklow County Council. A 'Wicklow Mountains Geopark' is a conceivable approach, but would require major commitment to consider taking that path. With consensus partnership approaches like those of the Wicklow Uplands Council (and the adjoining Dublin Mountains Partnership) and the existing National Park structures, the Geopark approach might be a superfluous vision. However, the experience of the Burren and Cliffs of Moher Geopark, where there is a multiplicity of agencies, organisations and umbrella bodies, may provide valuable guidance as to the viability or otherwise of a Wicklow Mountains Geopark. If considered, it should extend to include the Dublin local authorities of South Dublin County and Dun Laoghaire-Rathdown, for geological contiguity. It should be noted that the County Development Plan (2010-2016) includes a policy of supporting the promotion of geological heritage in the county through a Rocktrail, Geopark or other geo-tourism initiatives (SG5 in Chapter 17).

Proposals and ideas for promotion of geological heritage in Wicklow

The clear and significant inclusion of geological heritage in the County Wicklow Heritage Plan 2009-2014 is a most welcome and positive step, for a topic that is often undervalued and poorly known in the wider community. This section examines the existing points in the plan 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.

Objectives

1. To raise awareness and promote appreciation and enjoyment of heritage by all.

2. To develop and encourage best practice in order to deliver practical actions to enhance the protection of heritage in County Wicklow.
Audit Action: The audit may contribute to this action, providing easily understood data in a GIS format and a comprehensible report that may be used in many ways.

3. To compile information on County Wicklow's heritage resource in order to better understand it and to ensure the effective use of heritage data in policy formulation and decision making in the county.
Audit Action: The audit may contribute to this action, providing easily understood data in a GIS format, with a comprehensible report which will make geological heritage more accessible.

4. To encourage partnership and active participation among all for the benefit of heritage in County Wicklow.

Actions

1. Raise awareness and promote appreciation and enjoyment of heritage in County Wicklow.
1.1 Enhance public awareness of heritage in County Wicklow through circulating a Heritage Office newsletter, holding public events and training courses, optimising heritage content of Wicklow Local Authorities website, and utilising local media.
Audit Action: The auditors may contribute to this action by providing news/summary reports for the newsletter or website.

1.3 Work in partnership with Wicklow County Tourism to produce and disseminate in various formats, promotional material on the heritage of County Wicklow and on specific sites to visit. Look at erecting plaques/interpretation panels at selected buildings/houses of heritage interest in the county where appropriate.
Audit Action: The audit may contribute to this action, by providing easily understood material for panels

1.4 Organise Heritage Open Days whereby selected buildings, normally not publicly accessible are opened to the public for a specified time.
Audit Action: The audit may contribute to this action, through suggestions or arrangement of open days for normally inaccessible stone yard, quarry or mine sites.

1.5 Support efforts to promote heritage related tourism, in particular 'ecotourism' and genealogical based tourism, World Heritage Site status for Glendalough, and initiatives to highlight the heritage significance of the county's "Garden of Ireland" tourism.

Audit Action: The audit may broadly contribute to this action, through provision of quality information on the geological foundation of these aspirations.

1.6 Work with the Library Service to make relevant heritage collections (e.g. historic postcards, photographs, travel journals etc) accessible to the public online, and at new facilities such as the upcoming extension of Greystones library.
Audit Action: The audit may contribute to this action, since historical imagery will be accumulated in the research on geological heritage sites and can be provided for use where copyright is not an issue.

1.9 Explore the possibilities for developing a "Virtual Wicklow" web based project to provide a single repository for heritage information in the county, thereby promoting greater heritage awareness and appreciation, and encouraging heritage based tourism.
Audit Action: It is suggested that the audit report would provide an important element of such a repository.

1.10 Investigate the development of a "Heritage Village" initiative scheme for County Wicklow. Use this scheme as a means to complement existing Architectural Conservation Areas (ACA's) in the county, acknowledge and reward local community efforts, and to increase local awareness, appreciation and tourist potential.
Audit Action: It is suggested that Ballyknockan is a prime candidate for special treatment as a Heritage Village for the stone industry.

1.11 Develop with relevant partner organisations, an annual themed school education project/competition in the area of heritage in County Wicklow.
Audit Action: It is suggested that the Geological Survey of Ireland could be a partner in promoting the rich geological heritage of County Wicklow.

1.12 Explore the feasibility of developing a 'folk park' visitor facility in the county to promote a greater appreciation and awareness of vernacular buildings and styles in County Wicklow.
Audit Action: It is suggested that if this action is achieved or developed the topic of granite quarrying will be a very significant component, and the audit will provide a start point for developing the theme.

1.14 Encourage the publication of all national road scheme excavations carried out in County Wicklow, and hold a public event to highlight the significance of these archaeological discoveries.
Audit Action: The geological heritage element of the new road cuttings should not be overlooked.

2. Develop and encourage best practice in order to deliver practical actions to enhance the protection of heritage.

2.1 Produce information on the placenames of County Wicklow, and develop advice and guidance on naming new developments to reflect local heritage and culture.
Audit Action: The importance of the physical landscape, Earth resources and geomorphological features in place names should not be overlooked in this action.

2.2 Support the employment, as resources permit, of heritage related expertise in Wicklow Local Authorities, namely an Architectural Conservation Officer, Biodiversity Officer and Field Monument Advisor.

Audit Action: The option of a County Geologist can also be considered, with the potential to advise on engineering, groundwater, heritage, quarrying, planning and many other issues.

2.3 Produce guidance for the public on the protection afforded to various aspects of heritage in County Wicklow, include in this, procedures to follow and relevant contact details regarding reporting suspected unauthorised works or damage to protected structures, archaeological features, trees or other aspects of heritage.
Audit Action: The County Geological Site listing has no statutory protection, and is primarily a planning tool, but can also provide for wider public participation in the promotion and protection of any sites, especially as public awareness increases. However it is important to note that there is still a responsibility to consult with GSI over any proposed development that may impact on a CGS.

2.4 Develop guidance, possibly a dedicated website to promote best practice for new buildings in the landscape – appropriate materials, siting, design, planting, etc.
Audit Action: The audit may contribute to this action, through raising awareness of the importance of stone as a building material, and how Earth resources available in different places have developed local character.

2.8 Support the identification of Architectural Conservation Areas (ACAs) in towns and villages of County Wicklow to protect their special character.
Audit Action: The audit may contribute to this action, through raising awareness of the importance of stone as a building material, and how Earth resources available in different places have developed local character.

3. Compile information on County Wicklow's heritage in order to better understand it.

3.1 Support the production of an index of historical sources for County Wicklow to support historical research efforts. Include in this index, local journals, research projects, publications and other archival sources and relevant contacts.
Audit Action: The audit may contribute to this action, through research on geological heritage sites which can be provided to the Heritage Officer for inclusion in any index.

3.3 Carry out an audit of heritage sites in County Wicklow for tourism potential. The audit should look at issues such as site vulnerability, environmental sensitivities, car parking, visitor access, interpretation, links to public transport, and an assessment of the overall capacity of the site to operate as a tourist attraction.
Audit Action: The audit provides significant data on the geological heritage sites that could offer tourism potential.

3.5 Carry out an audit and interpretation of significance, of local heritage collections in County Wicklow, and national collections containing material of Wicklow interest. Seek and support the development of suitable facilities in the county for the public display of this material.
Audit Action: The audit may contribute to this action, through provision of data on geological collections, known to the authors, compiled in the course of the audit.

3.9 Carry out an audit of geological heritage sites in County Wicklow in partnership with the GSI.
Audit Action: The audit fully achieves this action.

3.11 Carry out a survey of the coastline and intertidal zone in County Wicklow to identify cultural heritage features, habitats, and recreational amenities sensitive to the effects of climate change (such as increased storms, erosion and rising sea levels). Use this information to plan and prioritise actions in relation the protection of heritage and recreational amenity resources.
Audit Action: It is suggested that the proposed survey should not overlook geological heritage issues on coastal sites, and the importance of the role of geology in a dynamic environment that can be quickly affected by measures such as protection of property or construction of marinas, harbours and other facilities.

4. Encourage partnership and active participation.

4.3 Support existing and new initiatives to enhance physical and intellectual access to, and interpretation of, heritage in County Wicklow, with an emphasis on the development of sustainable trails and walking routes as a means of achieving this.
Audit Action: The audit report includes site-specific suggestions where trails and walking routes are seen as positive options.

4.8 Work in partnership with local groups in the county to pursue suitable opportunities for developing visitor and interpretation potential of County Wicklow's Mining Heritage.
Audit Action: The audit report provides objective data on the mining heritage of County Wicklow, to underpin the efforts of the local groups and the Mining Heritage Trust of Ireland.

4.14 Support a "Ballyknockan Granite Park" initiative and seek to develop this proposed pilot project along with relevant partners, in order to promote and increase appreciation of the local stone cutting tradition.
Audit Action: It is suggested that the Geological Survey of Ireland could be a partner in promoting the rich stone cutting heritage of County Wicklow, and the Mining Heritage Trust of Ireland also.

The County Development Plan (2010-2016) also has important objectives regarding geological heritage integrated into the Section 17.6 Soils and Geology, but deals with wider issues relating to geology also.

Some of the topics or themes that recur in Wicklow's geological heritage are briefly discussed in the following sections before looking at specific ideas for raising awareness of them.

Geological heritage themes: Mining in Wicklow

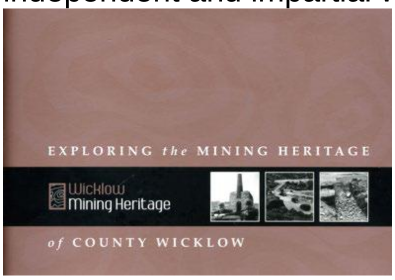
Wicklow has probably the most extensive range of mining heritage in the whole country. From early iron mining adjacent to Croghan Kinsella and at Ballard, to the Wicklow Gold Rush of 1798 in the Goldmines River, through to the relatively recent cessation of copper mining at Avoca, the geology has provided society with a wide range of minerals extracted from the ground.

The main interest in mining heritage in Wicklow lies in the 19th century working of vein deposits of lead ores in the margins of the Leinster Granite. Three main localities are found in the valleys of Glendasan, Glendalough and Glenmalure. These each had many mine workings, both shafts and adits driven into the hill, until at one time a traverse could be made from Glendasan to Glendalough through many levels underground in the mountain. Connecting the two sets of workings also allowed drainage to the lower side in Glendalough without the need for as much pumping out of water, using water wheels. The shortlived mine at Ballycorus in Dublin had a leadworks built, and the mining Company of Ireland who operated most of the 19th century lead mines kept it supplied with ore from their Wicklow mines.

At Glendalough, a phase of mining in the 1950s was the last occasion, and some ex-miners still live in the area and are working to promote their local mining heritage through the Glens of Lead Project. See www.glensoflead.com

The Avoca Mines on either side of the Avoca River have a long history over many centuries, probably including Bronze Age working. However the latest phases of mining usually destroy evidence of earlier phases, and large opencast pits at Avoca are clear proof of that. Avoca copper mines had several phases with the last one only ending in the early 1980s. The later mining of this volcanic massive sulphide deposit was primarily whole rock extraction to process large volumes of low percentage ore. Big open pits resulted at East Avoca, Cronebane and at West Avoca. The engine houses of 19th century steam power remain dotted amongst them.

As with many former mining areas, today's environmental standards are much stricter than in the past and efforts are being made to 'clean up' the site and stabilise problems of acid mine drainage in the Avoca River and other environmental concerns. Whilst this raises some conflicts of interest between different views on the site and its value to the area, the authors have aimed to report on the geological and mining heritage of the sites in as independent and impartial way as possible, to aid assessments of works and their impacts.



A recommended introduction to the mining heritage of County Wicklow has been published as an action of the County Wicklow Heritage Plan. It is available in print and as a downloadable pdf. http://www.heritagecouncil.ie/landscape/publications/article/exploring-the-mining-heritage-of-county-wicklow/?L=uxwpqerospk&tx_ttnews%5BbackPid%5D=1159

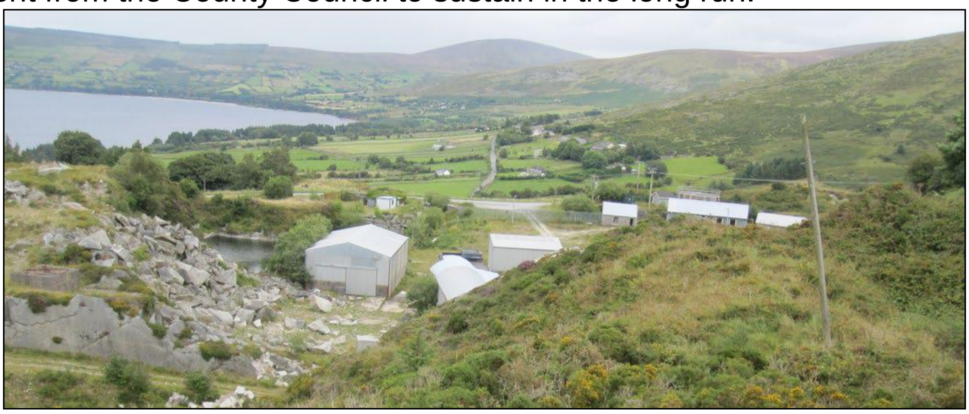
Geological heritage themes: Stone Cutting Traditions

Wicklow granite has been used as a building stone of choice for many centuries, especially in Dublin City, but also in innumerable buildings local to the outcrop of the rock. Whilst the Wicklow Granite outcrops over a very large area, it is actually composed of many different granite bodies that were intruded into the country, or host, rocks, and into itself in different phases. Consequently there are subtle differences in the mineralogy and especially in the crystal grain size (reflecting the rate of cooling of the bodies). These can be mapped geologically, but early stone cutters probably found by experience which bodies were best. This knowledge, combined with accessibility for transport and the practical choice of avoiding high mountainous areas with harsh weather, has meant that stone cutting has focused itself in certain areas.

In his book on the granite industry, Michael Conry has made it clear than a large part of the early working of stone involved simply cutting the large glacial erratic boulders which were prolific in many places. This had the advantage of clearing fields of the boulders and providing walling stone from the offcuts. However the constraints of transport, low altitude and rock quality meant that Golden Hill, near Manor Kilbride north of Blessington, was the early centre of cutting granite for buildings in Dublin.

Ó Maítiu and O'Reilly's (1997) history of stone quarrying at Ballyknockan, a village on the east side of the modern reservoir of Blessington Lake, records the shift of activity to around 1824, perhaps aided by the one landlord, the Cobbe family, owning both areas. From then on, quarrying developed strongly with several different families working different sections. There are a few subsidiary quarries but today, what appears to be only one large quarry in the centre of the southern part of Ballyknockan is actually comprised of many separate sections worked by and named after different families of stonecutters.

At its height some 200 men were employed in stonecutting and the rock was used to build very many of Dublin's finest buildings such as the railway stations, Glasnevin Cemetery Chapel, gateway and mortuary, St. Paul's on Arran Quay, the RDS entrance and many more. It was also used in buildings across Ireland such as Kylemore Castle, and even exported to Liverpool, France and for the Cathedral of St. John's in Newfoundland. The pride of the stonecutters in their work extended to their homes too, and the whole village of Ballyknockan is replete with quirky details of interest in the stonework of homes and even on barns and sheds, fenceposts, walls and pathways. There is considerable local pride and enthusiasm for promoting the stonecutting heritage of Ballyknockan, which probably needs a commitment from the County Council to sustain in the long run.



The view from above Creedon's Quarry over the main area.

Geological heritage themes: The Ice Age

The Ice Age, and glaciations, in County Wicklow

When it is considered that the Earth is 4.6 billion years old it is obvious that the Irish landscape has undergone huge changes within that time. The geological processes which have operated on the Irish landscape over these billions of years are extremely varied and complex, hence the records of these processes that are left in the surface form of the landscape and their underlying rocks are extremely complicated and fragmentary and difficult to decipher. To understand the landscape in its current form we must realise that various large scale, global events have been more important than others, and though geological processes (*e.g.* the action of rivers and the sea, peat formation) are still operating today in Ireland these have only a minor effect on the overall landscape. The last mega-geological event to have affected the Irish landscape is the last **ice age**, or **glaciation**. This occurred between 73,000 and 10,000 years ago and had a huge effect on our landscape and geology, being the final shaping action over the majority of our countryside.

Why did we have an ice age?

Since the beginning of the Earth's History the surface temperatures of the Earth have undergone huge variations, varying from intensely hot conditions to intense cold. These alternating hot and cold periods lasted for hundreds of millions of years. For example, we know that at the time of the dinosaurs the Earth's surface temperatures were high and the Earth's climate as a whole was essentially a tropical one. At present, and for the last 50 million years or so, we have been in a time when the temperatures are quite cold as a whole, therefore we are in a kind of global ice age. 50 million years ago Western European climate was sub-tropical. Temperatures have cooled gradually since then and about 2 million years ago the configuration of ice at the poles was pretty much as it is today. Within the last two million years the extent of ice at the poles has fluctuated greatly, extending at some times into the mid latitudes and beyond. It was during these time periods that ice engulfed Ireland bringing with it ice age effects and processes to this country.

Why does the ice at the poles 'grow' and engulf Ireland every now and then?

There are three factors which contribute to the development of glacial conditions in Ireland every few thousand years. These are all related to the Earth's position and geometry as an orbiting planet in the Solar System.

The **first factor** is known as the '**eccentricity**' effect. As the Earth orbits the sun, its orbit is not perfectly circular but resembles that of an ellipse, or stretched out circle. This means that over a cycle of 100,000 years the orbit brings the Earth further away from the sun when the elliptical orbit is at its most 'eccentric'. Being further away from the sun at these times obviously means we don't get as much heat from the sun. This has huge effects on Earth surface temperatures as a whole.

The **second attribute** is known as the '**tilt**' effect. The Earth's axis is tilted and the northern hemisphere leans towards the sun in June and away from it in December. The angle of tilt is not stable either meaning the Earth 'leans' towards the sun more at some times than it does on others. This means that if the tilt angle is higher the temperature range may be greater. Approximately every 41,000 years, the tilt is closest to vertical. Sunlight then strikes the poles at a sharper angle, and seasonal variations in temperature are reduced.

The **third factor** is the '**wobble**' effect. The Earth's axis wobbles like a spinning top, wobbling along a circular path every 23,000 years. This means that in the case of the northern hemisphere its summer occurs either when the Earth is furthest from the sun on its elliptical orbit, or when it is closest.

These three cycles combined means that the Earth goes through predictable sequences of temperature variations which, when combined and leading to a reduced global temperature, mean that snow and ice do not melt in the mid-to-high latitudes causing glacial conditions. The greatest and longest lasting ice ages occur when all three cycles coincide.

How does the ice collect and flow?

When snow falls it collects on the landscape but in today's climate it usually melts in a matter of hours. Not so during glacial conditions in Ireland. Every few thousand years conditions cause the Earth's temperature to fall as a whole which means that snow may not melt in all localities: if snow begins to accumulate it forms a compact, icy substance called **firn** or **neve**. This can further compact as accumulation increases and when this material attains a depth of 50m or so it begins to flow as blue glacier ice. This ice flows similar to the manner wet concrete flows. As the ice flows over its substrate small pieces of rock and soil over which it flows become stuck to the base by freezing on and are therefore 'plucked' from their resting place and incorporated into the base of the glacier. This makes the base of the glacier more grating and it can further erode the underlying material, just as coarse sandpaper will on wood. Therefore by **'plucking'** and **'abrasion'** processes the glacier ice continues to erode everything it passes over, smoothing and polishing underlying rock and picking up material in its basal layers.

In this way rock and soil debris get incorporated into the glacier and can be carried far from their source. Rock material carried in this way is known as erratic material and the individual rocks are known as **erratics**. The erratics may be small pebbles or sand grains forming soil or subsoil or may be large cobbles or boulders strewn across the landscape. Many erratic are seen throughout Wicklow, including the large granite blocks scattered haphazardly along valleys like Glendalough and Glenmacnass, and the limestones within the gravels in the Blessington District.

What was the geometry of the last ice sheet in Ireland?

During the last glaciation ice covered the entire country. The ice was moving all the time in the manner outlined above, and was up to 900m thick in places. Obviously, the erosive power of an ice sheet nearly one kilometre deep on the underlying landscape was phenomenal. Only our highest mountains peaks stuck up above the ice as **nunataks** so everything under this level was scoured, planed, smoothed or bulldozed, and in most cases then covered by the massive amount of debris that was left by the ice after it retreated. In Wicklow, only Luggala, Mullaghcleevaun, Lugnaquilla, Camenabologue and Tonelegee poked up above the ice.

The Irish ice sheet was not one great mass of ice but contained a number of independent domes and small ice caps which coalesced to form one overall ice sheet. These domes had ice which radiated out from their centres and moulded the countryside under them. As the ice domes started to melt they retreated in on themselves and huge amounts of glacial meltwater was released. Wicklow had its own ice dome, covering most of the mountains and merging with ice from the lowlands around it, within a huge ice mass across the Leinster landscape.

The centres themselves moulded the landscape in such a way that we can reconstruct their geometry by looking at certain ice flow indicators in the landscape.

Ice flow indicator 1: Striae.

Striae are scratches into bedrock which are formed by small pieces of rock or soil protruding from the base of the ice scratching the rock underneath them and leaving a groove mimicking ice flow. They are usually found on smooth outcrop surfaces where the rock has been polished by the abrasive ice. They are remarkably consistent features and many striae may be seen side by side on one small outcrop. They are also found on bedrock under subsoil and if you dig a hole deep enough to hit bedrock not only may the striae be seen, but the very rocks at the base of the subsoil which caused them as this subsoil was emplaced by the glacier all those thousands of year ago!!

Striae are very common in East Wicklow, on the fine-grained shales and greywackes, but are rarely found on the granites of the central mountain area, as the granites are too coarse to hold the etchings.

Ice flow indicator 2: Roche moutonnees.

Roche moutonnees are asymmetric bedrock bumps or hills with polished up-ice faces and jagged down-ice faces. The polished face is a result of ice abrasion on a bedrock obstruction at the base of the ice and the jagged face a result of plucking. They occur at a variety of scales and may be less than 1m to several hundred metres across. Many bedrock outcrops in Ireland look polished and on close inspection it is seen that they have jagged faces too, therefore with some detective work we can infer ice flow direction by simply examining bedrock outcrop at most localities. Roche moutonnees are common on the granite of Wicklow, as outcrops often have polished, smooth surfaces moulded by the ice. They are well expressed particularly along the sides of glacial valleys such as Glenmalure and Glendasan.

At the glacial maximum most of Wicklow was covered by ice, and in the early stages of glaciation preceding this, local mountain ice probably covered most of the county. As the large ice sheet covering the country (which was composed of domes with sources in the Irish Midlands and the Irish Sea Basin) expanded, the local mountain ice became confined to the central mountain area. The mountain ice merged with the general ice and flowed with it towards the south.

More detail on how the ice sheets melted at the end of glaciations is given in the overview report on ‘Glacial Meltwater Landforms in East and West Wicklow’ within the Site Reports.

Geological heritage themes: Wicklow's Gold Rush 1795

A painting by Thomas Sautell Roberts (c. 1760-1826) of searching for gold in Wicklow. Image by permission of the National Library of Ireland.

The Gold Mines River, flowing off Croghan Kinshelagh to join the Aughrim River, near Woodenbridge, was the site of a remarkable piece of Irish history, when there was a gold rush here from 1795. Forestry work in the river banks provided a gold nugget. There followed a rush of 'peasants' to the area and then to some adjacent rivers, to search for gold in the river bed and banks. Centred on the head of the valley at Ballinagore Bridge, it would seem that frantic digging activity transformed the area, with thousands of people either working or spectating or trading on the needs of so many others.

The thing that made this gold rush so distinctive was the prospect of finding a large nugget that could make a person's fortune in one go. The reputed largest nugget was of 22 oz and was given to King George III in 1796. It is rumoured that he had it made into a snuff box, but there is no certainty about this or many other gold stories originating in the Gold Mines River gold rush.

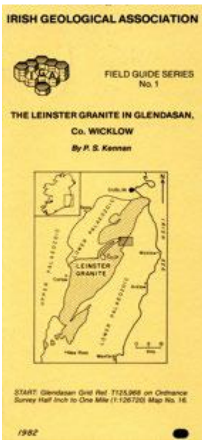
The original few weeks of gold rush were quickly brought under official control with bureaucratic controls backed up by a militia force. Government working of the area yielded more gold intermittently with pauses during rebellion, with a much more structured approach and the geologist Thomas Weaver overseeing operations. Geological and commercial studies ever since have tried to find a possible bedrock source for the alluvial gold, but it seems likely that the Ice Age gathered up residual gold from the weathering of an iron deposit on the Ballycoog-Moneyteige ridge and redeposited it in the Gold Mines River valley.

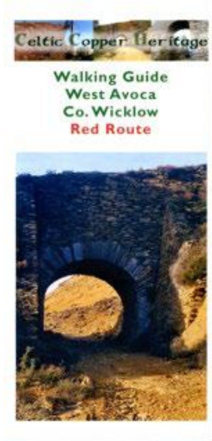
A book 'Gold Frenzy' by Peadar McArdle, former Director of the Geological Survey of Ireland, published by Science Spin tells all the stories in this remarkable lost history.

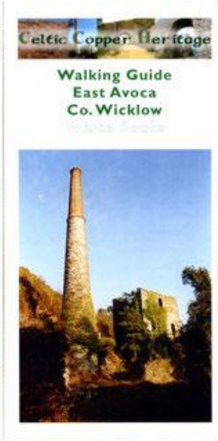
Specific Ideas for Raising Public Awareness of Geological Heritage in Wicklow

Leaflets

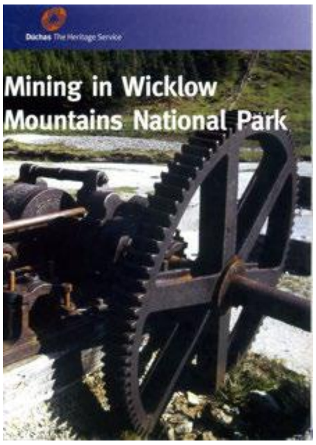
A few existing leaflets are known. The NPWS have an excellent simple leaflet on the mining heritage of Glendalough. Two walking trail leaflets have been produced for mining areas at Avoca, under an INTERREG project. The GSI produced the Wicklow Way walking guide set, but which is now out of print. The Irish Geological Association have older leaflets on areas of Wicklow and Dublin.







There is plenty of scope for other and different leaflets. For example, an NPWS leaflet on the topography, geology and minerals of the Wicklow Mountains National Park would be useful. Any leaflets produced could simply be made available as pdf downloads on the Council's website to avoid large costs of printing.



Guides

There are few existing guides to the geology of County Wicklow, apart from some GSI literature produced some time ago. The 1:100,000 map report for Sheet 16 covers Wicklow and is an essential resource. For general interest, *Wicklow in the Ice Age* is a useful resource. Although out of print, it is available digitally from the GSI. A more modern, excellent guide, *Wicklow in the grip of an ice age* is available from the Irish Quaternary Association. An excellent practical field guide to Leinster's Geology by Chris Stillman and George Sevastopulo is still in print through Dunedin Academic Press.

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

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

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

It is believed that there will soon be some explanatory signs installed at both Glendasan and Glendalough through co-operation between the National Parks and Wildlife Service (NPWS) and the Glens of Lead Project, representing the local mining heritage community. Both sites are in areas that require some simple explanation for visitors, who currently are left no wiser in passing the ruins and spoil heaps.

Museum exhibitions
As a result of the work to produce this report, the material for a panel based exhibition has been largely compiled. With some extra research covering human dependence on geology and resources, an interesting exhibition can be put together for display in the Wicklow County Council Offices, County Library branches or other venues. The model followed was that used for Carlow, Dun Laoghaire-Rathdown and Waterford. Images of those and other similar ones can be seen on the Geological Heritage/Exhibitions section of the GSI website http://www.gsi.ie/Programmes/Heritage+and+Planning/Public+Outreach+and+Education/

New media
There are increasing numbers of examples of new methods of promoting Earth Sciences, via mobile phone applications and other electronic media. Self-guiding apps on specific sites would be one of these, such as those produced by Ingenious Ireland for Dublin city geology and the recently launched app for tourists in the Burren and Cliffs of Moher Geopark. Plans for such products would require some considerable effort to produce and imagination to link sites across the county in coherent ways.

Earth Science Ireland Group and magazine [www.earthscienceireland.org]
The group Earth Science Ireland is an all-Ireland group promoting awareness of Earth sciences and supporting educational provision in the subject. A main vehicle for the efforts is the twice a year magazine *Earth Science Ireland* and this is distributed free to thousands

of individuals, schools, museums, centres and organisations. The editors would welcome more material from the Republic of Ireland and on Wicklow's geological heritage. It is anticipated by the authors of this report that they will contribute a summary article distilled from the audit report.

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

Geological Heritage Research Archive
If the Heritage Officer wanted to do something similar to that produced in the Burren and Cliffs of Moher Geopark, with downloadable (or links to) free access papers, then a lot of groundwork is already provided by the reference lists in this audit. Making available technical references of direct relevance to Wicklow geology and geomorphology will assist many users and researchers into the future.

Maps
A series of popular maps of the Wicklow Mountains produced by East West Mapping at a scale of 1:30,000 have been very innovative in taking the geological heritage site data from GSI and including it on the maps. This has been as point data. The completion of the audit will allow future editions of these maps to have more accurate data, with rejected sites removed, new sites added and area definitions if desired. It is hopefully a data layer that might also be adopted by the Ordnance Survey of Ireland in their future map editions of the 1:50,000 Discovery Series, for all counties where an audit has been completed. Similarly a Dublin Mountains Partnership map of the Dublin-Wicklow hills could also be improved in future editions by adding geological heritage site data.

A summary of the Geology of Wicklow

AGE (Million Years Ago)	*ERA*	*PERIOD*	*EVENTS IN WICKLOW*	*IF THIS TIMESCALE WERE A DAY LONG ...*
2.6	Cenozoic	Quaternary	Several ice ages smothering Wicklow, followed in the last 10,000 years by the spread of vegetation, growth of bogs and arrival of humans. Sculpting of corries and U-shaped valleys in the Wicklow mountains. Meltwater sculpts deep channels and deposits sands and gravels during deglaciation.	The ice ages would begin 38 seconds before midnight
66		*Tertiary*	*Erosion, weathering of rocks and denudation of land surface.* *No record of rocks of this age in Wicklow.*	The Tertiary period begins at 11.40 pm
145	Mezozoic	*Cretaceous*	*Erosion.* *No record of rocks of this age in Wicklow.*	11.15 pm
201		*Jurassic*	*Uplift and erosion.* *No record of rocks of this age in Wicklow.*	The age of the dinosaurs, starting at 10.55 pm
252		*Triassic*	*Desert conditions on land.* *No record of rocks of this age in Wicklow.*	10.42 pm
298	Palaeozoic	*Permian*		10.30 pm
359		*Carboniferous*	*Land became submerged, limestones with some shales and sandstones deposited in tropical seas across much of Ireland.* *No record of rocks of this age in Wicklow.*	Inundation of land by sea around 10.10 pm
419		Devonian	Caledonian mountain building. Leinster Batholith Granite intruded, forming Wicklow Mountains.	Granite intruded into Wicklow, at 9.52 pm
443		Silurian	Shallow seas, following closure of the Iapetus Ocean. Slates, greywacke and shales deposited along eastern extreme of Wicklow.	Starts at 9.42 pm
485		Ordovician	Slates, siltstones and volcanic rocks form across much of southern and eastern Wicklow, as well as portions along the Glen of Imaal.	Begins at 9.28 pm
541		Cambrian	Opening of the Iapetus Ocean. Greywackes and quartzites formed between Bray Head and Roundwood.	Starts at 9.11 pm
2500	Proterozoic	*Precambrian*	*Some of Irelands oldest rocks deposited in Mayo and Sligo.*	Beginning 11.00 am
4000	Archaean		*Oldest known rocks on Earth.*	Beginning 3.00 am
4600			*Age of the Earth.*	Beginning 1 second after midnight

The Geological Timescale and County Wicklow

Simple summary

The bedrock geology of Wicklow can be broadly subdivided into five units. The most distinctive unit in the county is the **Leinster Granite**, a large granite batholith intruded around 405 million years ago into a succession of Lower Palaeozoic sedimentary and volcanic rocks. The granite underlies much of the Wicklow Mountains. The oldest rocks in Wicklow, of Cambrian age, 541 to 485 million years old (Ma), comprise the **Bray Group**, a thick sequence of greywackes and quartzites that crop out between Bray Head and Ashford. The quartzites are hard rocks, resistant to weathering, and form prominent hills including the Great Sugarloaf and Little Sugarloaf. Ordovician (443—485 Ma) slates, mudstones and siltstones form the succeeding **Ribband Group**, so-called because of the distinctive colour-banded or striped appearance of many of these fine-grained lithologies. The Ribband Group underlies much of the eastern part of the county but also crops out in west and northwest Wicklow. The **Duncannon Group** comprises a northeast—southwest-trending belt of volcanic rocks in east Wicklow, 2—4 km wide and 15 km long, centred on Avoca. The Silurian (419—443 Ma) **Kilcullen Group**, a sequence of greywackes, siltstones and shales, crops out only in west Wicklow, between Brittas and Baltinglass.

These Lower Palaeozoic sedimentary rocks of Wicklow were deposited on the seafloor of the ancient Iapetus Ocean. The Iapetus, a deep ocean, lay between two continents, one to the north comprising rocks that today underlie Scotland, north America and the north of Ireland, the other, to the south, incorporating the rest of Ireland, England, Wales and Europe. The Iapetus Ocean filled with clastic sediments derived from the weathering of the continental landmass that lay to the northwest and southeast. The Bray Group rocks are proximal turbidites, deposited close to the margin of the ocean. The finer-grained Ribband Group rocks were deposited as muds and silts in the deeper part of the ocean. The Iapetus Ocean began to close during the Ordovician as a consequence of plate tectonic movements that led to subduction of the ocean floor beneath the continents. This led in turn to the development of volcanic arcs along the continental margins and within the ocean. Volcanic rocks that comprise most of the Duncannon Group around Avoca are the remnants in Wicklow of these volcanic arcs. The youngest sediments in the county, the Kilcullen Group, are also turbidites, deposited on the margin of the closing ocean.

As the ocean gradually closed between the Ordovician and the end of the Silurian, the opposing continents eventually collided, leading to the Caledonian orogeny, an event that had a profound effect on the geology of Ireland. The orogeny was an extended period of mountain building that involved intrusion of granite into the continental crust as well as widespread, intense deformation and metamorphism of the existing Lower Palaeozoic rocks. In Wicklow, the Leinster Granite, the largest granite batholith in Ireland or Britain, is the most obvious product of this orogenic event. Deformation gave rise to compression of the Lower Palaeozoic sedimentary and volcanic rocks, evident today in the intense cleavage present in most of these rocks and in the small- and large-scale folding visible throughout the county.

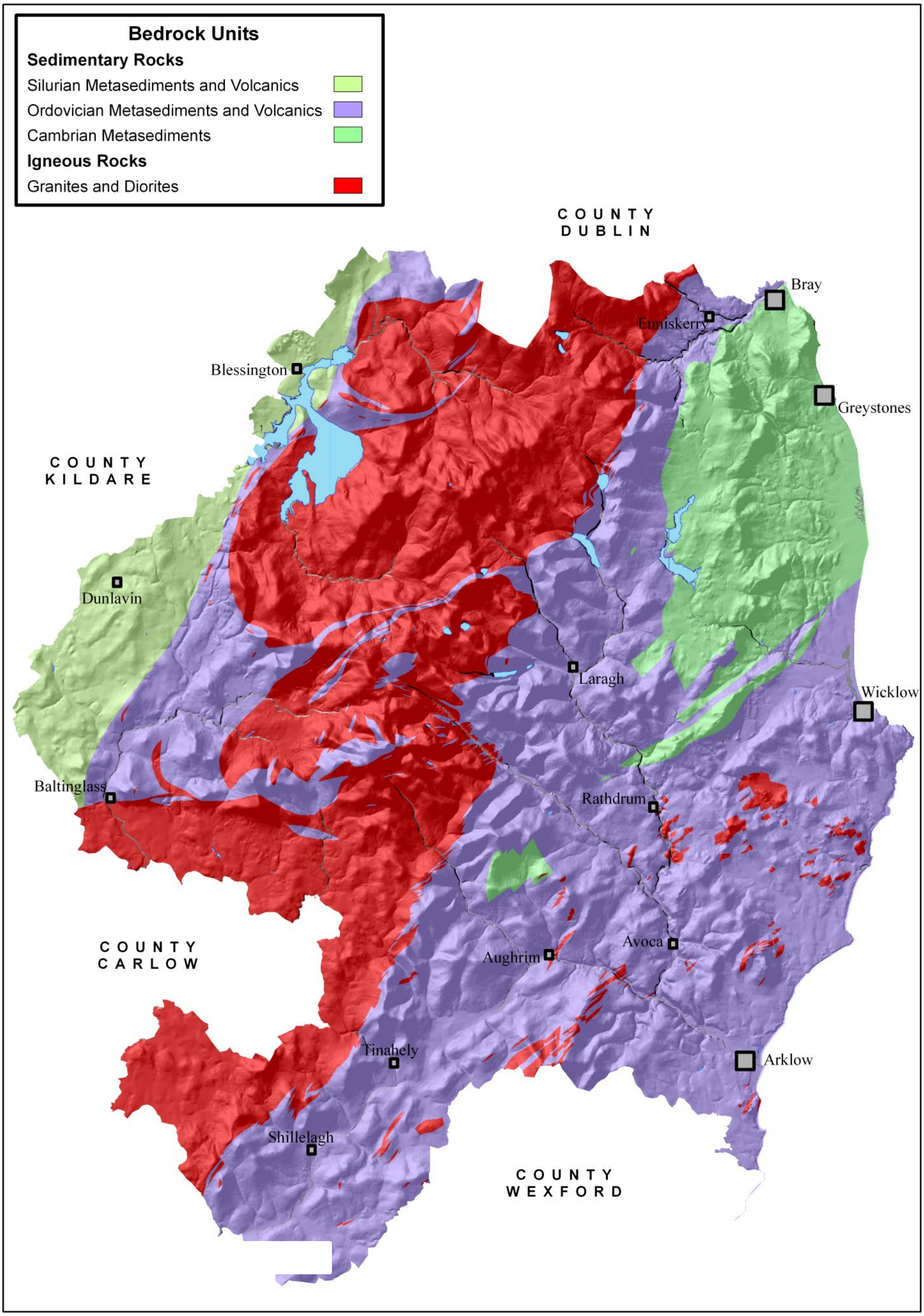
Apart from the Leinster Granite, Wicklow is notable for the variety and abundance of its igneous intrusions. These include a suite of minor granites intruded contemporaneously with and along the margin of the Leinster Granite. There is also a suite of diorites (410 Ma), centred on Carrigmore east of Rathdrum. Some ultrabasic rocks called appinites are intruded into the Lower Palaeozoic rocks around the margin of the Leinster Granite. In addition significant thicknesses of intermediate (50-70% SiO_2) volcanic rocks called andesite, are notable in west Wicklow around Slieve Donard and Dowery Hill, produced by volcanism contemporaneous with Leinster Granite intrusion. There also dolerites, intruded as dykes or large sills into the Lower Palaeozoic succession, e.g. Arklow Rock; and the Croghan Kinshelagh granite (454 Ma), an Ordovician granite intruded at the end of the Avoca volcanic belt with which it shares a similar chemistry and likely origin.

The 400 million year period following the Caledonian orogeny (Carboniferous through to the Tertiary) is not represented in the bedrock of Wicklow due to erosion.

The Pleistocene Period or Ice Age began 2 million years ago and several cold periods interspersed with warm periods saw glaciers form in the Wicklow Mountains and sculpt out superb features like Glendalough, Glenmalure and Glenmacnass, as well as corries like Lough Ouler and Lough Bray. The rock they ground down was deposited as till in thick blankets over much lower ground on the flanks of the mountains.

The ice sheet which covered Wicklow had a complex flow pattern which radiated out from the centre of the mountains in general. Only the highest peaks stuck up above the ice, such as Mullaghcleevaun and Lugnaquilla, since the ice was about 1km thick.

Since the Ice Age, during the Holocene, the modern drainage pattern was superimposed on the deglacial channel network, meaning there are some areas of haphazard drainage among the boulder clay and these are best developed along the Kings River. At this time peat also formed across much of the Wicklow Mountains. During this time along the coast, headlands, bays and cliffs, have been eroded by the sea, while beaches, bars, spits, lagoons and windblown sand dunes have formed.



A simplified geology map of Wicklow outlining the main geological units.

Geological heritage versus geological hazards

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

The difference between human timescales and geological timescales can be difficult to comprehend but, for many geological processes, there are periods of sudden activity encompassing major events, and then quiet periods in between. The sites in this audit represent evidence of past geological environments and processes, such as the building of high mountain chains, deep intrusion of massive granite bodies, volcanic eruption, glacier erosion of the land surface and so on. However, a few sites represent the active geomorphological or land-forming processes of today. These sites are generally coastal in or riverine in Wicklow. They are dynamic environments and can be subject to constant or intermittent, sometimes sudden, change.

Landslides and bog flows
The Geological Survey of Ireland has been compiling national data on landslides in the past decade. There are some 429 for Wicklow.
http://spatial.dcenr.gov.ie/GeologicalSurvey/LandslidesViewer/index.html

Flooding
There are two types of flooding which need consideration.

River flooding occurs inland when the rainfall exceeds the capacity of the ground to absorb moisture, and the river channels cannot adequately discharge it to the sea. The OPW website, www.floods.ie, can be consulted for details of individual flood events in County Wicklow. Some 117 events are recorded across the entire county. Some of these are recurring events in urban settings where rainfall exceeds the capacity of the local drains. Karstic flooding can occur when underground passages are unable to absorb high rainfall events. There is no Carboniferous limestone bedrock in County Wicklow, and hence there is no karstification, and none of these type of flood occurrences.

Groundwater pollution
Whilst not such an obvious hazard as physical collapses, flooding and landslides, the pollution of groundwater supplies carries a serious risk to human health. Large groundwater supplies require Source Protection Plans, which are delineated for them by the GSI and the EPA.

Sea level rise, coastal erosion and sedimentation
Geological heritage sites in coastal areas may be particularly vulnerable to wave erosion. The joint hazards of gradual sea level rise and high waves caused by increasing storminess need to be considered in any promotion of coastal geological heritage sites and in future planning. It should be remembered that coasts are dynamic geological environments, with changes to be expected in both erosion and deposition as normal features. Certainly, small changes to coastal situations, like building cliff defences for railway tracks or groynes for

sedimentation traps can have very rapid effects, with impacts further along a coast when such changes are made.

Radon

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

Glossary of geological terms

Geological term	Definition
Actinolite	a common rock forming silicate mineral in metamorphic rocks, asbestos is a fibrous form of the mineral
Adit	a horizontal or only gently inclined mine tunnel dug to access coal or mineral ore, or to drain, ventilate or further develop a mine.
Alluvial Deposit	unconsolidated clay, silt, sand and gravel, deposited by a body of running water.
Alluvial Fan	a fan-shaped deposit formed where a fast flowing river levels out and slows, typically from the mountain foot onto the plain.
Alluvium	a term for unconsolidated clay, silt, sand and gravel, deposited by a body of running water.
Aplite	a fine to medium-grained igneous rock found as veins within coarser-grained plutonic igneous rocks.
Appinite	plutonic igneous rock formed from hydrous magma of mantle origin, dioritic in composition, i.e. rich in hornblende, also containing plagioclase feldspar and/or alkali feldspar, with or without quartz; typically associated with breccia pipes in Donegal
Batholith	large igneous intrusion (100 km^2 or more)
Beach	a landform along the coast of an ocean, sea, lake, or river which consists of loose particles, often composed of rock, such as sand, gravel, shingle, pebbles, or cobbles.
Bedrock	a general term for the rock, usually solid, that underlies soil or other unconsolidated, superficial material.
Blanket Bogs	bog covering a large, fairly horizontal area, which depends on high rainfall or high humidity, rather than local water sources for its supply of moisture.
Bluff	a steep cliff or escarpment
Borehole	a narrow shaft bored in the ground, usually vertically, which is used for the extraction of water, gas or hydrocarbon.
Boulder Clay	unconsolidated, unsorted glacial deposits consisting of boulders and cobbles mixed with very finely ground-up rock or silt. Also known as till.
Braided River	a river that consists of a network of small channels separated by small and often temporary islands called braid bars.
Calcareous	containing significant calcium carbonate.
Caledonian	relates to Caledonian orogeny that took place towards the end of the Lower Palaeozoic era, affecting Ireland, Scotland, Scandinavia and Greenland
Carbonate	a rock (or mineral), most commonly limestone (calcite) and dolomite.
Cave	a natural underground space large enough for a human to enter, which is usually formed in either soluble limestone by karstic processes, or in exposed rock along the coastline, where the sea erodes natural rock fractures
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.
Clast	an individual constituent, grain or fragment of a sediment or rock, usually produced by mechanical weathering (disintegration) of a larger rock mass.
Cleavage	a flat plane of breakage caused by compressive deformation of rocks. e.g. the splitting of slate.
Corrie	a horseshoe-shaped, steep-walled valley formed by glacial erosion.
Crag and tail	a steep resistant rock mass (crag), with sloping softer sediments (tail) protected from glacial erosion or deposited as glacial debris on the crag's 'downstream' side.
Cross-bedding	layering in sedimentary rocks at an inclined angle to bedding formed by current-ripples.
Crust	the outermost, solid, layer of the Earth.

Delta	a low, nearly flat alluvial tract of land at or near the mouth of a river, commonly forming a fan or triangular shaped plain of considerable area, which is crossed by many smaller channels of the main river. Glacial deltas are formed by meltwater in a similar fashion, at the edge of glacial lakes.
Dimension stone	stone that is quarried and cut to specific shapes and sizes
Dip/dipping	when sedimentary strata are not horizontal they are dipping in a direction and the angle between horizontal and the inclined plane is measured as the dip of the strata or beds
Diorite	a grey to dark-grey intrusive igneous rock composed principally of plagioclase
Dune	a mound or ridge of drifted sand, occurring along the sea coast or in deserts.
Dyke	a sub-vertical sheet-like igneous intrusion, typically in-filling a fracture in the earth's crust
Erratic	a rock fragment carried far from its source area by glacial ice.
Erratic	a large rock fragment that has been transported, usually by ice, and deposited some distance from its source. It therefore generally differs from the underlying bedrock, the name "erratic" referring to the errant location of such boulders. Tracing their source can yield important information about glacial movements.
Esker	an elongated ridge of stratified sand and gravel which was deposited in a subglacial channel by meltwaters. Eskers are frequently several kilometres in length.
Extrusive	an igneous body emplaced (erupted) at the Earth's surface as lava.
Fan	a usually triangular deposit of sand and gravel deposited by a glacial stream, either under a lake or under air.
Fault	planar fracture in rocks across which there has been some displacement or movement
Fault Zone	a tabular volume containing many faults and fault rocks (rocks broken up by fault movement).
Floodplain	a flat or nearly flat land area adjacent to a stream or river that experiences occasional or periodic flooding.
Fluvial	pertaining to a river or stream.
Fold(ing)	flexure in layered rocks caused by compression.
Formation	a formal term for a sequence of related rock types differing significantly from adjacent sequences
Fossiliferous	rich in fossils.
Fossils	any remains, trace or imprint of a plant or animal that has been preserved in the Earth's crust since some past geological or prehistorical time.
Glacial	of or relating to the presence and activities of ice or glaciers.
Glacial striae	markings left on the surface of pebbles / boulders / bedrock by moving ice sheets.
Glaciofluvial	pertaining to the meltwater streams flowing from wasting glacier ice and especially to the deposits and landforms produced by such streams.
Glaciomarine	sediment, which originated in glaciated land areas and has been transported to the oceans by glaciers or icebergs.
Grading	a sorting effect with the coarsest material at the base of the bed and finest grained material at the top.
Granite	a coarsely crystalline intrusive igneous rock composed mostly of quartz and feldspar.
Graptolite	extinct colonial pelagic organism, particularly important in dating Ordovician and Silurian rocks.
Greywacke	dark grey, poorly sorted sandstone with more than 15% clay content.
Greywacke	an impure sandstone, characterised by poorly-sorted, angular grains in a muddy matrix, that was deposited rapidly by turbidity currents (submarine avalanches).
Grike	a solutionally widened vertical fracture separating clints on a limestone pavement.
Grus	crumbled granite sand formed by weathering
Gully	a deep valley created by running water eroding sharply into bedrock or subsoil
Haematite (Hematite)	a mineral form of iron oxide, which is the main ore mined as iron

Hornblende	hydrous (OH-bearing) silicate mineral containing Ca, Fe and Mg as major components
Hornfels/hornfelsed	contact metamorphosed rock, i.e. baked by heat of an igneous intrusion; hard and sometimes splintery, depending on original rock type
Hummock	a small hill or knoll in the landscape, which may be formed by many different processes.
Ice margin	the edge of an ice sheet or glacier
Igneous	a rock or mineral that solidified from molten or partially molten material i.e. from a magma.
Interglacial	the time interval between glacial stages, or pertaining to this time
Irish Sea Till	clay-rich till found along the eastern seaboard of Ireland, and occurring as much as 12km inland, which was deposited by an ice stream which occupied the Irish Sea Basin during the last glaciation.
Laminated	extremely fine stratification or bedding, typically exhibited by shales and fine-grained sandstones.
Lamprophyre	uncommon, basic or ultrabasic potassium-rich igneous rocks occurring typically as dykes and small intrusions
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.
Lodgement	process by which debris is released from the sliding base of a moving glacier/ice sheet and plastered or 'lodged' onto the glacier bed; also describes tills emplaced by this process (i.e. lodgement till).
Magma	molten rock, which cools to form igneous rocks.
Meander	a bend in a sinuous watercourse or river which forms when moving water in a stream erodes the outer banks and widens its valley, and the inner part of the river has less energy and deposits fine sediment.
Melt-out	process by which glacial debris is very slowly released from ice that is not sliding or deforming internally; also describes tills emplaced by this process (i.e. melt-out till).
Meltwater	water from melted snow or ice.
Meltwater channel	a channel cut by glacial meltwater, either under, along or in front of an ice margin.
Metamorphic	referring to the process of metamorphism or to the resulting metamorphic rock, transformed by heat and pressure from an originally igneous or sedimentary rock.
Metamorphic aureole	zone of country rock, in contact with an igneous intrusion, which has undergone metamorphism due to the heat of the intruding magma.
Metasediments	metamorphosed sediments.
Micaceous	rich in mica (shiny, flaky silicate minerals).
Microgranite	Medium-grained granite in which crystals are somewhat smaller than those typical of granite, indicating more rapid cooling of the magma
Misfit stream	a stream which is too small to have eroded the valley in which it flows, as is often the case with streams now flowing in meltwater channels.
Moraine	any glacially formed accumulation of unconsolidated debris, in glaciated regions, such as during an ice age.
Nunatak	an exposed, often rocky element of a ridge, mountain, or peak not covered with ice or snow poking up above an ice sheet or glacier.
Olivine	a green, magnesium iron silicate mineral, commonly found in mafic and ultramafic rocks from the Mantle or deep crust of the Earth
Ore	a mineral which is concentrated enough to be exploited by mining
Orogeny	the creation of a mountain belt as a result of tectonic activity.
Outcrop	part of a geologic formation or structure that appears at the surface of the Earth.
Outlier	area of younger bedrock completely surrounded by older bedrock
Oxbow lake	a U-shaped body of water that forms when a wide meander from the main stem of a river is cut off, creating a free-standing body of water

Peat hag	solitary banks of peat standing proud of surrounding areas of eroded and removed peat
Pegmatite	a very coarse-grained igneous rock of granitic composition.
Peridotite	dominant igneous rock type of the Earth's Mantle, composed of olivine and pyroxene
Periglacial	very cold but non-glacial climatic conditions
Phyllite	a foliated pelite.
Pingo	a landform formed when ground ice which developed during the freezing winter months as temperatures fall, following glaciation, was raised up as a circular mound of earth.
Plagioclase	a very common rock forming silicate mineral in many igneous and metamorphic rocks
Plate Tectonics	a theory that states that the crust is divided up into a number of plates, whose pattern of horizontal movement is controlled by the interaction of these plates at their boundaries with one another.
Plutonic	originating at great depth.
Pseudomorph	a mineral that replaces another but retains the form (morphology) of the original
Pyroxene	a group of minerals, of common rock forming occurrence in igneous and metamorphic rock types, especially mafic and ultramafic types
Quartz	the second most abundant mineral in the earth's crust, composed of silicon and oxygen (SiO_2).
Quartzite	a hard, metamorphosed sandstone, composed mostly of recrystallised quartz grains that are tightly interlocking. Quartzite is formed through heat and pressure usually related to tectonic compression.
Raft	large body of country rock entrained in an igneous body, such as a granite, during intrusion of the igneous rock, now visible as an isolated body separated from its original surroundings
Ravine	a steep-sided, deep gorge
Raised Bogs	an area of acid, peaty soil, in which the centre is relatively higher than the margins.
Regression	a recession of the sea from a land area.
Ribbon lake	a long, narrow and deep, lake occupying the floor of a U-shaped glacial valley
Sandstone	a fine to coarse sedimentary rock, deposited by water or wind, and composed of fragments of sand (quartz grains), cemented together by quartz or other minerals.
Sandur	a plain formed of glacial sediments deposited by meltwater outwash at the terminus of a glacier
Schist	a metamorphic rock exhibiting a foliation defined by the preferred alignment of tabular minerals.
Schistosity	planar alignment of platy minerals in metamorphic rocks in response to pressure, giving rise to a strong planar fabric throughout the rock
Scree	loose debris or talus deposits comprising angular stones and boulders
Semipelite	metamorphosed siltstone
Shaft	a vertical or inclined hole dug in a mine for access, ventilation, for hauling ore out or for pumping water out.
Shale	A fine-grained sedimentary rock, formed by the compaction and lithification of clay, silt, or mud. It has a finely laminated (composed of layers) structure that gives it a fissility, or tendency to split along bedding planes.
Shelf	part of the continental rising that is between the shoreline and the continental slope.
Siltstone	is similar to mudstone but with a predominance of silt sized (slightly coarser) particles.
Slate	is a fine-grained metamorphic rock produced from a sedimentary mudstone by pressure, imposing a cleavage along which the slate easily splits.
Spinel	non-silicate mineral consisting typically of various elements, including Mg, Fe, Mn, Cr, etc., in combination with Al and O; the spinel series includes magnetite and chromite
Spring	the point where an underground stream reaches the surface.

Stratiform	occurring as a bed or beds, arranged in strata
Stromatolites	an algal deposit usually found in shallow water.
Subduction	the sinking of one crustal plate beneath the edge of another through the process of plate tectonics.
Talc	Mg-rich platy or sheet-like mineral (phyllosilicate), with the lowest hardness (1) on the standard Mohs scale (1-10) of hardness.
Terrace	terraces are remnants of the former floodplain of a stream of river, formed by the downcutting of a river or stream channel into and the abandonment and lateral erosion of its former floodplain
Terrigenous	something derived from the land or continent.
Till	unconsolidated, unsorted glacial deposits consisting of boulders and cobbles mixed with very finely ground-up rock as sand, silt or clay.
Tor	a large, free-standing rock outcrop that rises abruptly from the surrounding smooth and gentle slopes of a rounded hill summit or ridge crest
Trilobites	extinct arthropods.
U-shaped valley	also known as a glacial trough, this is formed by the process of glaciation and has a characteristic *U* shape, with steep, straight sides and a flat bottom. Glaciated valleys are formed when a glacier travels across and down a slope, carving the valley by the action of scouring.
Vein quartz	white thin veins of quartz injected in rock fractures during episodes of stress. Also found as durable beach pebbles, once it has been eroded.
Volcanic Rock	any rock produced from volcanic material, e.g. ash, lava.
Waterfall	a place where water flows over a vertical drop in the course of a stream or river

Data sources on the geology of County Wicklow

This section is a brief summary of relevant GSI datasets, to assist any enquiry concerning geology and to target possible information easily. The GSI has very many datasets, accumulated since it began mapping Ireland's geology in 1845. A Document Management System (DMS) is freely available to any person at the GSI Customer Centre, into which about half a million documents and maps have been scanned. This means that any user can visit the GSI Customer Centre themselves and search on screen for data of relevance to them. High quality colour and black and white print-outs can be made or data supplied on CD, or via USB keys etc. **Data is available free of charge**. It is planned to make this resource available online within the next few years, although many subsets are already available within existing online data sets.

Key datasets include:

1:100,000 Map Report Series
All historical, modern and other mapping has been compiled into very useful maps and reports that describe the geology of the entire country. Sheets 16 and 19 cover Wicklow.

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

19th century one inch maps and Memoirs
Information from the detailed 19th century mapping was distilled into one inch to the mile maps, of which parts of Sheets 120, 121, 129, 130, 138, 139 and 148 cover County Wicklow. Each sheet or several sheets were accompanied by a Memoir which described the geology of that area in some detail. These still provide valuable records of observations even though interpretations may have changed with better geological understanding. Memoirs are in the Customer Centre library and scanned on the DMS.

Historical geological mapping is now available via a website:
http://www.geologicalmaps.net/irishhistmaps/history.cfm

Open File Data
Each Mineral Prospecting Licence issued by the Exploration and Mining Division (EMD), currently of the Department of Communications, Energy and Natural Resources, carries an obligation on the exploration company to lodge records of the work undertaken, for the common good. These records are held by the Geological Survey and are available as Open File Data, once a period of time has expired. They may include geological interpretations, borehole logs, geophysical and geochemical surveys and so on. Licences relate to numbered prospecting areas, and these are available on a map from EMD. See also www.mineralsireland.ie

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

Historic Mine Records
Abandonment plans and varied other material exists for the various mining ventures in the county, including those 19th century lead mines in the Glendalough, Glendasan and

Glenmalure valleys as well as the more modern phases of copper mining at Avoca. Some lesser mining enterprises such as Cloghleagh have very little in the official GSI record.

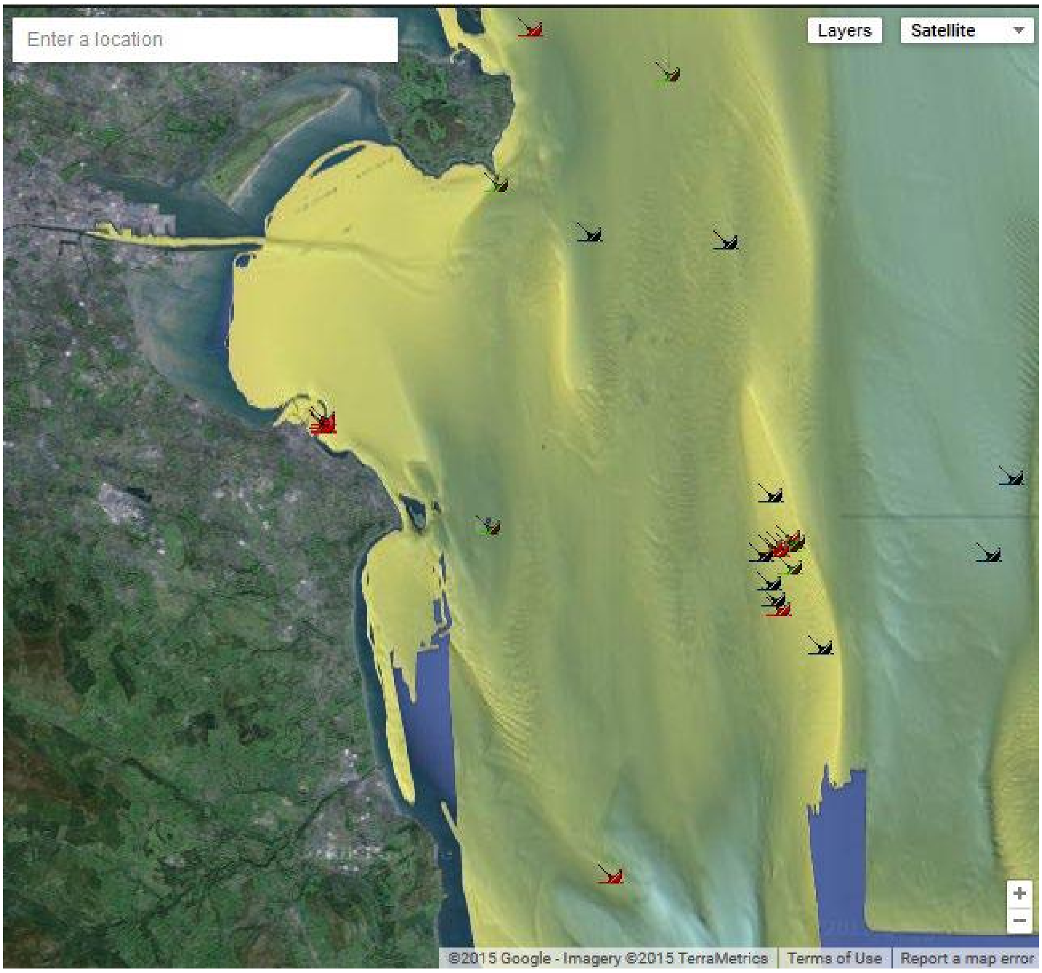
Subsoils Mapping

Since a Groundwater Protection Scheme has been completed by GSI (2012) for the entire country, a modern map of the subsoil types and depths across Wicklow exists, as well as the previously completed bedrock mapping. This provides a significant resource in general terms as well as for groundwater protection. Customised output is possible. Furthermore, detailed compilation of glacial geology datasets will provide more data from late 2014 onwards.

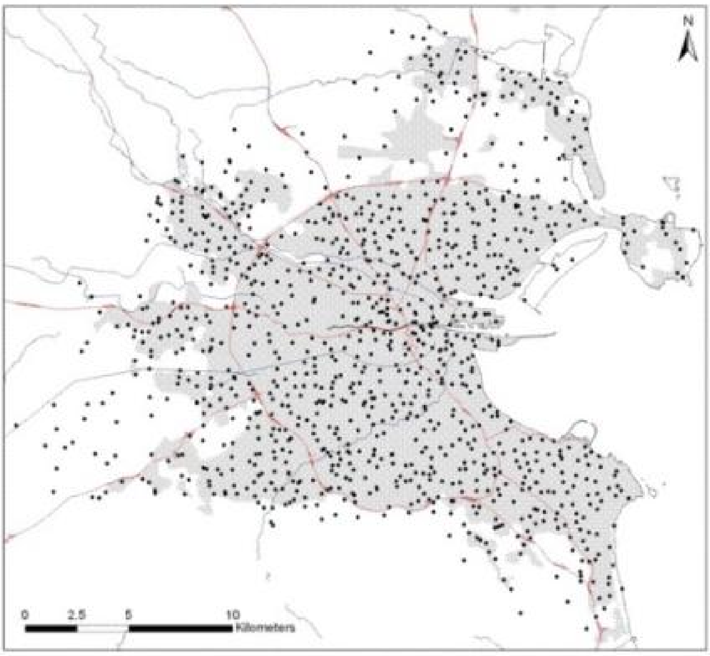
Digital mapping of many different datasets is now available via an easy to use public viewer on the GSI website: www.gsi.ie

Infomar data

The Infomar Programme in the GSI is mapping the seabed in targeted areas of the inshore coast of Ireland. The graphic below shows offshore in Dublin Bay, with some of the many wrecks identified by the survey. Infomar data is freely available for analysis and further processing from the Infomar data via the GSI website.
http://www.gsi.ie/Programmes/INFOMAR+Marine+Survey/
See also www.informar.ie



Dublin SURGE Project (Soil Urban Geochemistry)
GSI has carried out a chemical survey of the topsoil around Dublin city and county in 2012. It involved taking and analysing samples of soil from areas that are publicly accessible (e.g. public parks and school grounds). The aim of the survey was to acquire important information about Dublin soils that will help to better manage the environment.
See https://www.gsi.ie/Surge.htm



Shortlist of Key Geological References

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

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Full Geological references

See Appendix 2 for the full reference list of all papers, books, articles and some unpublished reports etc relating to the geology and geomorphology of Wicklow that could be traced.

Mining heritage references

Appendix 2 includes some references specifically pertaining to the mining heritage of County Wicklow. Assistance with locating these references may be provided by the Mining Heritage Trust of Ireland if required.

Quaternary References

The references in Appendix 3 all cover the Quaternary, or Ice Age, geology of Wicklow. They are split into references specifically covering sites or features in Wicklow, and a section of national or regional papers which have some data from or on Wicklow included.

Further sources of information and contacts

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

Web sites of interest

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

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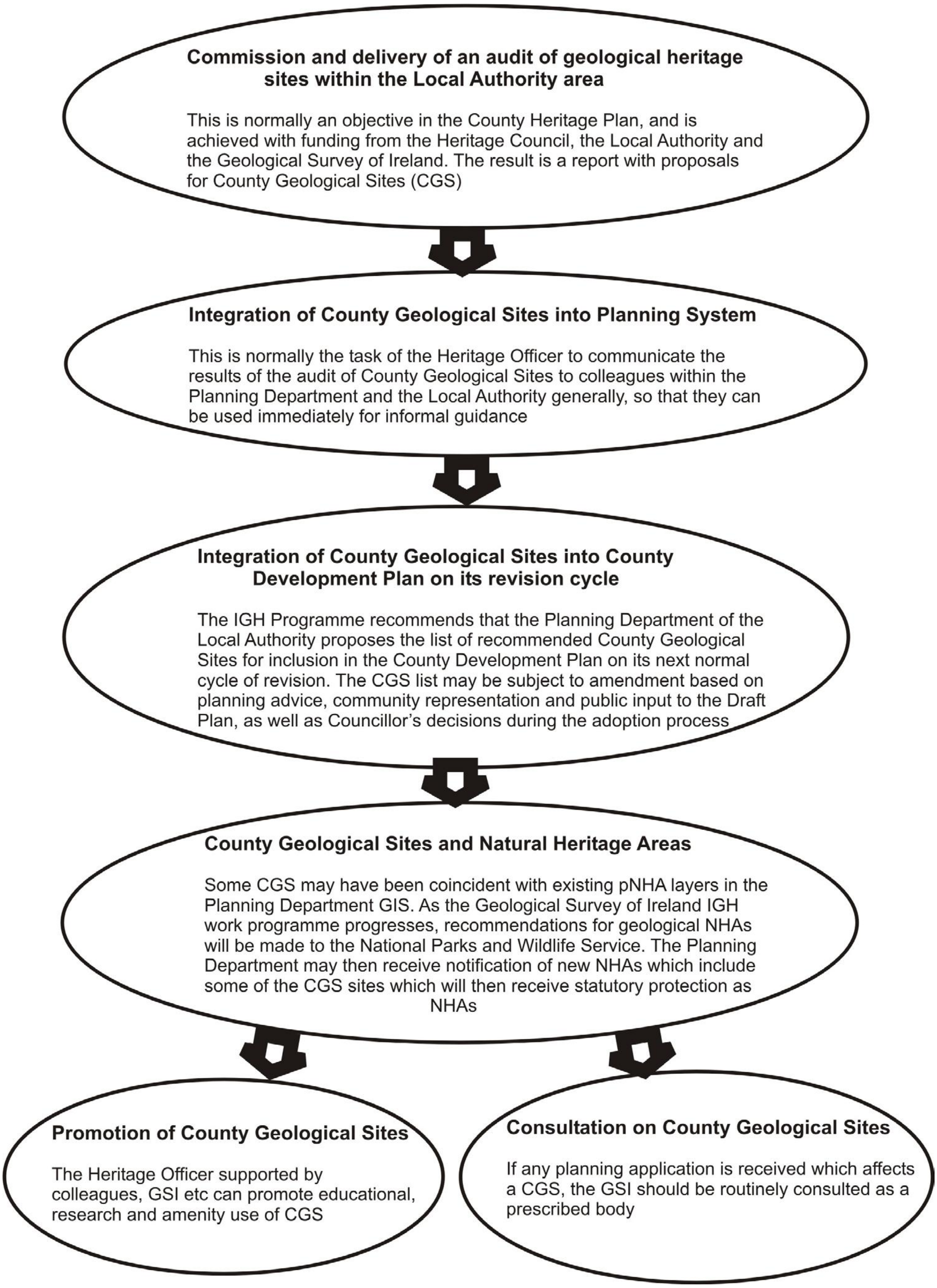
Appendix 1 – Geological heritage audits and the planning process

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

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

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

County Geological Sites - a step by step guide



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Appendix 3 - Bibliography – County Wicklow Quaternary References

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Appendix 4 – Rejected sites

A range of sites had been previously flagged for consideration in the IGH Master site list, and some were assessed as unsuitable for County Geological Site status in this audit. Similarly a range of additional sites were assessed in the audit, based on the authors' expert knowledge of County Wicklow's geology and mining heritage, and especially in the main mountain area. It was known, for example, that some quarry localities had not been adequately considered in the preparation of the IGH Master site list. Other sites were visited on spec during fieldwork. The rejected sites are listed below with brief notes as to why they were assessed as unsuitable for inclusion.

Rathdangan End Moraine

The Rathdangan End Moraine site was listed in the An Forás Forbartha report 'Areas of Scientific Interest in County Wicklow' in 1976, as being an important moraine site. A broad 'moraine' zone covering a wide area was indicated on the map, but no moraine can been seen on the ground in this area and, though some gravel pits cut into small fan features do exist at nearby Kiltegan, these were not deemed worthy of County Geological Site status.

The locality of the 'Rathdangan End Moraine', which is just rolling countryside with no discernable, impressive glacial features.

Table Mountain

Table Mountain was included in the IGH Master site list for 'peat hag' features. However, peat hags are common all over the blanket peatlands of Wicklow and are transient features; where occurring in other sites they have been mentioned but no site or area is deemed worthy of inclusion as a County Geological Site on the basis of having peat hags alone. On this premise, Table Mountain was rejected as a site.

River Slaney, Baltinglass

The River Slaney at Baltinglass was included as it was described as ‘gorge-like’. However, in the field the river at Baltinglass comprises a wide floodplain with relatively gentle backslopes on the bounding hills; from this there is no gorge feature at the locality. The river in the area has no notable features and from this, it is not included as a County Geological Site.

The River Slaney just north of Baltinglass, where no gorge exists.

Church Mountain

Located roughly between Hollywood and Donard, (ITM GR 694800 701290) Church Mountain is on the western margin of the Wicklow Mountains. At 544m, the summit affords wonderful views of the Kildare lowlands to the west and the Wicklow Mountains plateau to the east. A granite mountain on the very western fringe of the Leinster Granite, the lower western and southwestern slopes of Church Mountain comprise Ordovician schist, slate and volcanics. The IGH Master Site List records Church Mountain as a *Fluvial and Lacustrine Geomorphology (IGH14)* theme site for chemical weathering, rotted granite, screes and mass wasting. Whilst rotted granite and granitic quartz sands are exposed where peat has been eroded on the mountain, these features are not of significant merit to be recognised as a County Geological Site. Most of the granite summits in the Wicklow Mountains exhibit varying degrees of rotted granite, and as such Church Mountain is not specifically unique. The summit hosts a circular cairn of granite stones, which has been described as the remains of a passage tomb, and the centre of the cairn is hollowed out in which the remains of a church and a well have been reported.


Left: View north from Church Mountain towards Pollaphuca Reservoir.
Right: Granite rocks and sand on path to Church Mountain summit and cairn.

Cummer

Cummer is in County Wexford, immediately east of the county boundary with Wicklow. A serpentinite body with minor chromite minerlization occurs here and was drilled by GSI in the 1980s and again in 2013. Early GSI maps suggested an outcrop further west, in County Wicklow, based on the distribution of boulders. However, serpentinite has not been confirmed to occur there. The bedrock occurrence at Cummer in Wexford is the only confirmed occurrence of this rock in the region. Hence, Cummer is rejected as a Wicklow CGS but may well in future be designated a CGS for Wexford.

Baltinglass

Baltinglass is listed in the expert panel list as a site where tourmaline occurs with garnet schist. This is presumably a reference to the hypothesis that held that tourmaline-rich rocks (tourmalinites) found in the Lower Palaeozoic rocks on either side of the Leinster Granite were formed from hydrothermal fluid in a submarine-exhalative environment and could thus be linked to mineralization both in in the Lower Palaeozoic rocks themselves and in the Leinster Granite and other igneous bodies. Tourmalinites were seen as companion rocks to coticules, also linked to submarine exhalative environments. However, there is no consensus as to the significance of tourmaline in the context of the origin of particular mineral deposits in southeast Ireland. The exact location of the Baltinglass site is unknown and efforts to establish it for this audit failed. For this reason and because the significance of this particular occurrence of tourmaline has not been defined, this site is rejected as a CGS.

Crone Forest

Crone Forest is another tourmaline site where the mineral has been reported to occur associated with pegmatites at the margin of the Leinster Granite. There is no information about the nature of the tourmaline that is the basis for the suggestion to designate this site a CGS. A site visit failed to identify tourmaline in any of the numerous pegmatites observed, although this may be partly owing to the thick vegetation (ferns) that obscured much of the site during the audit. Nevertheless, the lack of detailed information about the site and the significance that is attached to tourmaline at this location (e.g. whether it is simply a good example of tourmaline as a mineral or whether it is linked to theories regarding mineralisation, etc.) do not allow any judgement to be made regarding its importance and this site is therefore rejected as a CGS.

Kilmacoo

Kilmacoo is the site of sub-economic gold mineralization, hosted by the Avoca Formation. The site is immediately adjacent the northeastern end of Avoca mine site (Connary). The gold is contained within sulphide-rich volcanic rocks similar to those that host the base metal mineralization at Avoca. The deposit has been defined entirely by drilling and appears to have no surface expression, i.e. there is no site as such. Those interested in the mineralisation must rely on examination of drill core. For this reason Kilmacoo is rejected as a CGS.

Derrywater and Derry River, Tinahely
The Derry River rises to the northwest of Tinahely, proximal to the Carlow-Wicklow border and flows southeast from a stream confluence to Tinahely, before turning south, and then southwest through Shillelagh before entering the River Slaney at Killdavin. The Derrywater rises to the northeast of Tinahely, and flows northeastward joining the Ow River near Aughrim, and then proceeding as the Aughrim River, joins the Avoca River near Woodenbridge. The IGH Master Site List records Derrywater and Derry River as a *Fluvial and Lacustrine Geomorphology (IGH14)* theme site for palaeo-channels that predate the fluvial captures and diversions. The palaeo-channels are not especially apparent at ground level and are best appreciated on aerial photography. Whilst the macro-features are of interest in fluvial geomorphology, they are not deemed of significant interest as a County Geological Site or in terms of public promotion or tourism.

Left: Derry River - looking upstream, N, from Railway Walk bridge at Tinahely
Right: Derry Water – view downstream, NE, from bridge at Drummin, NE of Tinahely

Ballybrew Quarries
This site was a large centre of stone quarrying for granite for many decades. It was most latterly run by Stone Developments who had their base there and did much work processing other rock types from around the world, when the extraction of Irish granite could not be cost effective compared to Chinese and others. However, today there is very little of interest at the site and not enough to merit CGS status. Almost no exposure of the Leinster Granite is available as the main quarry workings have either been backfiilled with demolition and other quarry waste rock, or are flooded and inaccessible. The buildings and sheds have all been demolished for safety reasons and only concrete footprints remain.

Ballybrew concrete footprint

Ballybrew main quarry, now flooded.

Callow Hill Upper
According to the paper by Oppenheim that originally described the occurrence of the chromium mineral eskolalite, the till in which the mineral coated pebbles occurred was subsequently removed, so there is no site to examine.

Lacken
This site was listed under IGH 14 for chemical weathering of granite. No site was located in the area displaying any rotted granite, and it is supposed that when originally suggested for the IGH list there was a transient exposure available in connection with a development. The site is therefore rejected. In any case, such chemical weathering of the granite is encompassed in other sites.

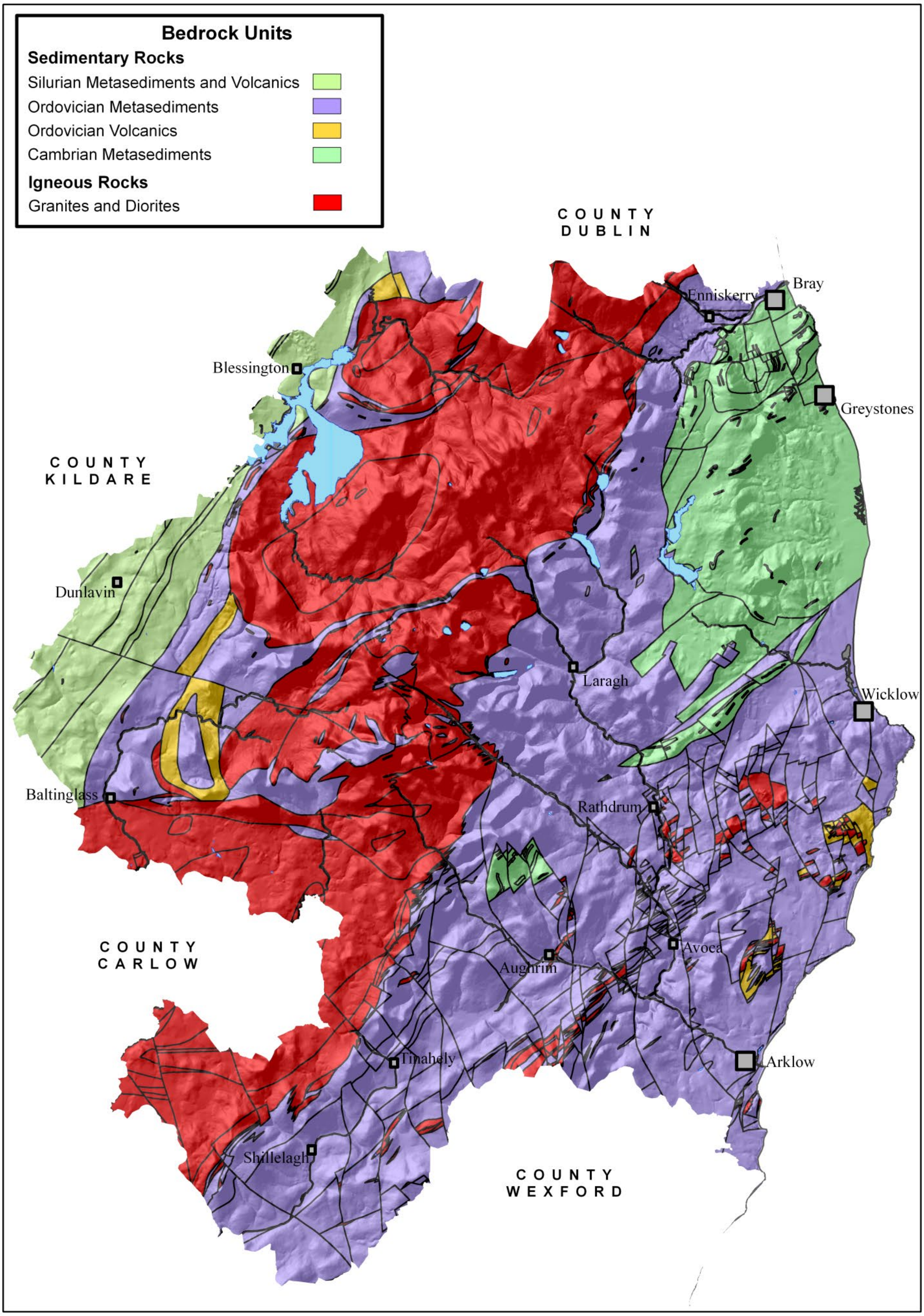
Lugduff
This site was originally listed for pseudokarstic pipes in peat deposits. Our investigations and consultation with expert panel members involved in the original proposal of them has determined that there is no meaningful site where they exist that could be assessed. They are very transitory features that are of some research interest across the Wicklow and other uplands, but no physical site is defined for this.

Wicklow Gap
This site when originally proposed was described as a small roadside quarry with granite pillars developing towards tors. Field investigation indicated that this site no longer exists and may have been affected by road works or lost through slumping and vegetation.

Ballycoog
Ballycoog is listed for “magnetite-siderite deposits in Avoca Volcanic Formation” and is described as the best example of this type of mineralization. The mineralization is minor and there are few remains either of the workings or of mineralization. A similar situation is found southwest along the ridge at Moneyteige, in a clearing in the forest, where no clear trace exists of the shafts that were sunk on the iron mineralization. The mineralization at these localities includes stratiform concentrations of magnetite that can be described as “banded iron formation” but, while of interest as mineral localities, the sites do not contain sufficient of interest to define a CGS here.

Ballard
Although there was a significant iron mine at Ballard south west of Wicklow Town, there is very little now visible of the workings. There are some areas of depressions and disturbed ground in two woodland areas that probably result from mining, and an adit stream outlet is present beside the road, but overall there is insufficient interest to define any site here. It is largely a mine that is defined by historical maps and reports rather than by physical evidence on the ground, despite relatively modern reports of open adits.

Appendix 5



A detailed geological map of County Wicklow

Appendix 6 - Geoschol leaflet on the geology of County Wicklow

WICKLOW

AREA OF COUNTY: 2,024 square kilometres or 781 square miles

COUNTY TOWN: Wicklow

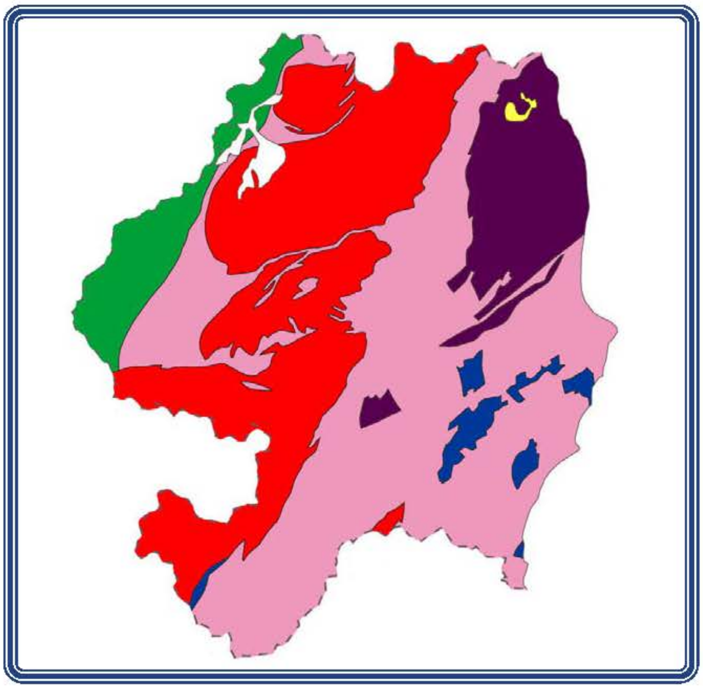
OTHER TOWNS: Arklow, Avoca, Baltinglass, Blessington, Bray, Dunlavin, Greystones, Rathdrum, Tinahely

GEOLOGY HIGHLIGHTS: Cambrian trace fossils, Glendalough mining activity, Avoca copper mines, Leinster granite mountains, Glacial deposits.

AGE OF ROCKS: Cambrian to Silurian; Pleistocene

View towards Bray Head along the prominade at Bray

Bray Head is composed of Cambrian red and green shales and greywackes together with quartzite which makes up the resistant ridges at the summit



Geological Map of County Wicklow

Purple: Cambrian shales and grewyackes; **Pale yellow:** Quartzite; **Pink:** Ordovician; **Green:** Silurian; **Red:** Granite; **Dark blue:** Ordovician volcanic rocks.

Geological history

The oldest rocks in Wicklow are those of the Cambrian period (550-490 million years ago [Ma]) that occur near Bray. These are a mixture of shales and greywackes that were deposited in deep water in an ocean called the Iapetus Ocean that divided Ireland in two. Sandstones deposited in this ocean were later metamorphosed into quartzite, and now make up the hard ridges of Bray Head and the distinctive Sugar Loaf mountains [these are **not** volcanoes but owe their shape to the weathering characteristics of quartzite].

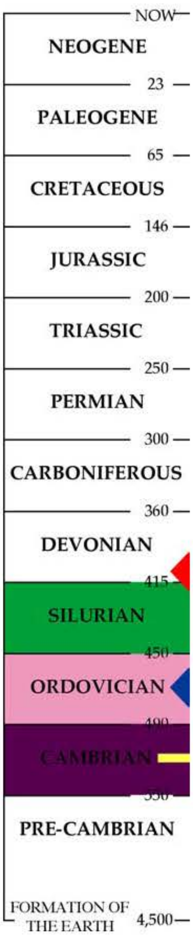
During the Ordovician period (490-450 Ma) Ireland was south of the equator, and the Iapetus Ocean had begun to close. Sediments continued to be deposited off the land into this ocean and volcanic rocks were also produced in this tectonically active region. At the start of the Devonian (405 Ma) molten granite magma was injected into the overlying rocks which were baked around the granite margins. At this time veins containing lead, zinc and silver formed in the granite. The granite was injected in several batches

Oldhamia radiatia, a Cambrian trace fossil from Bray Head (left) named after Thomas Oldham a Dublin geologist (right)

to form large masses called batholiths. As these cooled slowly below the surface they solidified into a coarsely crystalline rock. Eventually 100 million years later the overlying rocks had been eroded away so that by the Carboniferous period the granite was at the surface.

In the last million years Ireland was affected by the Ice Age. Glaciers flowed down mountain valleys forming icesheets and eroded rocks and deepened valleys. When the ice finally melted, large lakes at Enniskerry and Blessington formed into which sands and gravels were dumped. These are now useful resources for building. Sometimes the melt water rushed through valleys like the Glen of the Downs and widened them.

Glendalough situated in a U-shaped glaciated valley. This was deepened by a glacier that moved through it during the Ice Age. Since the Ice Age sediments have accumulated in the lake.



Geological timescale showing age of rocks in Wicklow.

Lead Mining, Gold & Building Stones

Glendalough and Glendasan were important mining centres in the 18th century when lead was the prime ore extracted from the veins that ran through the granite. The ore was moved to Ballycorus in Co. Dublin for smelting. At Avoca copper was extracted from the 1800s until very recently.

Glendalough showing some old mining buildings and the waste tips from mining,

Gold was found in the Gold Mines River near Woodenbridge in the 1790s and this resulted in a 'goldrush' where prospectors would use a goldpan and wash river sands looking for traces of gold. While some nuggets were discovered there was not enough gold recovered to allow long-term working.

Model of a Gold nugget 12 cm wide found in 1790s in the Gold Mines River.

Leinster Granite is a hard-wearing stone that can be cut into blocks and polished or left rough. Stone from Blessington and Ballyknockan was an important building and facing stone used in many buildings in Dublin from Georgian times.

Leinster Granite (polished) from Ballyknockan with interlocking crystals of glassy quartz, white felspar and black mica.

Map adapted with permission from Geological Survey of Ireland 1:1,000,000 map 2003.
Image credits: Patrick Wyse Jackson 1, 4 (bottom); Geological Museum, Trinity College, Dublin 3 (top left and right), 4 (centre); Matthew Parkes 3 (bottom), 4 (top).

Text by Patrick Wyse Jackson & Mike Simms

Section 2 - Site Reports

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

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

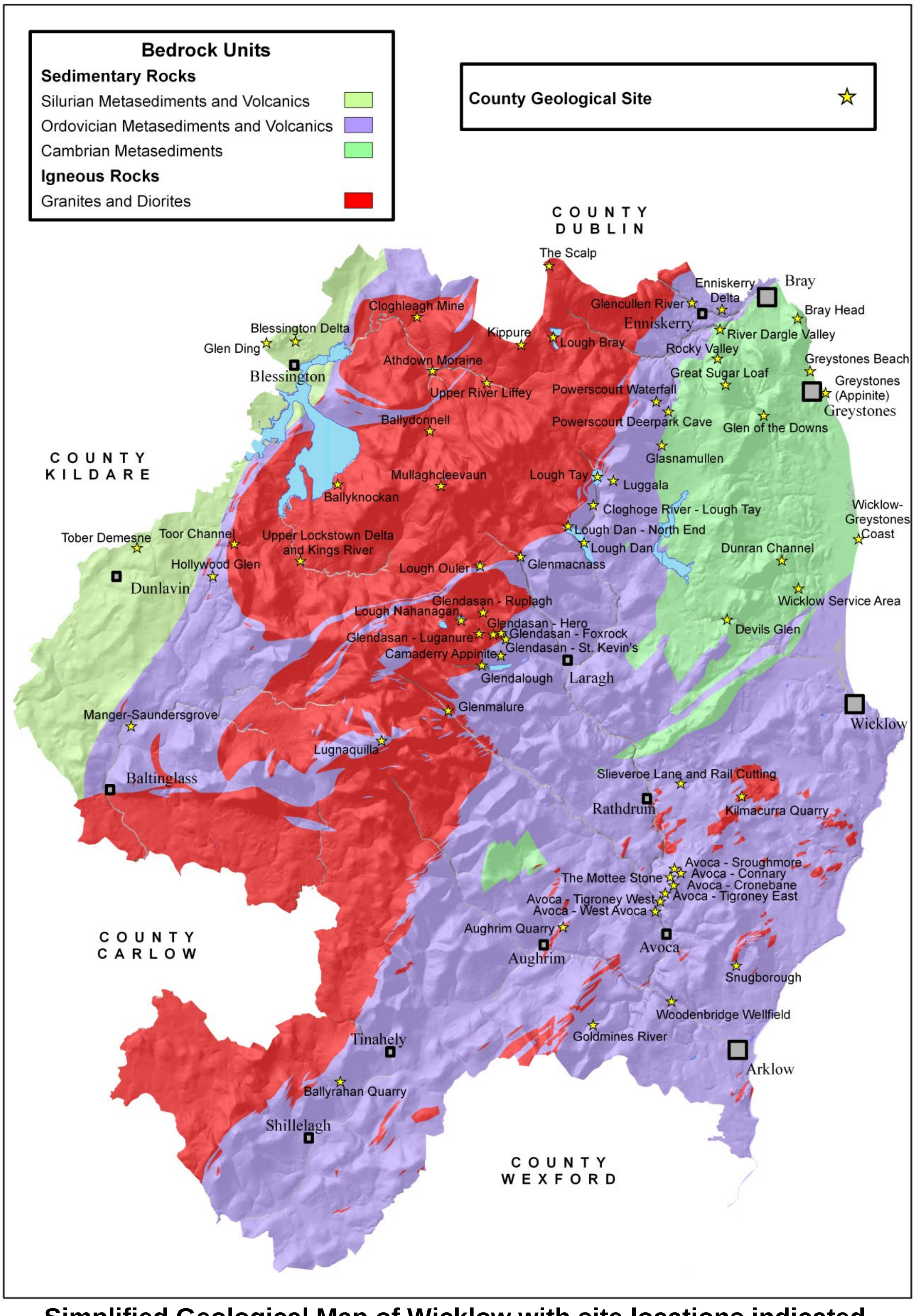
Irish Transverse Mercator (ITM) is the geographic projection co-ordinate system now in use for Ireland, and has been applied to all site localities in the site reports. It is the standard co-ordinate system for OSi maps, including the new Discovery map series, but a coordinate conversion tool is available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

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

For sites that have been recommended or which will be recommended for NHA designation detailed site boundary maps will become available to the Local Authority, through NPWS 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 GSI 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 Sarah Gatley, Head of the Heritage and Planning Programme, in the Geological Survey of Ireland, Beggars Bush, Haddington Road, Dublin 4. Phone 01-6782837. Email: sarah.gatley@gsi.ie



Simplified Geological Map of Wicklow with site locations indicated.