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

Geological Survey
Suirbhéireacht Gheolaíochta
Ireland | Éireann

Research Programme
- Short Call 2020, Final Report -

Lead Applicant Name	Dr Gordon Bromley
Host Organisation name	University of Galway (formerly NUI Galway)
Project Title	Quantifying Ireland's Dust Bowl: An interdisciplinary assessment of potential loess genesis, deposition, and dynamics in the Burren
Contract Number	2020-sc

This report covers the period 1st December 2020 to project end date 30th September 2022)

2. (a) Project information:

Final project report (*max 2500 words, excluding figures and headings*):

Executive summary (lay abstract, approx. 250 words):

The Burren is an iconic example of glacio-karst. While its expansive limestone pavements support a sparse, patchy soil cover today, a growing body of evidence suggests this cover was greater in the geologically recent past, prompting the questions: *How did soils originate on a glaciated limestone substrate? Where have these soils gone subsequently*? Our focus here is the first question. Our preliminary excavations revealed an apparently homogenous deposit at multiple sites in the Burren, including dolines, grikes, caves, and hillsides. Pilot geochemical and grain-size analyses describe a quartz-rich silt that cannot be attributed to local bedrock. While previous researchers have speculated that similar deposits are aeolian silt ('loess'), the Burren sediments have escaped rigorous geologic assessment; existing maps do not include these deposits. e will evaluate grain size, geochemistry, stratigraphy, botanical content, and age of the Burren's surficial sediments to resolve sediment origin, transport, and post-depositional evolution. These data will help establish whether the silts are indeed loess and if this was the parent material for the lost Burren soils. As well as providing a field-based analysis of a significant, hitherto undocumented geologic unit, this work impacts ecological/botanical and archaeological interests, with ramifications for assessing geological vulnerability and climate-geomorphology dynamics.

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

We conducted field-based surveys throughout the Burren and surrounding region to identify sites with good preservation of surficial sediments. In all, we focused on 12 sites (see Fig. 1) and identified two discrete sediment types: (1) *in-situ* massive silt, typically found overlying surfaces of glacial origin (e.g., striated bedrock, till, varves), and (2) a less-consolidated silt unit containing charcoal fragments and confined to topographic depressions, where it overlies the in-situ unit. Stratigraphically, unit 2 appears to have been reworked from unit 1.

At each site, we dug excavations by hand to permit detailed logging of sediment exposures and collection of samples for the multiple analyses listed below (see Implementation; Fig.

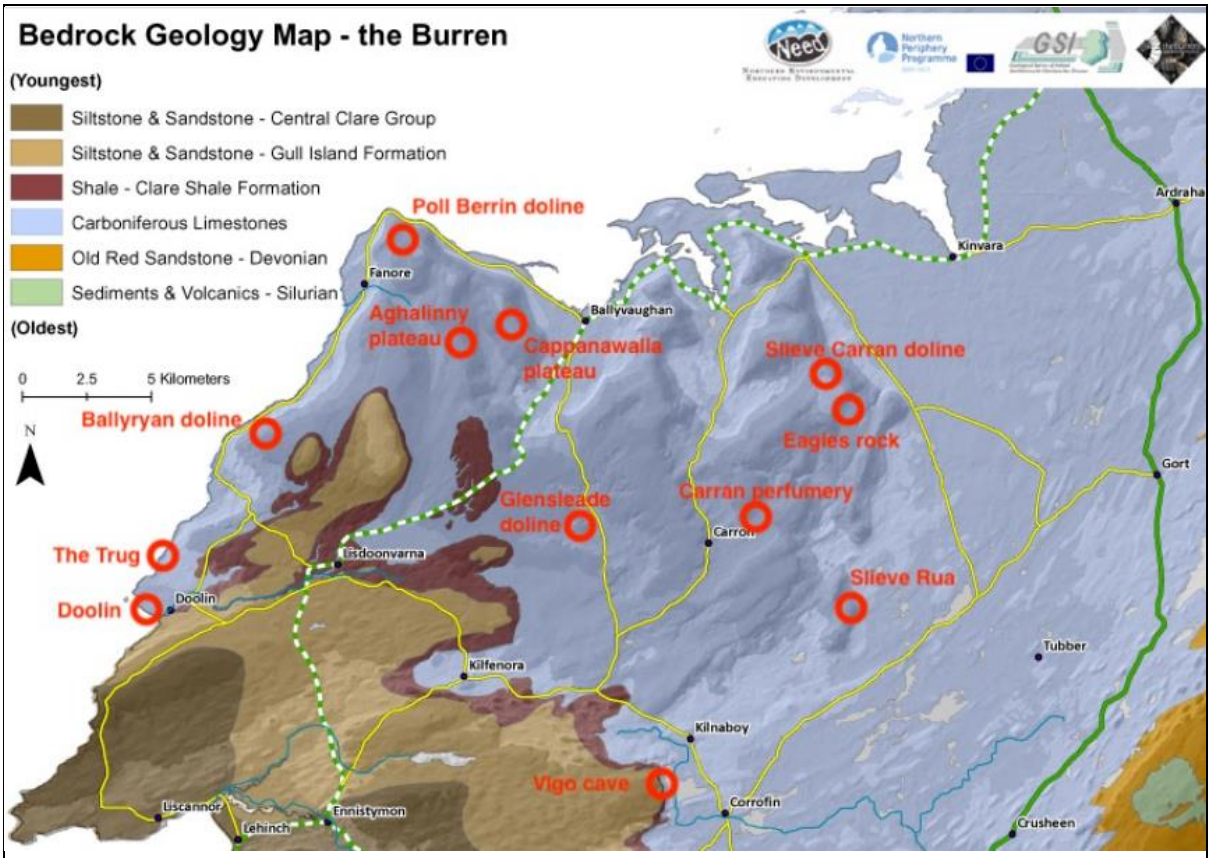

Fig. 1 Locations of our 12 field sites (red circles) in and adjacent the Burren uplands.

2). The high density of field sites, some of which we re-excavated several times, has provided us an unprecedented view of the Burren silt deposits. Our grain-size and SEM/EDX analyses confirm that the material is predominantly quartz silt (Fig. 3) – and thus loess – but also reveal that the unit is considerably finer-grained than typical loess, suggesting either a more distal source (e.g., farther travelled Eurasian material) or a distinct parent material. Our subsequent measurement of U-Pb ratios in six zircon separates (from six sites; Fig. 4) has identified the source as the Tullig Formation (Clare Basin), which is both highly local and ultra-fine-grained, thereby addressing this question fully.

Fig. 2 Excavations in the Burren loess deposits: (Left) Vigo Cave, 2021; (Right) Glen of Clab (2022). With the exception of Vigo, all excavations were full depth, extending down to the base of the silt unit to reach underlying substrate.

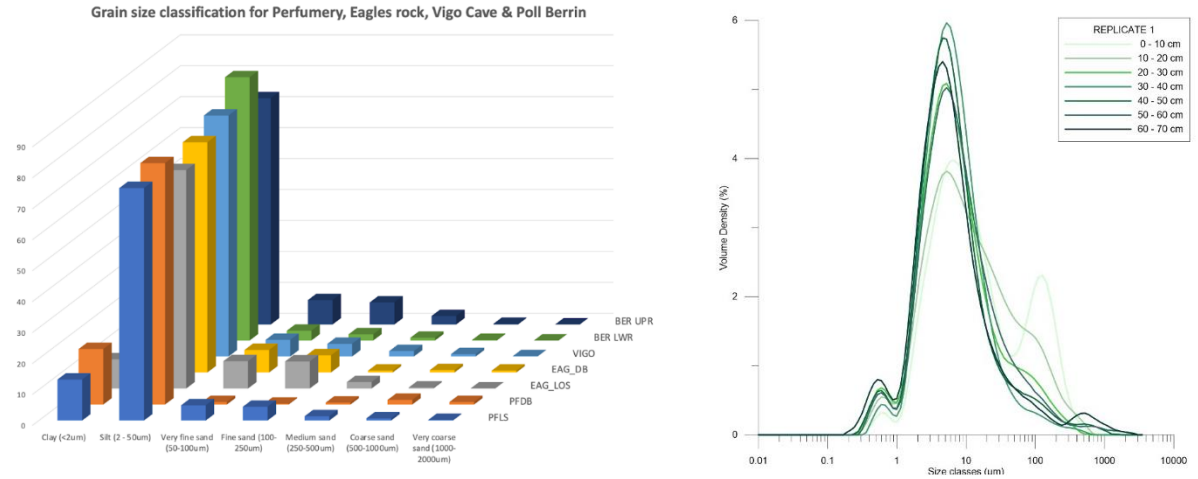

Fig. 3 Grain-size determinations for Burren loess samples. All measurements show that the material is silt size and within the observed range of global loess deposits. Nonetheless, the Burren silts are generally finer-grained than typical Eurasian loess, which we attribute to the predominant Tullig Formation parent rock.

XRF analysis was provided by the ESRL as part of this project. In all, we measured the full range of elements in 50 samples of quartz silt to quantify and identify trends in chemical composition. This constitutes the highest-resolution geochemical assay of a specific soil type in Ireland to date and has revealed broad elemental similarities with Eurasian loess deposits. Crucially, these XRF data also provide us a strong foundation for the project's phase 2: establishing post-depositional soil processes (e.g., weathering) in Burren loess from soil chemistry indices.

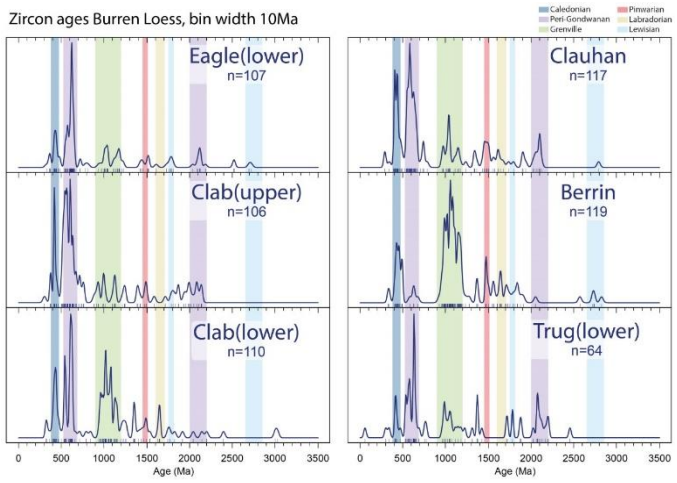

Fig. 4 U-Pb age spectra for six zircon samples of Burren silt (10 Myr bin width). Sites correspond to those listed in Fig. 1. Spectra reveal a strong dominance of material with age signal matching that of the Tullig cyclothem of the adjacent Clare Basin, suggesting a local source.

Constraining the timing of loess deposition has presented the greatest challenge in this project. ^{14}C dates have proven valuable in the upper silt unit, which our preliminary anisotropic magnetic susceptibility (AMS) measurements suggest has been reworked, owing to the preservation of charcoal fragments therein. All samples are mid-Holocene in age, indicating reworking of the *in-situ* sediments at this time. We note that this period also coincides with deteriorating climatic conditions and intensified human land clearance. Organic remains are absent from the lower silt unit; pending OSL ages will provide clarity on the age of that deposition, though our stratigraphy strongly suggests an immediately post-glacial emplacement. As it became apparent that constraining the deglacial history of the

Burren was fundamental to this project, we utilised existing funds to measure cosmogenic ^{10}Be in occasional perched granite erratics and quartz veins in glacially moulded bedrock to reconstruct when the last ice sheet melted away and the landscape became exposure for loess deposition. To date, four ^{10}Be ages reveal deglaciation occurred between 18 and 17 ka (Fig. 5), coincident with a period of intensely cold winters but warming summers in the North Atlantic.

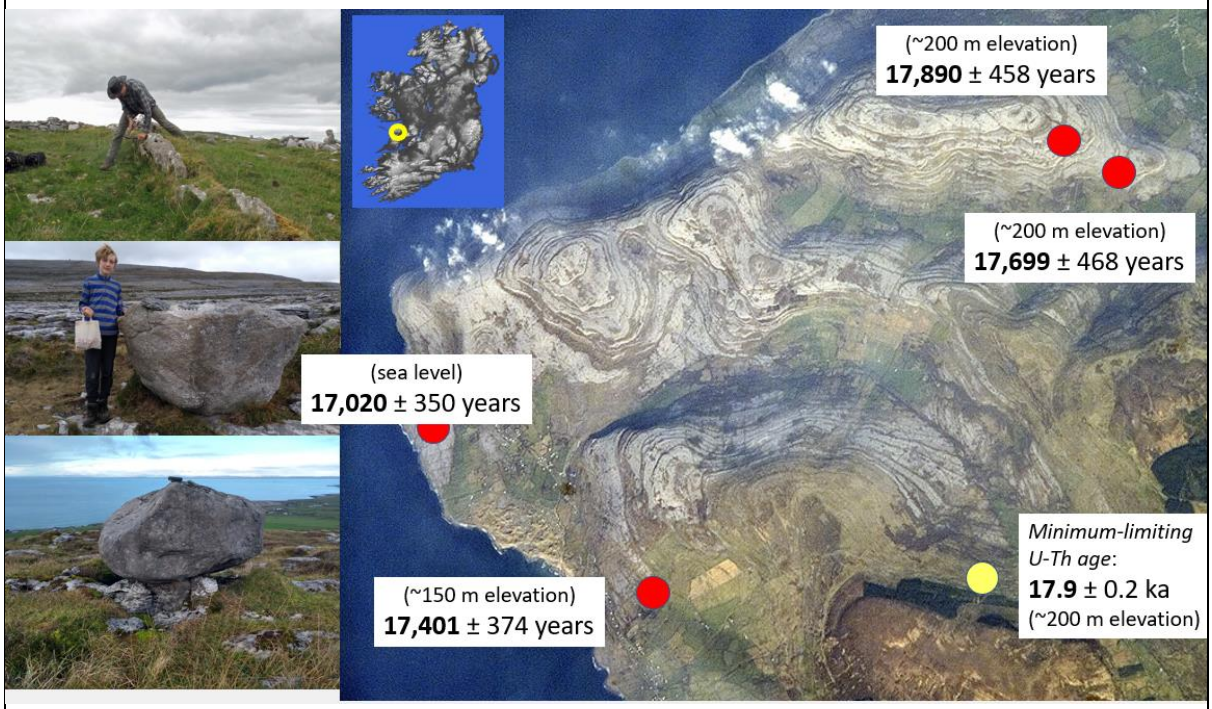

Fig. 5 Locations of preliminary ^{10}Be surface-exposure ages from the Burren, indicating that deglaciation occurred between ~18 ka, when the plateau emerged from the ice, and ~17 ka, when the adjacent lowlands were revealed. This chronology provides a critical maximum-limiting age for the onset of loess entrainment, transport, and deposition.

Together, our existing dataset indicates that (i) the quartz-rich silt mantling the Burren is indeed loess, (ii) that the original deposition likely occurred during the permafrost conditions of the immediate post-glacial period 17–14.7 ka (OSL chronology will soon quantify this age), and (iii) the *in-situ* unit was severely reworked by erosion during the mid-Holocene.

(ii) Implementation (milestones, deliverables, project management)

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

Grain size and XRF: These deliverables are complete. We have produced a wealth of physical and chemical data for 50 samples spanning 12 sites throughout the Burren region.

Loss-on-ignition, SEM, and EDX: Deliverables are complete. LOI was performed along vertical transects of all 12 excavations; SEM and EDX measurements were made on subsamples from each site both to confirm the loess mineralogy and assess surface characteristics of individual grains.

U-Pb dating: Three initial samples were so eye-opening that we analysed a further three. All six measurements reveal local sources for the loess, specifically the dominance of Clare Basin lithologies and input from the Slieve Aughty mountains to the east.

OSL and ^{14}C dating: Due to COVID restrictions, the OSL dating was delayed until later in the project. All sample preparation is complete and measurements are currently being made by collaborator Fitzsimmons at Tubingen. All ^{14}C dating of secondary loess units is complete, showing a mid-Holocene age for soil erosion.

Anisotropic magnetic susceptibility: Deliverable is complete. Collaborator Guilderson visited the Burren in November 2021 to collect samples; Bunce travelled to Uppsala in spring 2022 to prepare samples. Analysis took place in summer 2022 and reveals remobilisation of upper loess unit.

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 this autumn. Additional publication of data will take place in winter 2022 and spring 2023.

(iii) Outputs to date

Production of geologic datasets:

This project has resulted multiple five new geologic datasets, with one dataset pending completion of OSL dating this autumn. New data include:

- Grain-size measurements and spectra for 50 samples of Burren loess.
- XRF measurements for 50 samples of Burren loess, provided by the ESRL.
- Loss-on-ignition, SEM, and EDX data for 50 samples.
- Anisotropic magnetic susceptibility
- U-Pb isotope measurements and resulting age spectra for six samples.
- ^{14}C cages of charcoal material preserved in the upper (remobilised) loess unit.
- All cosmogenic ^{10}Be ages, and the metadata required to calculate them, are stored on the publicly accessible ICE-D database: https://version2.ice-d.org/alpine/

To date, all XRF, grain size, U-Pb, and SEM data are stored on the project website. Upon publication in the forthcoming 2023 *Quaternary Research* special edition (see below), all geochemical and sedimentologic data will be archived both online in the journal's supplementary resources and on the NOAA NCEI data repository.

Public outreach and scientific presentation of data:

- '*Purls of Wisdom.*' Participation by PI Bromley in iCRAG's Heritage Week 2022 event combining geoscience (i.e., our loess project) and fibre crafts. Ardrahan, Galway. 20/08/22.
- '*Total meltdown: The end of the ice age in the Burren*.' Burren and Cliffs of Moher public lecture by PI Bromley, Heritage Week, 18/08/22.
- '*Constraining the deglaciation of the Burren, Co. Clare: Setting the scene for Ireland's dustbowl.'* 65th IGRM, Belfast. Poster presentation by Bunce, 25/02/22.
- '*Postglacial climate change in the Burren.*' IQUA Autumn Symposium [topic: abrupt climate change], 26/11/22. Oral presentation by Bunce.
- '*Towards a Lateglacial history of the Burren.*' IQUA Newsletter no. 68.
- '*Constraining the end of the ice age in the Burren: Setting the stage for Ireland's dustbowl.*' IQUA newsletter no. 67.

- '*Digging the Burren – quantifying Ireland's dustbowl.*' IQUA newsletter no. 66.
- Project website launched January 2021: https://sites.google.com/view/burren-loess/home
- Development of virtual tour for the Irish Ice Age Trail: https://sites.google.com/view/irishiceagetrail

(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, we have delivered the first geochemical and physical constraint of this widespread soil type, which has implications for soil stability and distribution of vegetation cover. High-resolution XRF data from throughout the Burren will augment the Tellus programme's overall objectives of characterising Ireland's soil types. Second, our active engagement schedule has enabled us to deliver project rationale and findings to public audiences (schools, geoheritage visitors, local interest groups) throughout the project's duration. Complementing the live outreach, the virtual tour of our Burren sites brings these data to a broader geoscience audience online.

- Other impacts

- Three graduate students (Marta Cabello and Martin Nauton (Galway); Sarah Walton (Sheffield)) have been involved in various aspects of the project. Each is committed to contributing sections to our invited manuscript for the forthcoming *Quaternary Research* special edition, *Loess environments: generation, transport, deposition, and human adaption*.
- Recognising that our chronological datasets are incomplete at this time, our findings on the local provenance of Irish loess has important implications for the broader loess and atmospheric dynamics communities. Establishing the footprint of relict loess affords a means to reconstruct patterns of atmospheric circulation, particularly during abrupt climate disturbances; in demonstrating a local source for Irish loess, our data support persistence of prevailing SW airflow during stadial conditions and preclude the anomalous dominance of easterly airflow (as a Eurasian source would require).
- University of Galway has developed the capacity and expertise to prepare samples for OSL dating. The PI is now exploring the feasibility of building infrastructure to also measure OSL samples, thereby bringing this much-used geochronological technique to Ireland.

Publications:

Bunce, C., Smalley, I., Stevens, T. and Assadi-Langroudi, A., 2022. Loess in Britain and Ireland: Formation, modification and environmental significance, a review in memory of John Catt (1937–2017). *Proceedings of the Geologists' Association*.

Bunce, C., Bromley, G., Cabello, M., Nauton, M., Tyrrell, S., Chew, D., 2022. Constraining the deglaciation of the Burren, Co. Clare: Setting the scene for Ireland's dustbowl.65th IGRM, Belfast.