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Geoscience Research
GSI
Suirbhéireacht Gheolaíochta Éireann
Geological Survey of Ireland

Geological Survey of Ireland Research Programme
- Short Call 2015, Final Report -

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Organisation name	British Geological Survey		
Organisation type:	☐HEI	☒Public Sector (other)	☐Private Sector
Department/section	Geological Survey of Northern Ireland		

Project Title	An All-Ireland Quaternary Map
Contract No.	2015-sc-050

INFOMAR
Integrated Mapping for the Sustainable Development of Ireland's Marine Resource

Tellus
Understanding Underground

Marine Institute
Foras na Mara

2. Project information:

Title of project	An All-Ireland Quaternary Map
Did you make any formal amendment to the project workplan / budget?	☐ yes ☒ no If yes, please specify:

Project Report:

1. Objectives and scientific/engineering targets beyond the state of the art

The project set out the following objectives to progress the state of large-scale Quaternary mapping in Ireland. These were all achieved, progressing the state of the art for Quaternary mapping in Ireland. Some solutions were alternative solutions were developed to produce a better map product.

Objective 1. *Create lookup tables to enable two-way translation between GSI iQuaD database and GSNI NIDigMap database attributes.*

A new 1:500,000 scale classification was completed by geologists from GSI and GSNI.

Objective 2. *Classify the geochemical properties of different GSI till types by compositional data analysis of Tellus Border soil geochemistry data.*

This was achieved, but did not encompass all GSI till types due to restricted spatial coverage of data.

Objective 3. *Apply classification scheme to NI Tellus soil geochemistry to determine till lithology types in NI.*

This was achieved through a levelling exercise. However, some till types had shared classifications (below).

Objective 4. *Classify remaining till types that are not represented in RoI (e.g. basaltic till) using principal component analysis following Dempster et al. (2013).*

Basalitic till was classified automatically into tills derived from Lower and Upper Antrim Lava groups because they displayed different geochemical signatures (Figure 1). Tills derived from metamorphic lithologies was to heterogenous to identify geochemically.

Objective 5. *Dissolve and union polygons using simplified lookup tables to create a set of simplified polygons.*

Achieved using 64-bit ArcGIS Pro licence to address large memory allocation (>4 Gb).

Objective 6. *Manually QC map data.*

Achieved internally and through public feedback at conferences.

Objective 7. *Digital delivery of publication standard digital Quaternary deposits map at 1:500000 scale to GSI.*

Achieved using ArcMap map packages.

Objective 8. *Develop recommendations for creating an All-Ireland Quaternary map at 1:50,000 using a pilot study area across the Cavan-Fermanagh border.*

These were developed in conjunction with planned fieldwork campaigns.

Objective 9. *Write report providing introduction, project rationale, methods, results and conclusions of the project. Provide recommendations for creating an All-Ireland Quaternary map at 1:50000 scale. Python scripts used to execute geochemical data analysis and polygon management will be supplied in an appendix.*

The contents of this report.

2. Implementation

The project was executed in January and February 2016 with the specific objective of presenting the work at the Irish Geoscience Research Meeting and the Irish Quaternary Association Spring Meeting. This enabled the project to receive critical feedback and make adjustments well in advance of the November Deadline and present subsequent revisions to topology and cartography.

The project used a combination of Python and Matlab scripting to implement both the topological generalisation and subdivision of Northern Irish till domains. The motivation behind this was to enable a systematic and well documented approach that would allow changes to the process be made at any point and the script re-executed.

The GSI 1: 50,000 classification scheme consist of eighty-three sediment types. These categories were generalised for the 1:500,000 scale map into sixteen broader categories: peat, lacustrine sediments, alluvium, windblown sands, marine and estuarine sediments, slope deposits, glaciofluvial sand and gravels, glaciomarine sediments and tills (Table A2.1: Appendix 2). Blanket, raised and fen peat bogs were generalised into a single peat category. Five alluvium and five lacustrine types differentiated by the dominant grain-size were merged into two main classes. Lake marl was also incorporated to the lacustrine category. Windblown sand sheets and sands in dunes were categorised as windblown sands. Marine beach sands, estuarine silts and clays, tidal marsh and raised beaches were combined into the marine and estuarine deposits category. Glaciomarine deposits were kept as a separate category. Twenty-seven till types categorised in the 1:50,000 scale map according to their dominant petrologic component and

their age were generalized into eight classes indicating the dominant clast lithology. The age descriptor was kept only for Devonian sandstone tills, as this till type encompasses particularly differing physical properties from other sandstone tills. Sixteen glaciofluvial sand and gravel types including esker sand and gravel were merged into a single category namely glaciofluvial/glaciolacustrine sand and gravel.

The GSNI 1: 250,000 Superficial classification scheme consists of twelve categories. Of these twelve categories, four were generalised: glacial sands and gravels and glaciolacustrine deposits were combined to glaciofluvial/glaciolacustrine sands and gravels, and diatomite was combined with lacustrine sediments. The till category, composed of undifferentiated glacial till, was subdivided into the eight classes listed above. Objectives 2, 3 and 4 describe the process by which undifferentiated till in Northern Ireland was subdivided.

Objectives 2, 3 and 4 were addressed by applying compositional data analysis in Matlab to Tellus and Tellus Border soil A horizon geochemistry for samples in areas classified as 'Till' (for full details see scripts in Appendix 3). The resulting geochemical groupings were identified using cluster analysis of principal components derived from log-ratio transformed geochemical data. These groups were broadly consistent with the underlying bedrock geology (Figure 1). The complexity of the underlying bedrock geology is such that the eight clusters identified are not appropriate for a 1:500,000 scale map. The following reasons for these complexities are: (1) There was a high degree of geochemical similarity between metamorphic lithologies and non-metamorphic lithologies (e.g. sandstone and psammite, or greywacke and pelite). (2) Some clusters reflected mixing between till types (e.g. granodiorite dominated till and greywacke-dominated till) that do not persist over large areas. (3) Generalised till lithologies for complex areas (e.g. the Dalradian) were impossible to delineate using a single geochemical signature. (4) Some geochemical groupings were spatially persistent but exhibited low contiguity (e.g. till derived from Moffat shale within the Longford-Down terrane).

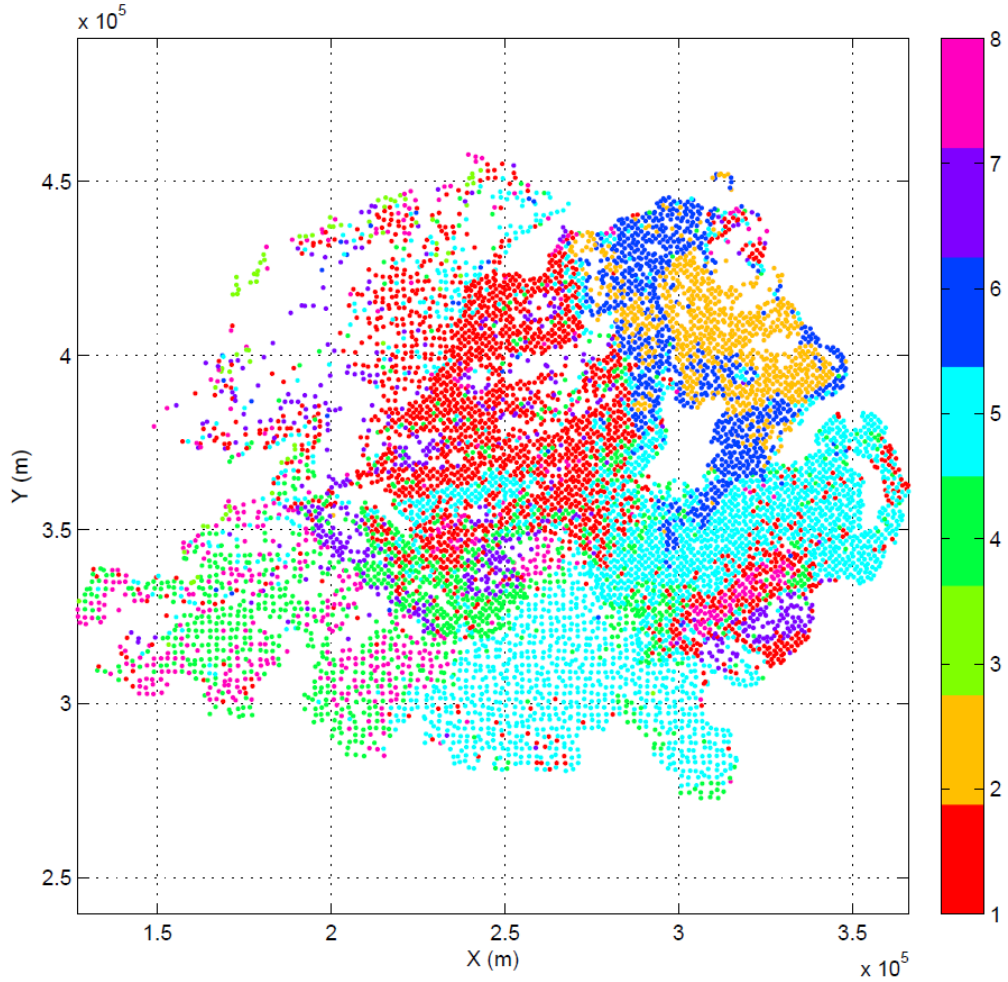

Figure 1. *Map of the eight clusters derived from principal component scores of log-ratio transformed geochemical data using k-means cluster analysis. Geochemical data are for soil A horizon samples collected during the Tellus and Tellus Border surveys in areas classified as 'Till'.*

To address the lack of spatial continuity between till types an alternative approach was adopted using the data collected by airborne Gamma-ray detection by the Tellus and Tellus Border surveys. The radiometric data were viewed as a ternary map of the ratio of radionuclides potassium, thorium and uranium. Areas of different till lithology can be readily identified from these data and broadly corresponded with the newly classified areas of till lithology. Areas where till has been 'smeared' across a lithological boundary can also be clearly seen. The 1:500,000 scale Bedrock Geology polygons were used to subdivide the Northern Ireland till polygons into different till-lithologies. Till-lithology polygons were adjusted to match the geochemical and radiometric distributions observed using ArcMap.

The generalisation off GSI and GSNI polygons using the simplified 1: 500,000 scale classification scheme was achieved using Python scripting in ArcGIS Pro (Appendix 3).

Quality checking of polygons, polylines, points and cartography has been undertaken by Xavier Pellicer and Sam Roberson on-screen using ArcMap, and via public dissemination of the map at academic conferences (Appendix 1).

Data were delivered to GSI by exporting feature classes from the project geodatabase as Map Packages and shape files. The data and ArcMap document containing the cartographic formatting were supplied to GSI.

GSNI and GSI have previously produced cross-border maps of the Marble-Arch Global Geopark in Cavan and Fermanagh. Objective 8 was addressed throughout the assessment of field records involving both GSNI 1:10,000 superficial (Quaternary) sediment data in County Fermanagh and GSI 1:50,000 Quaternary data in County Cavan. The datasets showed significant differences on the classification scheme used, the mapping detail and the along-border interpretations . The future development of an All-Ireland 1:50,000 scale map should involve the following:

(1) a degree of generalisation to account for discrepancies between the two classification schemes (e.g. GSI till and glaciofluvial sediments till classes will need to be generalized into a less detailed classification scheme to match GSNI classification).

(2) the use of Tellus radiometric data to subdivide sediment classified as 'TILL' in Northern Ireland to match the till classification scheme used by the Geological Survey of Ireland;

(3) an evaluation of data along the national borders to resolve discrepancies on the interpretation of neighbouring polygons and field records;

(4) a field truthing exercise involving mapping geologists from GSI and GSNI to establish how both organisations identify different features in the field;

GSNI are nearing completion of the 1:10,000 Superficial (Quaternary) mapping in Armagh and Down, while GSI are continuing to field check their 1: 50,000 Quaternary data in Cavan and Monaghan. This close spatial proximity of mapping campaigns indicates that the last point should be achievable in the near future.

3. Outputs

- Short Call Final Report and appendices detailing 1:500,000 scale map classification schemes and scripts for map preparation.
- 1: 500,000 scale Quaternary map with 1: 2,000,000 scale inset of glacial flow lines and offshore moraines at Last Glacial Maximum (LGM).
- 1: 500,000 scale Quaternary sediment polygons
- 1: 500,000 scale esker polylines
- 1: 500,000 scale moraine polylines
- 1: 500,000 scale drumlin polylines
- 1: 2,000,0000 scale ice sheet flow line polylines
- 1: 2,000,0000 scale offshore moraine polylines.

Impact/value of the project:

The main outputs from this project will allow a large number of bodies across Ireland and the UK to

improve their awareness and understanding of the distribution and nature of Quaternary sediments and landforms in Ireland.

- Science:
  - a better understanding of the distribution of Quaternary sediments and landforms, increasing understandings of the processes that have led to their formation
  - improved constraint of areas of groundwater vulnerability

- Education:
  - The earlier uptake of 'Quaternary' as a term in Ireland and the UK and an appreciation of the importance of the Quaternary in shaping the landscape.
  - Distribution of the Quaternary map for teaching about the Quaternary and the geological legacy of glaciation.

- Engineering:
  - The zonation of tills using Tellus soil geochemistry and radiometrics will contribute to ongoing work documenting the geotechnical properties of tills by GSNI in Northern Ireland.

- Planning:
  - Improved awareness of Quaternary sediment and landform distribution and properties will assist planning for infrastructure, housing and land use across Ireland.

Appendix 1 – Publications & Presentations:

[Conference Publication] Roberson, S.; Pellicer, X. (2016) An All-Ireland Quaternary Map, *Irish Geological Research Meeting,* Galway, Ireland, 20-FEB-2016

[Conference Publication] Roberson, S.; Pellicer, X. (2016) An All-Ireland Quaternary Map, *Irish Quaternary Association Spring Meeting,* Coleraine, United Kingdom, 9-APR-2016

[Conference Publication] Roberson, S.; Pellicer, X.; Sheehy, M; Cooper, M. (2016) An All-Ireland Quaternary Map, *Conference of Irish Geographers,* Dublin, Ireland, 6-May-2016

[Conference Publication] Roberson, S.; Pellicer, X. (2016) An All-Ireland Quaternary Map, *Geoscience 2016,* Dublin, Ireland, 2-Nov-2016

Appendix 2 – 1:500,000 Map codes

Table A2.1. *Description of 1:500,000 scale sediment codes shown in the 1:500,000 scale Quaternary Geology Map of Ireland.*

Peat	**Peat** is a post-glacial deposit, consisting mostly of partially decomposed vegetation. The peat may be deposited as blanket bog accumulating in elevated areas with excessive rainfall and as raised bogs or fens on the lower ground areas. Much of Ireland's peat has been cut away for burning as solid fuel or has been oxidized as the result of agricultural drainage schemes
Lacustrine sediments	**Lacustrine sediments** were deposited during deglaciation or post-glacially in depressions left behind by the ice during ice retreat. These sediments are generally composed of sands, silt and clays and are often overlain by peat bogs infilling former lakes
Alluvium	**Alluvium** is a post-glacial deposit recorded along river valleys consisting of generally bedded gravel, sand, silt or clay in a variety of combinations, often with a fairly high percentage of organic carbon (10%-30%). Alluvium is mapped on modern day river floodplains or Holocene river terraces
Wind-blown sand	**Wind-blown sand deposits** are composed of well sorted medium to fine sands deposited along coastal areas geomorphologically expressed as sand dunes or sand sheets
Marine and estuarine deposits	**Marine and estuarine deposits** comprise sand and gravel beach sediments, raised beaches, tidal marsh deposits and estuarine silts and clays
Slope deposits	**Slope deposits** consist of an assemblage of rock fragments, blocks and sediments deposited along the mountain cliffs associated with large slope movements, continuous rock falls, peat slides, debris flows or periglacial processes. These are often expressed as colluvium cones or sheets

Glaciofluvial/glaciolacustrine sand and gravel	**Glaciofluvial-Glaciolacustrine sand and gravel** are indirect glacial deposits transported to their final position by melt-water during the ice sheet meltdown and sorted in this process. Glaciofluvial deposits are generally represented by stratified 'sands and gravels', the clasts are usually (sub)rounded and loosely packed. Glaciolacustrine sediments often include bottomsets facies composed of fine sand and silts overlain by coarser sediments ascribable to foreset and topset facies
Glaciomarine sediments	**Glaciomarine sediments** are indirect glacial sediments recorded in marine depositional environments including glaciodeltaic sediments, subaquesous fans and submarine avalanche deposits.
Till derived from limestones **Till derived from sandstones and shales** **Till derived from sandstones** **Till derived from Devonian sandstones** **Till derived from acidic volcanic rocks** **Till derived from basic igneous rocks** **Till derived from granites** **Till derived from metamorphic rocks**	**Tills** consist of over consolidated, or tightly packed, unsorted, unbedded, glacial deposits possessing many different particle sizes with commonly sharp, angular clasts. Tills are categorised from (1) their dominant petrologic component identified from lithological analyses of medium gravel sized pebbles (5 to 10 mm diameter); (2) Analysis and processing of geochemistry and gamma-ray data obtained from the Tellus and Tellus border project. Soil geochemistry sample analysis provides an indication of the dominant lithology these soils were derived from. Radiometric data illustrates the distribution of potassium, thorium and uranium concentrations within the upper 30-40cm of soil and rock. Variations in these three radionuclides help in mapping main lithological differences between till types.

Table A2.2. *Description of geomorphological features shown in the 1:500,000 scale Quaternary Geological Map of Ireland and the 1: 2,000,000 scale inset.*

Drumlins	**Drumlins** are smooth oval shaped hills composed of glacial sediments, typically with a long axis aligned with ice direction. Drumlins are very well preserved in the northern sector of Ireland. Several ice directions associated with drumlin orientation are indicative of a number of ice sheets interacting in the region during the last glacial period.
Eskers	**Eskers** are elongate, sinuous ridges composed of glaciofluvial sands and gravels. Eskers are formed by the infilling of ice-walled channels and record deposition in subglacial, englacial or supraglacial drainage networks. The planform of an esker network may illustrate the geometry of a subglacial drainage network during deglaciation. Eskers are common across the Central lowlands and are generally 10-20 m high and 100-250 m wide. Individual segments can be up to 10 km long
Moraines	**Moraines** demarcate former ice margins, where a complex interaction of glacigenic and paraglacial processes have combined to form a ridge at the limit of the ice sheet. Moraines are particularly well expressed and well researched in montane regions in Ireland.

Ice Flow Lines	**Ice Flow Lines** indicate the overall direction of ice sheet flow for a single time period at the peak of the last glacial period c. 23 thousand years BP. Flow lines are mapped from a range of ice flow indicators, including striations, drumlins, ribbed moraines, moraines, glacial lineations and roche moutonnées.
Offshore Moraines	**Offshore Moraines** indicate the maximum extent of the grounded ice during the Weichselian glacial period.

Table 3. *Description of Dateable Deposits shown on the 1:500,000 scale Quaternary Geological Map of Ireland.*

Last Glacial	Sites dated recording sediments deposited between the Kilfenora Interstadial at Marine Isotope Stage (MIS) 5d/c (120 – 115 ka BP) and the Younger Dryas at isotope stage 2 (c. 12.9 – 11.7 ka BP).
Last Interglacial	Sites dated recording sediments deposited during MIS 5e (132 – 120 ka BP). Two key sites are Knocknacran in Co. Monaghan and the Screen Hills in Co. Wexford. However, dates from the Knocknacran could be interpreted as MIS 4, while the age of the deposits at the Screen Hills are based solely on pollen assemblages.
Middle Pleistocene	These sites record sediments deposited between MIS 11 (c. 424 – 374 ka BP) and isotope stage 6 (c. 198 – 132 ka BP). Most sites have been assigned to the Gortian interstadial, but it remains unclear whether this stage is equivalent to MIS 7 or MIS 9.
Pre Pleistocene	Sites recording sediments deposited during the Pliocene (>2,600 ka BP). Ages have been largely inferred from floral and faunal assemblages within these deposits.