Roinn Cumarsáide, Gníomhaithe ar son na hAeráide & Comhshaoil
Department of Communications, Climate Action & Environment

Geological Survey
Suirbhéireacht Gheolaíochta
Ireland | Éireann

Research Programme
- Short Call 2022 –
- Final Report -

Lead Applicant Name	Gordon Bromley
Host Organisation name	University of Galway
Project Title	A multi-proxy geology approach to resolving critical uncertainties in Irish cosmogenic nuclide geochronology
Contract Number	2022-sc-006

Declaration
I declare that the information provided is accurate and correct. I agree that the Geological Survey Ireland Research Programme management may make any enquires it considers necessary to verify the information provided herein.

This report covers the period 1st December 2020 to project end date (31/01/24)

Research Programme
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Final Report

1. **(a) Project information**:

Final project report:

Executive summary:

Anthropogenic climate change is the defining socio-economic force of the 21st Century, posing a direct threat to economic vitality, human well-being, and environmental integrity in Ireland and globally. Principal challenges include (1) minimising knowledge gaps surrounding climate's capacity for rapid shifts, thereby boosting our ability to predict future change, and (2) improving our understanding of climate's role in landscape evolution, which is fundamental to geohazard risk assessment under warming conditions. Concurrently, novel technologies are key to accessing the resources to fuel Ireland's transition to a low-carbon economy. These challenges draw heavily from geoscience, **in which cosmogenic nuclide geochronology plays an increasingly vital role**.

Despite its growing reputation, the efficacy of the cosmogenic toolset is undercut by persistent uncertainty surrounding nuclide production rates, particularly at boreal mid latitudes (i.e., Ireland). Employing a coupled geologic–geochemical (U-Th/^{14}C/^{10}Be) approach, we will [**1**] quantify the beryllium-10 production rate in Ireland, [**2**] establish whether this rate has fluctuated temporally (e.g., due to geomagnetic variability), and [**3**] appraise how well current scaling models account for these fluctuations. Reflecting the diverse application of cosmogenic nuclides, this work impacts the fields of palaeo-/climatology, coastal vulnerability/geohazards, sediment tracing, and rare-earth element prospecting, with ramifications for archaeologic and geoheritage interests.

(i) Results, scientific/engineering targets reached beyond the state of the art and conclusions

We conducted field surveys of prospective calibration sites in Dingle (Pedlar's Lake, Conor Pass), the Burren (plateau), and Lough Corrib (Ballyquirk). We also assessed a fourth site at Cong, Co. Galway, and a firth at the Cavan Burren, which unfortunately did not meet the project criteria. Our three target sites exhibit the following requisite characteristics: excellent preservation of deglacial rock surfaces (for measurement of beryllium-10) and the means to provide minimum-limiting or direct age control for deglaciation (e.g., radiocarbon, U-Th dating). It was also important for us to identify sites corresponding to different exposure periods, since that affords the unique opportunity to establish whether the temporal variability in geomagnetic field strength impacts the in situ production of cosmogenic nuclides.

Figure 1. Extracting a sediment core from Pedlar's Lake, Dingle. This core extends back ~11.7 ka (based on C14 ages) and provides independent age control for the beryllium concentrations measured in erratics and bedrock visible in the foreground. Photo: Eugene Farrell, University of Galway.

For each target site, we first identified suitable target rock surfaces for beryllium measurement. These include glacial erratic boulders (e.g., granite erratics perched on glacially moulded bedrock) and ice-moulded bedrock, all of which needs to contain sufficient quartz for a clean measurement. With few exceptions, the sample populations for each site returned discrete populations, confirming that we had established statistically significant beryllium concentrations for target surfaces. For the Dingle and

Corrib sites, where the minimum-limiting age control is provided by radiocarbon, we extracted sediment cores from lake sediments that, stratigraphically, can be proven to overlie – and thus postdate – the target rock surfaces (Fig. 1). This was achieved with an Usinger corer. Subsequently, we extracted terrestrial macrofossils for radiocarbon dating at the 14Chrono facility, Queen's University. Basal ages are internally consistent.

For the Burren site, where independent age control for the calibration process is provided by U-Th dating of postglacial speleothems, we first had to identify suitable flowstone and stalagmite samples for microsampling. We identified such specimens in Doolin Cave, Cool Cave, and Poulnagollum; the team extracted samples in summer 2023, after which speleothems were cut and polished at Maynooth University. A challenge in this task has been personal leave of one team member and the wholesale movement of the UCD lab tasked with U-Th measurement; both obstacles have been surmounted and we anticipate final data in the coming months.

Figure 2. Project team member, Nick Scroxton (Maynooth U.), sampling a flowstone in Doolin Cave for U-Th dating. This minimally invasive technique enables us to date the speleothem without causing visible damage to cave surfaces. U-Th ages from speleothems afford the minimum-limiting age control for calibrating nuclide production.

Thus far, the comparison of measured beryllium-10 concentrations in deglacial rock surfaces to their respective minimum-limiting age control suggests that the production of beryllium-10 is relatively invariable over time, at least for the period 18,000-11,000 years ago. Moreover, we find that the Rannoch Moor production rate calibrated in

Scotland (and thus at a similar geomagnetic latitude to Ireland) gives the closest – albeit not perfect – fit to the independent dating control at our sites. Conversely, the global average production routinely violates the independent dating control, being much too high. We await final calibration of one of our sites, but preliminary data from there suggests this pattern is robust. Final confirmation (or refuting) of this will be reported in our two forthcoming publications.

(ii) Project Implementation

Details of all work completed are given below. For deliverables currently pending, anticipated dates for completion are provided.

Beryllium-10 sampling and measurement: This deliverable is complete. We have measured beryllium ratios in 15 samples collected from glacial erratic boulders and bedrock, located in glacial settings at Conor Pass, the Burren, and the western shore of Lough Corrib. Concentrations are generally internally consistent and have provided us robust bases for calibrating the production rate for three different time periods: ~12,000 years, 16,000 years, and 18,000 years ago.

Radiocarbon dating: This deliverable is complete. We measured samples of macrofossils preserved in the basal sediments of cores collected from two lake basins: Pedlar's Lake (Dingle) and Ballyquirk Lough (Galway). These ages provide the requisite bracketing ages for the adjacent rock surfaces used as calibration sites.

U-Th dating: We anticipate completion of this deliverable in May 2024. All speleothem samples have been collected, including specimens from Doolin Cave, Cool Cave, and Poulnagollum. Samples have been cut, polished, and sampled and we now await the final U-Th values for age calculation.

Data presentation and outreach: This deliverable is complete yet still active. We have achieved our stated outreach goals but have new opportunities to discuss data with public audiences during the spring and summer. We anticipate submitting manuscripts for publication in spring 2024.

(iii) Outputs to date

Production of geologic datasets:
This project has produced two broad new geologic datasets, with a third dataset pending completion of U-Th data this spring. New data include:

- Be-10 concentrations and surface-exposure data from three Irish sites: Dingle, Burren, and Lough Corrib.
- Radiocarbon ages on postglacial sediments in lake basins at two of these sites (Dingle, Lough Corrib), which afford minimum-limiting age control for deglaciation and minimum-limiting production rate control for beryllium-10.
- Sedimentological characterisation data for the lake cores, including radiograph imagery of chronologically important varved sections.
- Calibration data produced via the University of Washington online production rate calculator: https://hess.ess.washington.edu/math/v3/v3_cal_in.html

- All cosmogenic ^{10}Be ages, and the metadata required to calculate them, are due to be uploaded to the publicly accessible ICE-D database: https://version2.ice-d.org/alpine/

Upon publication in *Quaternary Geochronology*, all geochemical and sedimentologic data will be archived both online in the journal's supplementary resources and on the NOAA NCEI data repository, as per the proposal.

Public outreach and scientific presentation of data:

- '*Meet the Scientist*' Participation by PI Bromley in this island-wide online event showcasing geoscience (including this calibration work) for > 2000 primary-level students. 11/01/2023.
- '*Burren & Cliffs of Moher Geopark Academy fieldtrip*' PI co-led the Academy fieldtrip in the Burren, with specific focus on glacial geology and how our project is using Quaternary landforms of the Burren to improve geoscience methods and knowledge. 28/05/2023.
- '*2° Curso de Isotopía Cosmogénica Aplicada a Geociencias*' PI was invited to co-led a postgraduate-level course in the application of cosmogenic geochronology to geoscience problems at the Universidad Nacional (Colombia) Medellín, drawing heavily from output from this project. This 5-day event was organised in conjunction with the PI's Colombian and Dartmouth College collaborators and hosted by the Facultad de Minas in Medellín.

(iv) Impact

- Relevance/application to GSI programmes, where applicable

The data produced during this project support the GSI Research Roadmap objectives of (1) risk mitigation for geologic hazards and (2) public perception of geosciences. First, by constraining the cosmogenic beryllium-10 production rate for two (and ultimately three) different periods in and around Ireland, we have strengthened the methodology available to geoscientists researching, e.g., causes and mechanisms of slope failures/coastal erosion, rates of karstification, and relative sea level change (via better benchmarks for the glacial models informing those estimates). Second, our public engagement has enabled the team to discuss our project's rationale with public audiences (e.g., geoheritage visitors, local interest groups) during and beyond the project's duration. The project's output also serves GSI Research Roadmap objective Sustainability and Management of Earth Resources, albeit indirectly: Our access to and use of Ireland's resources, including land surfaces, depends in no small part on our ability to project future environmental and climate change, particularly in the 21st Century. The refined cosmogenic toolkit is vital to three ongoing projects (one co-funded by GSI, one by iCRAG, and one by EPA) in Ireland seeking to constrain the terrestrial impact of climate change and help refine the frontline models projecting Ireland's future climate.

- Other impacts

- Four University of Galway graduate students (Adrienne Foreman, Paulo Rodriguez, Raluca Niculae, and Chris Stewart) have participated in the various aspects of sample collection and lab-based sample preparation, thereby receiving valuable experience and hands-on training in applied geoscience.
- To date, we have completed two of the three planned calibrations. Even at this incomplete stage, our findings afford novel new insight into the impact (or lack thereof) of geomagnetic field variability on the *in situ* production of cosmogenic nuclides at Earth's surface, information that undoubtedly will prove fundamental to future research into the cosmic ray flux and scaling schemes.
- The PI has developed a valuable new collaboration between the University of Galway and Stockholm University (specifically the Bolin Climate Centre) in part due to the calibration work for this project and its implications for dating abrupt climate shifts. This collaboration has already fostered new research ideas, including plans to seek EU funding for climate change research.
- Implementation of project data in a public/academic workshop on applied cosmogenic geochronology in Medellin, Colombia, has boosted Ireland's global reputation as a key player in the refinement of geoscience methods and valid partner in geoscience research.

Publications:
No publications to date (final data interpretation is still underway) but our findings were presented by the PI at the 2023 Comer Climate Conference in Wisconsin, USA (invited talk), and again at the Bolin Climate Centre, Stockholm University (invited talk). Two manuscripts, documenting our Clare and Kerry calibrations, will be ready for submission in spring 2024.

3. Supplemental information/datasets *(please clearly mark any sensitive or confidential information that should not be published and include a justification for the request)*