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Quaternary Newsletter

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QUATERNARY NEWSLETTER

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Instructions to authors

Quaternary Newsletter is issued in February, June and October. Articles, reviews, notices of forthcoming meetings, news of personal and joint research projects etc. are invited and should be sent to the Editor. Closing dates for submission of copy (news, notices, reports etc.) for the relevant issues are 5th January, 1st May and 1st September. These dates will be strictly adhered to in order to expedite publication. **Articles must be submitted at least 6 weeks before these dates in order to be reviewed and revised in time for the next issue of QN, otherwise they may appear in a subsequent issue.**

Suggested word limits are as follows: obituaries (2000 words); articles (3000 words); reports on meetings (2000 words); reports on QRA grants (800 words); reviews (1000 words); letters to the Editor (500 words); abstracts (500 words). Authors submitting work as Word documents that include figures must send separate copies of the figures in .eps, .tif or .jpg format (minimum resolution of 300 dpi is required for accurate reproduction). Quaternary Research Fund and New Researchers Award Scheme reports should limit themselves to describing the results and significance of the actual research funded by QRA grants. The suggested format for these reports is as follows: (1) background and rationale (including a summary of how the grant facilitated the research), (2) results, (3) significance, (4) acknowledgments (if applicable). The reports should not (1) detail the aims and objectives of affiliated and larger projects (e.g. Ph.D. topics), (2) outline future research and (3) cite lengthy reference lists. No more than one figure per report is necessary. Recipients of awards who have written reports are encouraged to submit full-length articles on related or larger research projects.

NB: Updated guidelines on the formatting of contributions are available on the QRA website or from the editor.

COVER PHOTOGRAPH

Flimston Churchyard and its erratic boulders. Some are used as grave headstones. The churchyard is on the limestone coast of South Pembrokeshire, and the erratics are mostly igneous, probably from the St David's Peninsula. How and when were they transported? *(Photo: Louise Trotter)*

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JAMES CROLL AWARD: PROFESSOR COLIN BALLANTYNE

The James Croll Medal is the highest award of the QRA and is named in honour of James Croll (1821-1890). Croll is most closely associated with fundamental work on the astronomical theory of the ice ages, but he also made seminal contributions on the glacial geology of Scotland, on the mechanisms that drive ocean circulation and the impact of that circulation on recent climate, on tidal theory and the rotation of the Earth. These are all major issues that occupy Quaternary scientists to this day. Croll was effectively self-taught. His work and example demonstrate that any individuals from all backgrounds can rise to national eminence and generate science of lasting and major international impact, and that it is not who you are or where you come from but what you do that is important. These are the qualities that the QRA seeks to celebrate in the award of the James Croll Medal.

The Medal is therefore normally awarded to a member of the QRA who has not only made an outstanding contribution to the field of Quaternary science, but whose work has also had a significant international impact.

The QRA is pleased to announce that this year's recipient of the James Croll Medal, the senior medal of the QRA, is Professor Colin Ballantyne.

Colin Ballantyne was appointed Lecturer in Geography at the University of St Andrews in January 1980, then Senior Lecturer in 1987, and Professor in Physical Geography in 1994. Colin has also been a visiting Lecturer at the University Centre in Svalbard and twice an Erskine Fellow at the University of Canterbury in New Zealand.

Colin first developed his interest in Quaternary science and geomorphology at the University of Glasgow. With the encouragement of Rob Price he undertook an MSc degree at McMaster University in Canada, where two field seasons in the high arctic stimulated his enduring interest in periglacial environments. Returning to Scotland to undertake his PhD, he chose to study the periglacial processes and landforms on mountains in NW Scotland, supervised by Brian Sissons.

Colin's research has focused on periglacial landforms and processes. His work on periglacial phenomena led to his collaboration with Charles Harris in writing "The Periglaciation of Great Britain" (Cambridge University Press, 1994). A second focus has concerned the reconstruction of former glaciers, particularly those formed during the Younger Dryas period in Scotland. This included a significant amount of field mapping in remote parts of Scotland. These interests combined in the development of his research on the dimensions of the last British-Irish Ice Sheet. Colin has published over 150 papers, many of them influential and highly cited bench-mark papers in the field. He has also contributed over 50 chapters in books and he has edited a number of QRA field guides. At St Andrews, Colin was an enthusiastic teacher, unsurprisingly leading many student field trips. He has also taken on many administrative and leadership roles at St Andrews. He has supervised many undergraduate dissertations and a number of his PhD students are now themselves in research and teaching careers. He is a keen hillwalker, having climbed all the Scottish Munros twice, as well as climbing peaks around the world.

His high-quality research has been recognised in numerous awards and prizes including from the

British Geomorphological Research Group and the Royal Scottish Geographical Society's President's Medal (1991), Newbigin Prize (1992) and Coppock Research Medal (2015). In 2015 he was awarded the prestigious Lyell Medal by the Geological Society of London. He was elected Fellow of the Royal Society of Edinburgh in 1996 and awarded the degree of DSc by the University of St Andrews in 2000.

Since retiring in 2015 Colin has remained actively involved in research projects, publishing a number of books and papers and also leading QRA field meetings, including the field meeting to Wester Ross in May 2023.

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Honorary Members

Every year we nominate individuals for Honorary Membership of the Quaternary Research Association in recognition of significant, long-standing contributions to the QRA and to Quaternary science more widely. This year I am delighted to say that we have awarded Honorary Membership of the QRA to Mary Edwards and Martin Bell.

PROFESSOR MARY EDWARDS

Mary's interests are centred on environmental change – understanding climate-driven and human-driven alteration of landscape, vegetation, and ecosystem processes over various temporal and spatial scales. She has worked for many years in Northern ecosystems but also in temperate and tropical regions; beyond the UK, she has held positions in the USA and Norway as well as in the UK.

Her doctoral research was on the biodiversity conservation status and human-use history of oceanic woodlands in Snowdonia. This was followed by a postdoc at U Washington (Seattle) on Alaskan vegetation change, and then a faculty position at the University of Alaska-Fairbanks where her research was broad-ranging, encompassing vegetation histories, the first lake-level studies in Alaska (with Bruce Finney and Mark Abbott), and the ecology of modern plant communities that resembled the enigmatic "steppe-tundra", home of mammoths and the other northern megafauna (with Scott Armbruster). Other collaborative work on Alaska/Beringia has included pioneering studies of Alaskan boreal fire history and chironomid-based temperature reconstructions, exploration of Holocene thaw-lake dynamics, and late-Quaternary data-model comparisons. In the early 90s Mary participated in joint Russia-US field expeditions in both parts of Beringia bringing together US and Russian colleagues, in particular the late Andrei Sher (Moscow). These revealed new insights into Beringia, helped bring Russian Beringian studies into the international literature and, importantly, led to the establishment of long-term academic friendships, which stand today, despite the new political chill.

Mary retired in 2021 and is now Emerita at Southampton, where she is continuing a NERC project with Maarten van Hardenbroek (Newcastle) on the Holocene history of methane evolution from Alaskan lakes. She remains active as an adjunct faculty member at the University of Alaska-Fairbanks, currently working with colleagues on late-Quaternary sedaDNA records in archaeological settings. Mary has participated in QRA meetings and has recently been on the judging panel for the QRA Undergraduate dissertation prize.

PROFESSOR MARTIN BELL

Martin Bell was Professor of Archaeological Science at Reading University until July 2021 when he retired and was given Emeritus status. He was previously employed at the University of Wales, Lampeter, Bristol University and before that part-time at the Polytechnic of North London. He studied at the Institute of Archaeology now part of University College London where his PhD was on Valley sediments as evidence of Prehistoric land use. Unifying themes of his research are geoarchaeology, environmental and experimental archaeology and their contribution to environmental conservation. Since 1983 he has been involved in fieldwork on prehistoric intertidal and coastal sites in the Severn Estuary and four research monographs have been published on this topic. He is the author with Professor Mike Walker of Late Quaternary Environmental Change (second edition 2005) and he co-edited with Professor John Boardman Past and Present Soil Erosion (1992). His most recent book is Making One's Way in the World: the footprints and trackways of prehistoric People (Oxbow 2020). His active fieldwork on Mesolithic sites and sediments in the Severn Estuary and Kennet Valley and Experimental Archaeology continues.

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Was there a Late Devensian ice-free corridor in Pembrokeshire?

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Abstract

An ice-free enclave or corridor covering most of Pembrokeshire has featured in many of the recent reconstructions of glacial activity in western Britain during the LGM. This appears to be a hangover from the days when the terms "Older Drift" and "Newer Drift" were frequently used in the literature. However, the supposed ice-free corridor is not well supported in published studies, and it causes difficulty for those involved in ice-sheet modelling. With the aid of new field observations from scores of sites across West Wales, it is suggested that there is no convincing evidence in support of the ice-free hypothesis. The regional Quaternary stratigraphy in Central and South Pembrokeshire matches that of North Pembrokeshire and the St Brides Bay coast, and it is suggested that the whole of the peninsula was inundated by the ice of the Irish Sea Ice Stream travelling broadly NW to SE at the time of peak glaciation, around 26,000 years ago.

Introduction

In recent attempts to define the LGM limit in the western part of the British Isles there is one very strange anomaly, namely an ice-free enclave or corridor covering most of central and southern Pembrokeshire and extending south-eastwards towards the Bristol Channel (Lockhart, 2019; Chiverrell *et al*, 2020; Scourse *et al*, 2021). The LGM limit shown in Figure 1 is mirrored in many other publications. In the large paper summarising the findings of the BRITICE-CHRONO project (Clark *et al*, 2022) the authors commented on the difficulty they had in reconciling their modelling work with evidence collected in the field, but it appears that they were largely dependent upon fieldwork observations made several decades ago (Mitchell, 1960; Bowen, 1970, 1982; John, 1971; Campbell & Bowen, 1989).

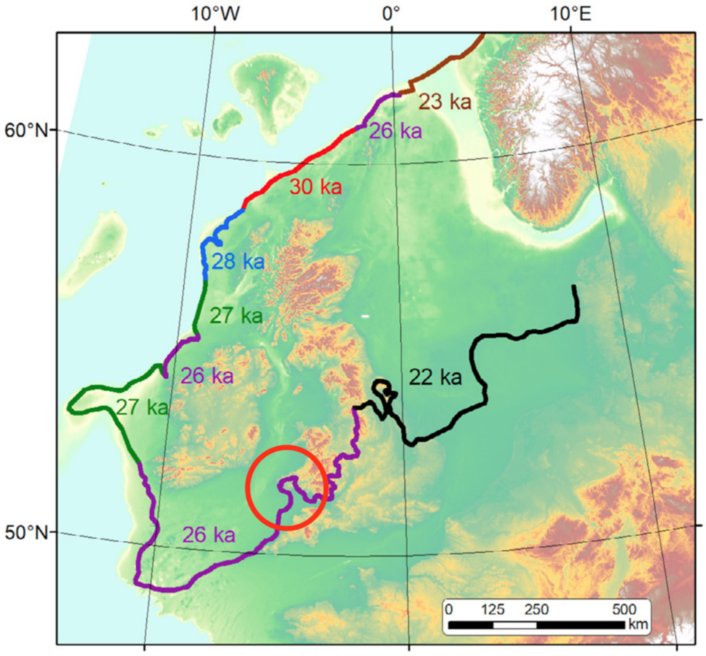

Figure 1. The 26 ka ice limit for the southern part of the British / Irish Ice Sheet, as drawn by the BRITICE-CHRONO team. Source: Clark *et al*, 2022. Most of the Pembrokeshire peninsula is shown as ice-free. The red circle shows the current study area.

The assumption of an ice-free enclave or corridor comes initially from an assertion by Charlesworth (1929) that Pembrokeshire, south of his "South Wales End Moraine", was an area of "Older Drift". This was carried through by DQ Bowen and others who thought that there was a pre-Devensian "Penfro Till Formation" (part of the Albion Glacigenic Group) across the landscape to the south of Mynydd Preseli (Bowen, 1999, 2005). However, the type localities cited by the BGS (Llandre and West Angle) have never been adequately described in the literature. At Llandre (SN092203), in a small flooded gravel pit, there is no till, and at West Angle (SM854032) the recorded stratigraphy was misinterpreted by Campbell & Bowen (1989). This may be because a steep erosional contact between a reddish glacial diamicton and a series of underlying interglacial silts and clays was not visible when the site was examined by Bowen (see below). There are indeed ancient till deposits in Pembrokeshire, but not at those two named sites. The three known ancient till exposures, all cemented, are at Black Mixen, Lydstep (SN088974), Ceibwr (SN108457) and Witches Cauldron (SN102451) (Fig. 2). None of these ties into the late Quaternary stratigraphy of West Wales, suggesting that they predate the Last Interglacial.

Whatever the shortcomings of the BGS lithostratigraphy might be, the great majority of researchers (and I include myself) have until very recently opted for an acceptance of an LGM ice-free area to the south of Mynydd Preseli in Pembrokeshire (Campbell & Bowen, 1989; McCarroll, 2001; John, 2019a; Scourse *et al*, 2021; Clark *et al*, 2022). As for the delimitation of glacial limits, the situation is best described as chaotic (Fig. 3)

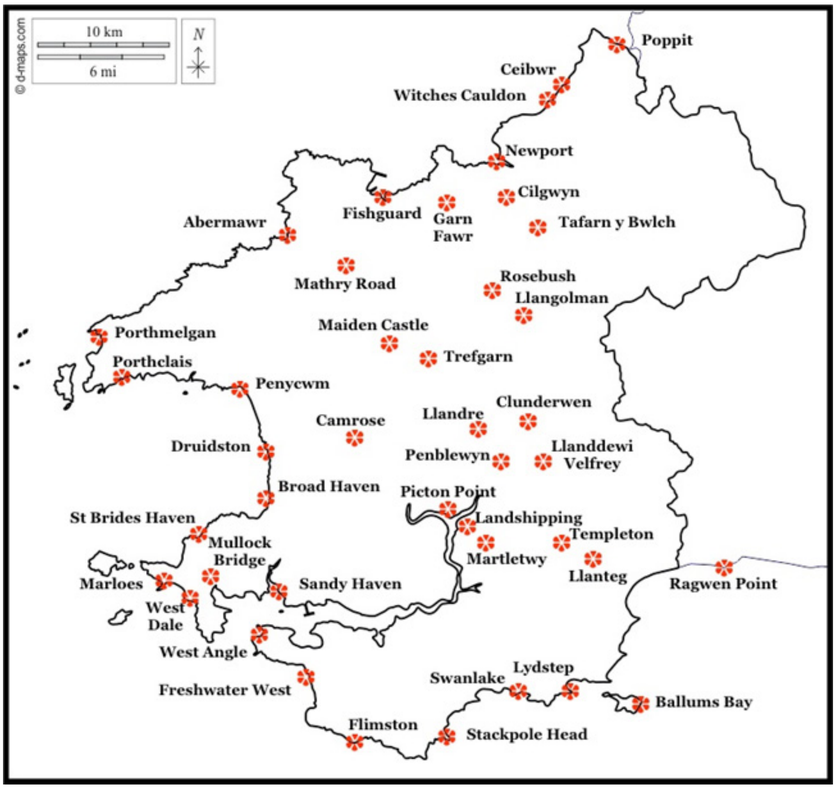

Figure 2. Locations of key Quaternary sites referred to in the text. See Appendix 1 for locational details.

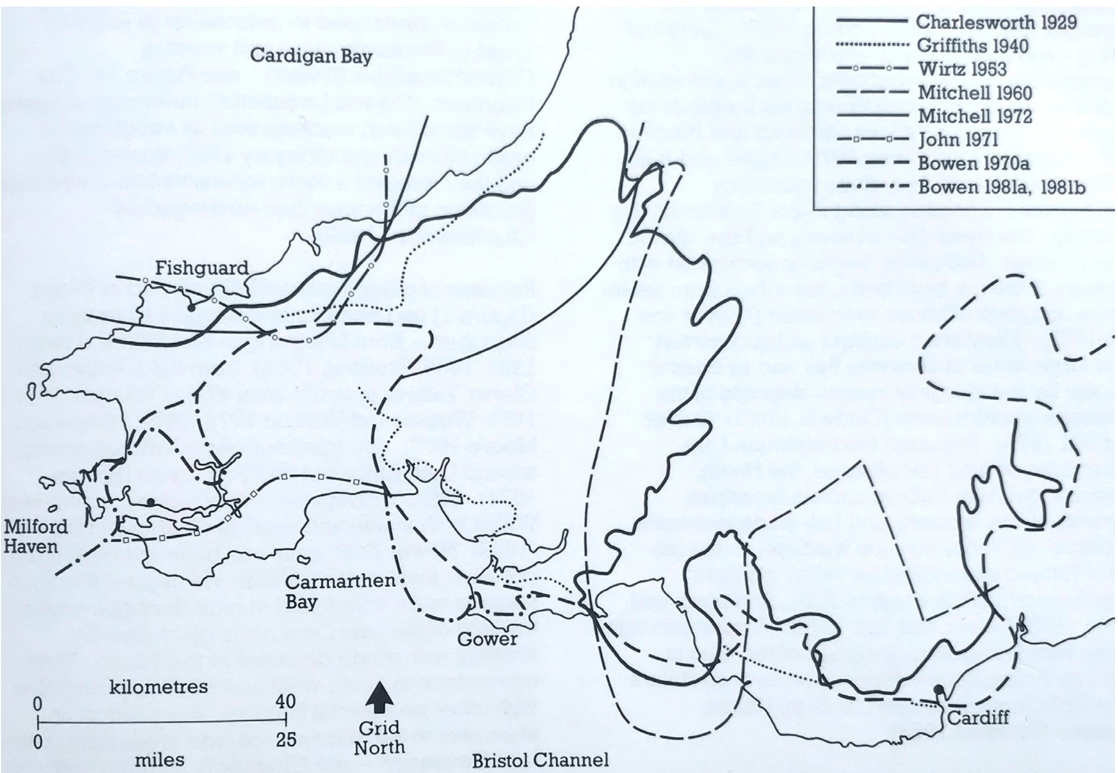

Figure 3. A confusion of suggested Devensian ice limits in West Wales. Source: Campbell and Bowen, 1989.

For some years I have been investigating the hypothesis of an ice-free or permafrost enclave or corridor across most of South Pembrokeshire at the height of the Late Devensian glaciation. The accumulating evidence is outlined below. It is hoped that this will provide a reasonable answer to this dilemma, and encourage new fieldwork and other contributions to the debate.

Glaciological considerations

If there really was an ice-free LGM corridor as shown in Figures 1 and 4, it is difficult to see how it can be explained by reference to the laws of ice physics. An ice edge as shown, running diagonally across Mynydd Preseli, is unsupported by any evidence and would in any case be an anomaly. At the LGM (c 26 ka) it is now accepted that the ice of the Irish Sea Ice Stream reached the Celtic Sea shelf edge, some 450 km to the south-west. For forward flow to be maintained, there must have been a continuous ice surface gradient from the St George's Channel and Mynydd Preseli to the shelf edge. It is now believed that the LGM ice surface altitude was possibly c 1500m in Snowdonia (Hubbard *et al*, 2011; Glasser *et al*, 2018; Clark *et al*, 2022) and c 1000m in north Pembrokeshire, as suggested in the latest BRITICE-CHRONO modelling. The ice must have spread laterally far to the east of the ice edge position shown in some reconstructions. Ice flow parallel to the ice edge, as shown in a number of maps (eg Lockhart, 2019; Van Landeghem and Chiverrell, 2020) was highly unlikely (Fig. 5) since there is no evidence of Welsh ice covering the Pembrokeshire peninsula and "blocking" ice from the west.

Off the west Pembrokeshire coast the ice was not constrained within a bedrock trough or any other deep topographic depression; the Celtic Deep is a relatively minor feature. It therefore makes glaciological sense for the eastern part of the LGM Irish Sea ice stream

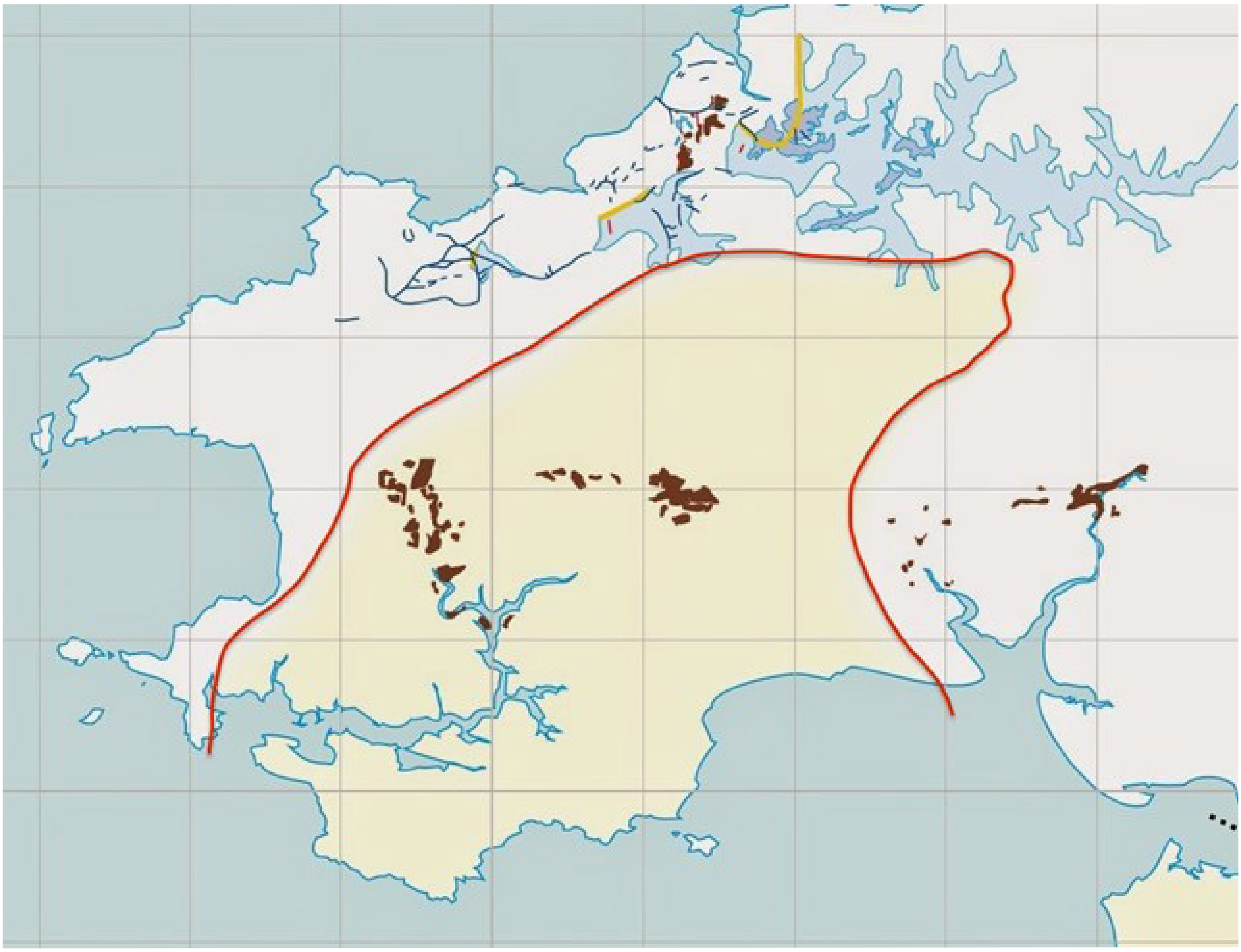

Figure 4. The BRITICE-CHRONO (2004) map of glacial deposits in the supposed Devensian ice-free area of West Wales. The cream coloured areas are assumed to have been unglaciated in the Devensian. Patches shown in brown are interpreted as pre-Devensian glacial and glaciofluvial deposits — but many similar deposits have been ignored in the mapping. Thanks to BRITICE-CHRONO / Creative Commons.

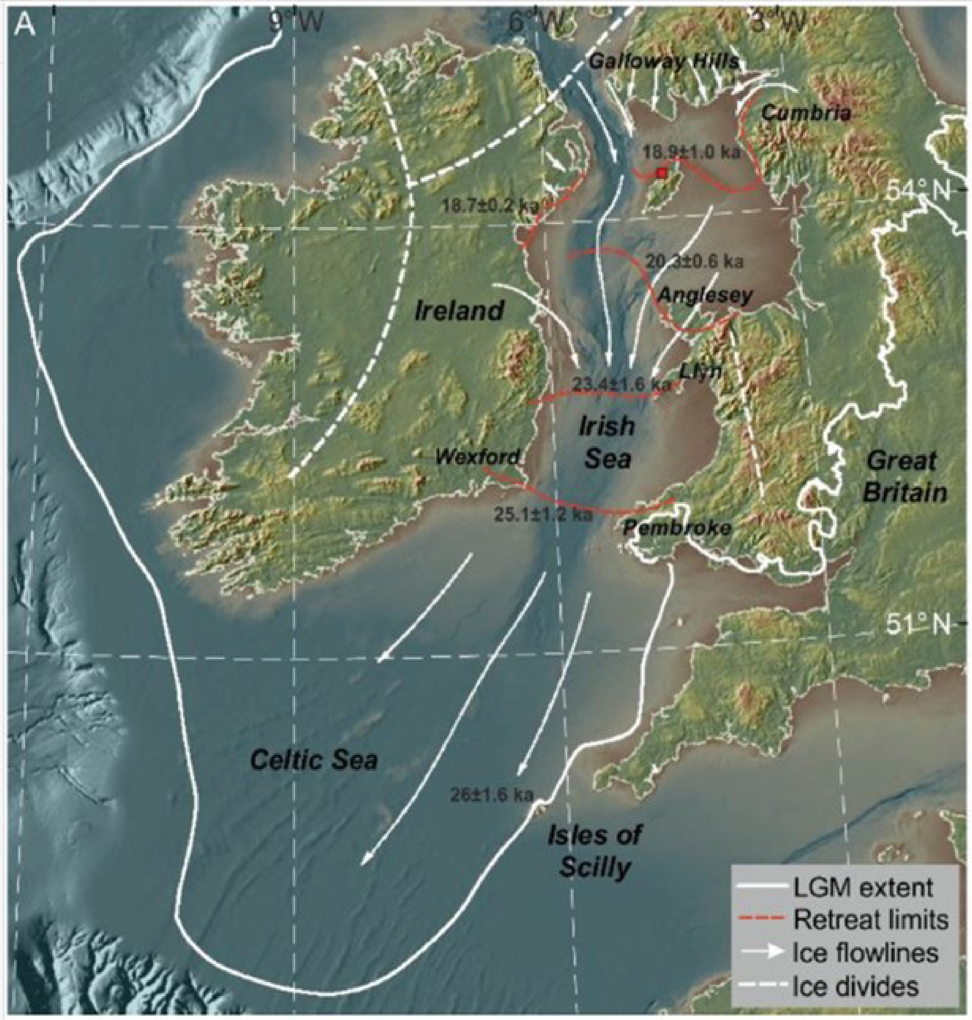

Figure 5. Hypothetical ice streaming directions through St George's Channel and the Celtic Deep. Thanks to Jenkins *et al* 2018 / Creative Commons. It is likely that there was much more lateral spreading on the eastern flank, unless the Bristol Channel was filled with Welsh ice. Across Pembrokeshire the field evidence all points to ice movement towards the SE, not the SW.

to have flowed not south-westwards but broadly south-eastwards, into Carmarthen Bay and the outer reaches of the Bristol Channel (John, 1968, 2018a and 2018b). So might this ice have affected central and south Pembrokeshire? It must have done, unless there was a steep and spectacular ice ramp or ice cliff in St Bride's Bay.

Field Observations and Interpretations

1. There are many more extensive spreads of glacial and fluvio-glacial deposits than those shown on Figure 4, in the areas deemed to be outside the LGM limit. Some of the deposits appear to be unweathered, and some even have surface expression, as at Llangolman (SN116269), Rosebush (SN071229) and Clunderwen (SN120192). They are by no means all "degraded or denuded" and they are not restricted to hilltops or interfluves, as was suggested by Charlesworth (1929). The extensive exposure of till running eastwards from Martletwy (SN049113) via Templeton (SN112115) to Llanteg (SN181103) runs across a number of terrain types. Some deposits incorporate weathered or rotten clasts, and there is a possibility that there has been considerable recycling of older materials. The evidence of these extensive superficial deposits is accessible on the BGS map viewer.

2. On the coasts of St Bride's Bay, and around the mouth of Milford Haven, sites such as Broad Haven (SM860144), Druidston (SM863172), St Bride's Haven (SM802111), Dale (SM799043), Westdale (SM800058), Mullock Bridge (SM811082) and Marloes (SM782076) tell a consistent story. At Sandy Haven (SM860072), assumed by many to be outside the LGM ice limit, the Quaternary succession is as follows:

6. Modern soil
5. Fine-grained colluvium (aeolian? slope wash?) up to 1m thick
4. Thin slope breccia generally c 1m thick, incorporating glacial debris
3. Sandy gravelly diamicton (till) up to 4m thick, incorporating slope breccia
2. Slope breccia and colluvial deposits -- many different facies
1. Raised beach cobbles -- c 20 cm thick (disturbed?)

Erratics and sediment sequences show — as on the north Pembrokeshire coast — a substantial ingress of ice from the west and north-west, pressing some distance inland. At Marloes there are glaciotectonic structures in the glacial deposits.

3. The proposition that glacier ice was streaming from north to south, or NE to SW, is not supported by bedrock striae recorded in coastal locations. At six sites along the north Pembrokeshire coast (namely Poppit, Newport, Parrog, Abermawr, Porthmelgan and Whitesands) detailed measurements show that the predominant direction of ice flow was NW - SE, and this accords with the records of glacial erratic movement published by Geological Survey field workers more than a century ago (Dixon, 1921) and by Griffiths (1940).

4. Roadworks in the Redstone - Penblewyn - Llanddewi Velfrey area, north of Narberth, in 2022, reveal up to 8m of stony clay-rich diamictons and sand and gravel deposits across the landscape but unmapped by the BGS. Near Penblewyn Roundabout (SN123167) a sheet of sticky blue-grey and relatively unweathered diamicton is exposed at the surface; it has a similar texture and colour to the Irish Sea till exposed at Abermawr (SM883347), Druidston (SM863172) and Porthmelgan (SM727279). Faceted and striated boulders and cobbles are found in temporary roadworks exposures. One prominent boulder of red sandstone has a weathering crust which has been striated, suggesting that older deposits have been recycled and incorporated by overriding ice. Other deposits with a reduced content of silts and clays, and a higher proportion of sands and gravels, are interpreted as meltout tills, flowtills and glaciofluvial accumulations. These appear just as fresh and unweathered as the glacial deposits exposed in North Pembrokeshire coastal sections, and there is no reason thus far to assume that they are any older.

5. The diamictons in the valleys and on the clifftops of the South Pembrokeshire coastal plateau are so abundant and so fresh in appearance that they are most likely related in age and origin to those on the North Pembrokeshire cliffs. At Swanlake (SS045980) the exposures in the cliffline adjacent to the beach mostly comprise ORS rockfall and slope breccia accumulations, but adjacent to one of the footpath gullies there is an exposure of uncemented clay-rich diamicton with abundant erratic pebbles, some of which show evidence of pressure fractures. Above this, erratic pebbles are incorporated into matrix-supported slope deposits. On the flat Carboniferous Limestone clifftops around Stackpole Head (SR992943) and Stackpole Warren (SR984942) there is a sandy and silty diamicton occasionally over 1m thick, containing pebbles of all shapes and sizes.

The main rock types represented are limestone, shale and mudstone, ORS sandstones and grits, and flints. The deposits are uncemented. In a number of locations the most striking characteristic of the diamictons is the presence of abundant well rounded quartz pebbles and cobbles which must be related to the Oligocene quartz pebble accumulations found in clay pits on the coastal plateau near Flimston (SR927952). In the graveyard at Flimston there are seven igneous erratics, some of which have been used as headstones for graves. They have come from the St David's area (Dixon, 1921), and most of them were collected from within a few km of the churchyard. They are heavily weathered and abraded. On the nearby clifftops there are abundant exposures of unconsolidated diamicton, up to 2m thick, with well rounded quartz pebbles set

Figure 6. Stony sandy diamicton with striated erratics and locally derived quartz pebbles on a flat-topped clifftop near Bullslaughter Bay, South Pembrokeshire. This is not a gash breccia, nor is it cemented, nor is it a slope deposit, and it is interpreted as an *in situ* Devensian till.

in a sandy and gravelly matrix. The BGS surveyors recorded the presence of striated igneous pebbles. There are other exposures of reddish diamicton up to 3m thick and containing abundant rounded and faceted erratic pebbles on the clifftops near Huntsman's Leap (SR961929), Mewsford Point (SR942938), and Bullslaughter Bay (SR941943) (Fig. 6). The only deposits overlying these diamictons are reddish sandy loams and blown sand, generally less than 1m thick. At Stackpole Quay (SR993956), at an altitude of c 35m, there is a deposit of gravelly diamicton about 3m thick, incorporating igneous erratics. All of these diamictons studied are uncemented, even when capping limestone cliffs where carbonate cement is abundant. They have to be interpreted as fresh tills similar in appearance to the tills on the south coast of the St David's Peninsula, with lithological variations in tune with local source materials. They are not recycled or redeposited slope accumulations, since many of them rest on a flat plateau surface. Thus they should probably be interpreted as Late Devensian in age.

6. Other key locations outside the postulated LGM ice limit include the sandy beaches at Freshwater West (SR880005), Lydstep (SS087977), and Amroth, (SN161068), where clay-rich diamictons with abundant faceted erratic cobbles and boulders are seen beneath Holocene peat beds and "submerged forest" remnants which are intermittently exposed between HWM and LWM. At Ragwen Point (SS219071) near Pendine in Carmarthen Bay, the following sequence of deposits is seen:

9. Modern soil and colluvium —30 cm
8. Upper slope breccia — up to 2m
7. Patchy blue-grey clay-rich diamicton (till) — c 2m. (in part slumped to beach level)
6. Lower slope breccia and rockfall debris — up to 4m
5. Hardpan / cemented silty layers c 40 cm
4. Dark organic silts 30 cm
3. Iron-stained sandy layer (cemented) 1m
2. Buff coloured sandrock with cavities and rockfall inclusions 2m
1. Raised beach with large embedded boulders and sandrock layers 2m

At West Angle (SM854032) the Quaternary sequence is interpreted as follows:

10. Soil and colluvium — c 1m
9. Dark red stratified horizon — 3m, late glacial
8. Dark red diamicton (non-stratified) — till c 3m
7. Orange silt and clay series — 2m, interglacial dune slack environment (freshwater)
6. Grey silt and clay series — 2m, interglacial dune slack environment (freshwater)
5. Peat and peaty silt — 60 cm, interglacial dune slack environment (freshwater)
4. Stony grey silts — c 1.5 m thick with slope breccia — interglacial
3. Stained bedded sands and gravels — c 1.5 m thick — interglacial shoreline deposits
2. Rounded pebbles / beach shingle — c 1.8 m thick — interglacial raised beach
1. Sand — more than 1 m thick — interglacial sandy beach

Contrary to the claims of earlier researchers including DQ Bowen (1974), there is no ancient till at this site beneath the raised beach and interglacial silt and clay sequence. But there is a striking erosional contact deformed by glaciotectonics towards the northern end of the cliff exposure, visible only after careful excavation, showing slabs or lenses of interglacial silts and clays incorporated into dark red till by overriding ice. Bowen clearly saw a part of one of these lenses and assumed that it belonged to an in situ interglacial layer which was younger than the till that it now rests upon.

At each of these sites the diamictons interpreted as tills occupy stratigraphic positions identical to their equivalents in North Pembrokeshire, and they are are so close to the surface that they must be interpreted as late Devensian in age. There is no reason, anywhere, for them to be interpreted as recycled or redeposited ancient tills. The interglacial sediments at West Angle are interpreted as Ipswichian in age, but the pollen analyses are difficult to interpret (Stevenson and Moore, 1982). New work is needed, but unfortunately the peaty sediments now appear to have eroded away.

7. The diamicton in Ballum's Bay (SS147966) on Caldey Island which was discussed in QN 149 with Prof John Hiemstra and others is unconsolidated and is similar in texture and appearance to other deposits on the island. It is stratigraphically younger than the adjacent cemented raised beach and slope breccia deposits in Ballum's Bay which are reasonably interpreted as Ipswichian and Early Devensian in age (Hiemstra *et al*, 2019; John 2019a). There is no reason why the diamicton should not be interpreted as an *in situ* till, since no firm evidence has been brought

forward to show that it is reconstituted or recycled. Its reddish colour is down to the incorporation of Devonian sandstone debris, which means that it has been transported by ice from the west.

8. The stony clay-rich diamictons and the sands and gravels around Picton Point (SN002118) and Landshipping (SN008114), in the centre of the county at the confluence of the two Cleddau rivers, are indistinguishable from the related deposits of North Pembrokeshire, and appear to have been emplaced during a relatively recent glaciation. They cannot adequately be explained without invoking a complete ice cover across Pembrokeshire. There is also coherent till near Camrose. The sheets of fluvioglacial gravels that partly fill the Western Cleddau valley both to north and south of the Trefgarn Gorge (SM960250) are here interpreted as deposits linked to catastrophic Late Devensian ice wastage and southwards drainage diversion. These gravels might well be amenable to OSL dating.

9. There are apparent trimlines and glacial deposits at a variety of altitudes on the northern flank of Mynydd Preseli, up to an altitude of at least 340m, and possibly as high as 420m. In the past I have interpreted that as the altitude of the highest Devensian ice surface associated with Irish Sea ice, but I now consider it more likely to indicate a transition from a cold-based to a warm-based ice cover. This would accord with the modelled BRITICE-CHRONO ice surface reconstruction at c1000m. Ice must have filled the Cwm Gwaun depression and its pre-existing meltwater channels, and there are apparent morainic features above and on the south side of the main channel, and at Pont Ceunant (SN046375), Cilgwyn (SN075363) and Tafarn y Bwlch (SN083333). It is also possible that the other morainic ridges and glaciofluvial mounds in and around the Preseli uplands may be associated with retreat stages or short-lived readvances around 25,000 yrs BP, either associated with a Preseli ice cap or with invasive ice from Cardigan Bay (Scourse *et al*, 2021). These stages are still to be defined, as are their links with the fluvioglacial sands, gravels and lacustrine deposits in the Cardigan area.

10. Ice moulded or streamlined bedrock surfaces are abundant, and they are not restricted to Preseli. Examples can be seen on Carnllidi, near Strumble Head, in Lower Town Fishguard, on Dinas Mountain (Fig. 7), on Carningli, at Carnedd Meibion Owen and on Carn Goedog, Carn Alw and Carn Meini on the Preseli upland. The "denuded tors" between Dinas and Newport are often cited as evidence of a Late Devensian ice cover; and the fragile appearance of Maiden Castle tor (SM955248), near Trefgarn, is cited as evidence that it cannot have been glaciated so recently. But tor survival and modification is a very complex matter, and a cosmogenic dating programme is needed in order to establish which features are inherited, and which are genuinely of Devensian age (Hall and Sugden, 2006; Gunnell *et al*, 2013).

Figure 7. Striated and ice moulded rock surface on the dolerite tor of Garn Fawr, Mynydd Dinas. The bedrock is heavily fractured unspotted dolerite. Altitude 300m.

11. Similarly, the evidence of glacial erratic transport and distribution cannot safely be cited in support of any LGM reconstructions (Griffiths, 1940). But there is now a good database of erratic boulders with known geological provenances that have ended up in other places, broadly to the south or south-east. The distances of travel also vary greatly. Igneous boulders (such as those at Flimston, St Bride's Haven, Druidston and Broad Haven) have almost certainly followed zig-zag courses during the Quaternary glacial episodes, and may have been moved on at least three separate occasions.

12. If Pembrokeshire to the south of Mynydd Preseli had been ice-free for the duration of the Ipswichian interglacial and the Devensian cold phase, we would expect the known Quaternary deposits to have been capped with slope breccia and colluvium; there are some patches but they are no thicker or more prominent than those of the north coast. Furthermore, there are no extensive occurrences of patterned ground, or other evidence of prolonged permafrost conditions across a full glacial cycle. There are churned gravels and fossil ice wedges in the gravel pit at Llangolman (SN116268), but they are no more extensive or prominent than the periglacial features seen in glaciofluvial terraces at Mullock Bridge and Mathry Road (SM923312) which are interpreted as Late Glacial in age (John, 1970).

13. If the concept of complete ice cover on Pembrokeshire during the LGM is to stand up, it must also fit with the evidence obtained in the South Pembrokeshire and Gower bone caves including Eel Point, Ogof yr Ychen, Coygan and Paviland (Walker, 2019). It looks as if the evidence does hold, although great care must be taken because of the uncertainties surrounding radiocarbon age determinations and calibrations. Elizabeth Walker thinks that there might have been human occupation of some caves on the limestone coast prior to 30,000 years ago, and Schulting *et al* (2005) refer to occupation by the "Red Lady of Paviland" and by humans at Eel Point on Caldey Island after 26,000 yrs BP and many other caves by about 12,000 years ago. There appears to have been a gap, so it is suggested tentatively that the human occupation and tundra animal evidence does fit around a short-lived glacial episode culminating around 26,000 years ago (Scourse *et al*, 2021).

14. There are no linear features such as terminal or marginal moraines along any of the postulated Irish Sea Ice Stream LGM ice edges in West Wales. The "South Wales End Moraine" has long since been dismissed as a significant ice edge marker (John, 1970).

Discussion

From an assessment of multiple sites inland and on the coast, this is the regional Quaternary stratigraphy for South Pembrokeshire:

8. Sandy loam and blown sand
7. Upper slope breccia (uncemented)
6. Fluvioglacial sands and gravels -- mostly inland exposures
5b. Meltout till / flowtill— many coastal exposures
5a. Lodgement till from LGM (Devensian) glaciation — inland exposures
4c. Lower slope breccia (cemented in some localities)
4b. Cemented sands (sandrock)
4a. Slope breccia incorporating raised beach cobbles (cemented)
3. Cemented raised beach (Ipswichian)
2. Older glacial deposits -- mostly destroyed, but exposed at Lydstep (Black Mixen)
1. Raised beach platform (complex modifications over several interglacials?)

This stratigraphy is essentially the same as that established for North Pembrokeshire, in the area long since accepted as having been affected by Irish Sea ice during the LGM. If we cannot identify any strong distinguishing features in the landscape and Quaternary sediments to the south of Mynydd Preseli, then we cannot sustain the narrative involving an LGM ice-free corridor or enclave. The lack of identifiable constructional landforms associated with glaciation (eg moraines, kames and eskers) in South Pembrokeshire may be cited as evidence for the lack of a Devensian ice cover; but there are no such features in the St David's Peninsula and on Pencaer either, and these areas have never been referred to as "Devensian ice free enclaves". Clearly, we still do not fully understand why glacial deposits and landforms seem to be clustered into some areas and not others!

But there is one persistent question that has to be answered: What if the South Pembrokeshire "glacial deposits" are all recycled or redeposited tills of great age, moved during the last glacial cycle by slope processes? After all, the pseudo-stratified slope deposits of Morfa Bychan, on Cardigan Bay have

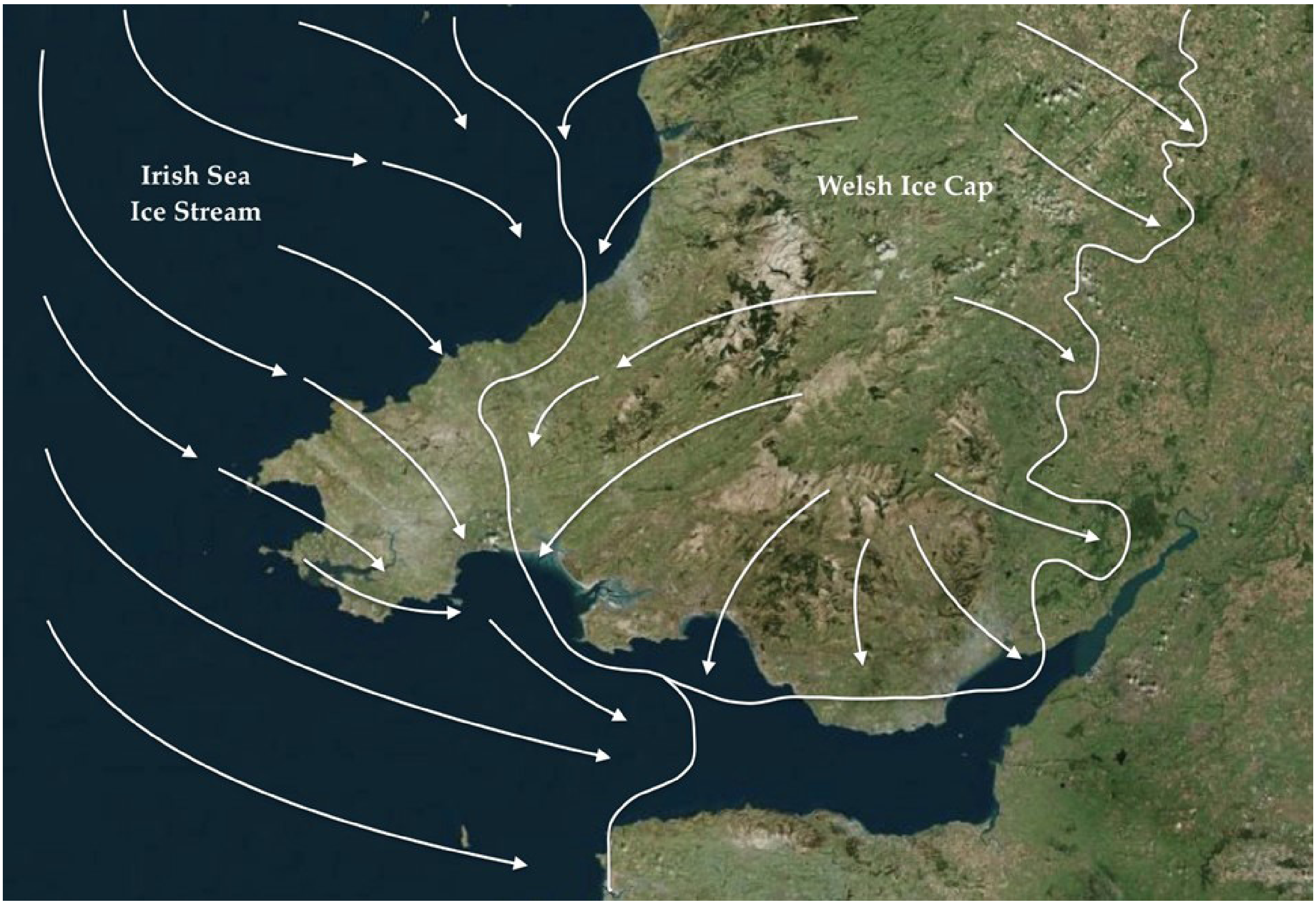

Figure 8. Hypothetical flowline pattern of glaciation for West Wales at the time of the Devensian LGM. Ice edge oscillations on the eastern flank of the Welsh Ice Cap may not have been synchronous with those on the western flank.

been interpreted by Watson (1970) as slope deposits incorporating older glacial materials; and Hiemstra and Shakesby (2015) have suggested that the deposits at Rotherslade, Gower, are not *in situ* glacial deposits but materials remobilised and re-deposited with the aid of meltwater under paraglacial conditions. The pseudo-stratified deposits at Westdale (SM799057) may be interpreted in a similar fashion. However, very few of the West Wales Quaternary deposits can be interpreted as lodgement tills, and where till does occur in cliff exposures it is sometimes deformed and is often associated with glaciofluvial deposits. So the mobilisation and redistribution of glacially derived materials was commonplace, and tells us much about the chaotic conditions that must have prevailed at a time of catastrophic ice wastage around 25,000 years ago.

There is just one known deposit in the study area that is clearly in a secondary position. As noted above, at Ragwen Point a grey clay-rich diamicton interpreted as a till is seen at beach level surrounded by sandy brown slope breccia mixed with colluvium. Both deposits have clearly slumped recently from higher up the cliff as a result of ongoing coastal erosion.

If the South Pembrokeshire tills were really re-deposited pre-Ipswichian glacial deposits they would almost certainly have been cemented (especially in carbonate-rich environments) and they would be expected to appear more or less randomly in Devensian slope deposits either as lenses or as erratic clusters. There is no such sedimentary association, although here and there (as at Whitesands) we find "boulder beds" associated with the raised beach (at the base of the Quaternary successions) and which may well be linked with destroyed Wolstonian or Anglian glacial deposits.

Conclusion

If Late Devensian ice from the N or NW covered the northern uplands of Pembrokeshire and had a surface elevation of c 1000m, it would make no sense for the ice edge to be at or near present sea level around the mid and south Pembrokeshire coast. Nor does it make any sense for an ice edge to be parked around the 200m contour in the vicinity of Wolfscastle and Letterston, as suggested by the BGS (2010). If the ice was coming in from the NW, it MUST have inundated the whole of Pembrokeshire to the south of Preseli, given that the ice was dynamic and fast-flowing (Boulton & Hagdorn, 2006; Scourse *et al*, 2021). The ice edge might of course have been slightly lower on the southern flank of the uplands, once the disintegration of the Irish Sea Ice Stream had commenced.

The Preseli trimline is a subtle one, and the presence of thin local tills suggest that there was a Preseli ice cap early and late in the Devensian glacial cycle, as suggested in the modelling by Henry Patton *et al* (2017) in association with studies of the Welsh ice cap. The junction between the Preseli ice and the Irish Sea ice is unlikely to have been static, and it will be interesting to see what further fieldwork and modelling work might reveal.

The field evidence from the south Pembrokeshire coast and from inland sites suggests that the deposits tie in lithologically and stratigraphically with those of North Pembrokeshire, and there appears no reason to differentiate between them as the products of older and newer glacial episodes.

The simplest interpretation of the accumulating field evidence is that there was no Late Devensian ice-free enclave or corridor in south Pembrokeshire (Fig. 8). It is therefore suggested that the WHOLE of the peninsula was ice-covered around 26,000 years ago, and it is quite possible that the ice cover also extended across Carmarthen Bay and the Gower Peninsula. It is also suggested that there was no Early Devensian glacial episode that affected the Pembrokeshire peninsula. This was a time dominated by snowfields, permafrost and the accumulation of brecciated slope deposits.

It is hoped that this hypothesis will encourage further research, including the cosmogenic dating of erratics and exposed rock surfaces in Pembrokeshire. But here is another question: where are the glacial and related deposits that might be considered as the equivalents of the Wolstonian and Anglian unconsolidated strata described in eastern England?

Notes

I am grateful to Dr Bethan Davies for her helpful comments on the original draft of this article, and I have learned much from discussions with many of those whose works I have cited. I also thank members of the BRITICE-CHRONO team for consent to use a number of their published illustrations.

In this short paper it is not possible to detail the field evidence from multiple sites. However, detailed descriptions and interpretations from scores of named locations are contained in the author's blog site, via the search facility: https://brian-mountainman.blogspot.com/ The site is archived by the National Library of Wales as a resource for data and debate in the fields of Quaternary studies, glacial geomorphology and archaeology.

Appendix 1

Geographical coordinates for key locations: mentioned in the text:

Abermawr 51.970615, -5.082866
Amroth 51.730007, -4.663867
Ballum's Bay 51.637549, -4.678081
Broad Haven 51.787828 -5.103833
Bullslaughter Bay 51.610258, -4.976904
Camrose 51.83896, -5.00800
Ceibwr 52.07798, -4.76285
Cilgwyn 51.993226, -4.801698
Clunderwen 51.992041 -4.889001
Dale 51.787828 -5.103833
Druidston 51.813198, -5.103692
Flimston 51.612919, -4.988760
Flimston Claypits 51.617696, -4.995016
Freshwater West 51.663545, -5.065606
Huntsmans Leap 51.599311, -4.944953
Landshipping 51.765169, -4.888542
Llanddewi Velfrey 51.822520, -4.690913
Llandre 51.84822,-4.77129
Llangolman 51.908453, -4.740323
Llanteg 51.76123, -4.63508
Lydstep 51.643456, -4.764696
Maiden Castle 51.884524 -4.974400
Marloes 51.723541, -5.214248
Martletwy 51.760678, -4.845621
Mathry Road 51.940011, -5.023764
Mewsford Point 51.60603, -4.97217
Mullock Bridge 51.729463 -5.169435
Parrog 52.022244, -4.848200
Penblewyn 51.817070, -4.727234
Picton Point 51.768802, -4.896984
Pont Ceunant 51.999691, -4.849897
Porthmelgan 51.903608, -5.303722
Ragwen Point 51.735029, -4.580841
Rosebush 51.928104, -4.805773

Sandy Haven 51.723364, -5.102251
St Brides Haven 51.729463 -5.169435
Stackpole Head 51.611409, -4.900273
Stockpole Quay 51.623525, -4.901412
Stackpole Warren 51.611481, -4.914393
Swanlake 51.646656, -4.825613
Tafarn y Bwlch 51.965316, -4.792336
Templeton 51.771486, -4.741989
Trefgarn Gorge 51.880155, -4.967766
West Angle 51.685550, -5.106653
Westdale 51.708268, -5.186299
Whitesands 51.895342, -5.295662
Witches Cauldron 52.070961, -4.771064

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Quaternary Newsletter
Article

THE 70 AND 45 METRE O.D. STRANDLINES IN THE VALE of PICKERING

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Introduction

While Carvill Lewis (1894) is accredited with the earliest recognition of a glacial or extra-morainic lake in the Vale of Pickering by Kendall in 1902, the first mention of two temporally defined stands of a Glacial Lake Pickering was provided by Straw (1979). Straw (1979) considered that the two phases of the glacial lake included a high-level phase at 70 m O.D. and a low-level phase at 45 m O.D. Evans *et al*. (2017) likewise also recognized two levels of Glacial Lake Pickering. Based on luminescence dating, from East Heslerton, Evans *et al*. (2017) concluded that the 45 m level of Glacial Lake Pickering dates to c. 17.6 ka with the 70 m lake level being much earlier and relates to ice-damming the Coxwold-Gilling Gap and the Derwent Valley near Kirkham Priory, south of Malton (Evans *et al*., 2017; see also Bateman *et al*. 2015). It was also considered by Evans *et al*. (2017) that the 70 m lake may have drained through a spillway at Hunmanby.

Confirmation of the generation of two glacial lakes in the Vale of Pickering resulted from landform mapping by Fairburn (2019), who identified two distinct sets of alluvial fans on both the northern and southern flanks of the Vale of Pickering: the implication of this mapping was that drainage from the Vale has been blocked on two occasions. The erosional and/or depositional boundaries of the major landforms in the Vale, such as the Hutton Buscel Terrace and Wykeham

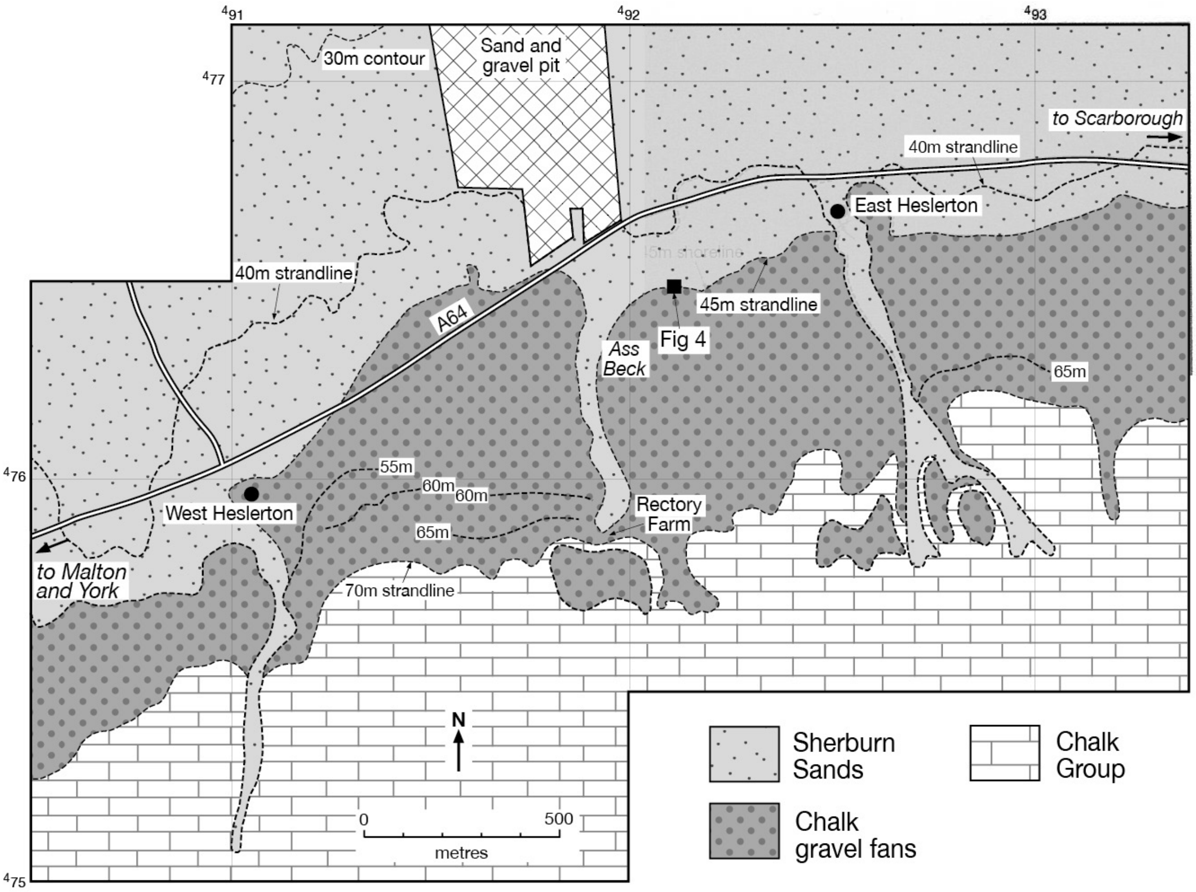

Figure 1. Landform and geological map of the Vale of Pickering between East and West Heslerton showing the 45 m and 70 m O.D. strandlines and the location of Figure 4). From Fairburn and Bateman 2021, (with permission).

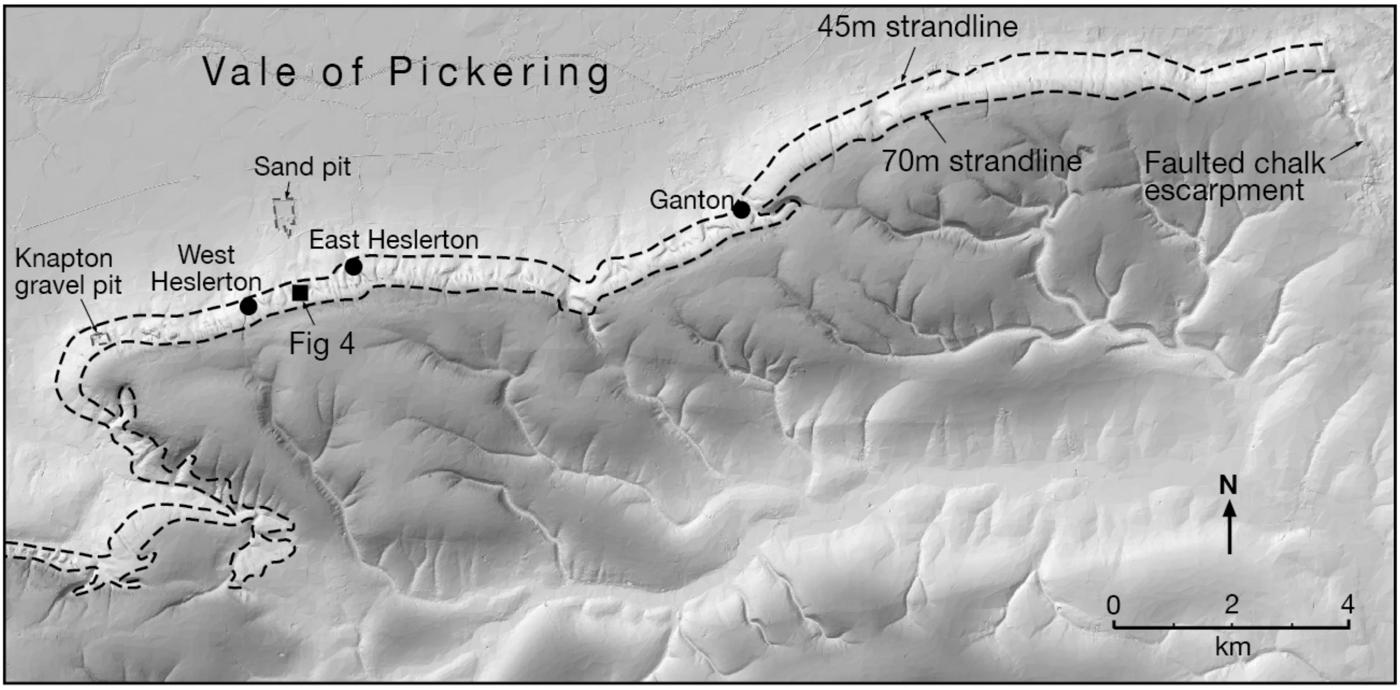

Figure 2. Digital elevation model of part of the southern margin of the Vale of Pickering showing the hummocky chalk-gravel alluvial in between the 45 m and 70 m O.D. strandline and the location of Figure 4. From Fairburn 2019, (with permission).

Moraine at c. 45 m O.D. and c. 70 m O.D., attest to the model. Consequently, the field mapping, supported by mapping from digital elevation models (Fairburn, 2019), provide robust evidence for the validity of the glacial lakes and their imprinted strandlines. Claims by Eddey *et al*. (2022) that the geomorphic evidence for a Glacial Lake Pickering is 'weak and contested' does not appear credible.

The objective of this article, while redefining the origin and extent of the 70 m O.D. strandline on the present landscape, is mainly designed to provide additional field evidence for the validity of the more obscure 45 m O.D. strandline.

The 70 m O.D. Strandline

A suggestion by Eddey *et al*. (2022) that there is no unequivocal evidence for a well-defined 70 m shoreline in the Vale of Pickering is not supported by the observations of Evans *et al*. (2017) or by field mapping, as the 70 m shoreline forms a distinct boundary between chalk gravel fans and the Chalk Group of the Yorkshire Wolds on the southern side of the Vale (Figures 1 and 2; Fairburn and Bateman, 2021) and between fluvial sediments and Jurassic limestones on the northern side of the Vale (Fairburn, 2019, Fairburn and Bateman, 2021). In places the boundary is enhanced by a riser above the 70 m O.D. strandline (Fairburn and Bateman, 2021).

An alternative suggestion for the origin of the 70 m O.D. strandline was proposed by Fairburn (2022), who concluded that c. 70 m O.D. lake never existed and that the 70 m O.D. strandline is a rebound surface resulting from post-MIS 6 glacioisostatic uplift of terracing from a c. 40 m O.D. mid-Pleistocene lake. This rebound surface is therefore part of the surface of the so-called 52 metre Strandline, defined by Penny (1974), that rises from c. 40 m O.D. near Elloughton to 70 m O.D. near Crambe (Fairburn, 2022). That such significant post-glacial rebound can occur is based on the current realization that an MIS 6 terrestrial glaciation could have been a widespread Saalian advance in the UK (Powell *et al*., 2016; Gibbard *et al*., 2018; Evans *et al*., 2019, Gibson *et al*., 2022) likely extending from north of the Vale of Pickering to North Norfolk. A significant part of this 52 metre Strandline, between Goodmanham (55 m) and North Cliff (65 m) is shown in Figure 3. The strandline must have a maximum age of 156 ± 12 ka – an IRSL date of fluvial sediments below the strandline in Yedman Dale (Fairburn and Bateman, 2021).

The 45 m O.D. Strandline

Based on 'new geographic mapping' and 'paleographical reconstructions' Eddey *et al*. (2022) suggested that Paleolake Pickering was feasible up to 45 m O.D. It should be noted that a 45 m O.D. strandline, extending through East and West Heslerton has been mapped in the field by Fairburn and Bateman (2021). The 45 m O.D. strandline also provides a marked cutoff at the base of the Hutton Buscel Terrace (Fairburn 2019) and outlines the base of the Wykeham Moraine (Fairburn, 2022). It is also clearly depicted on LiDAR imagery below the Chalk Group escarpment (Figure 2). Recent newly acquired photography from near East Heslerton provides a further presentation of the 45 m O.D. strandline where it is backed by an approximate 1.0 m riser below the chalk gravel alluvial fans (Figure 4). Contrary to the mapping of Fairburn and Bateman (2021), Eddey *et al*. (2022) have interpreted the 45 m O.D. strandline as the northern boundary of the Yorkshire Wolds escarpment.

Conclusions

Based on geological mapping and LiDAR imagery, supported by IRSL dating (Fairburn, 2019; Fairburn and Bateman, 2021), two temporally distinct lakes (during MIS 2 and MIS 6) have been firmly identified in the Vale of Pickering. This contrasts with the opinions of Eddey *et al*. (2022) that 'geomorphic evidence' for the existence of a glacial lake in the Vale of Pickering is 'weak and contested.'

Failure to accept geological mapping in the Vale of Pickering has led to incorrect location recognition of the Wolds Escarpment.

The 70 m O.D. strandline has probably resulted from post-MIS 6 isostatic rebound.

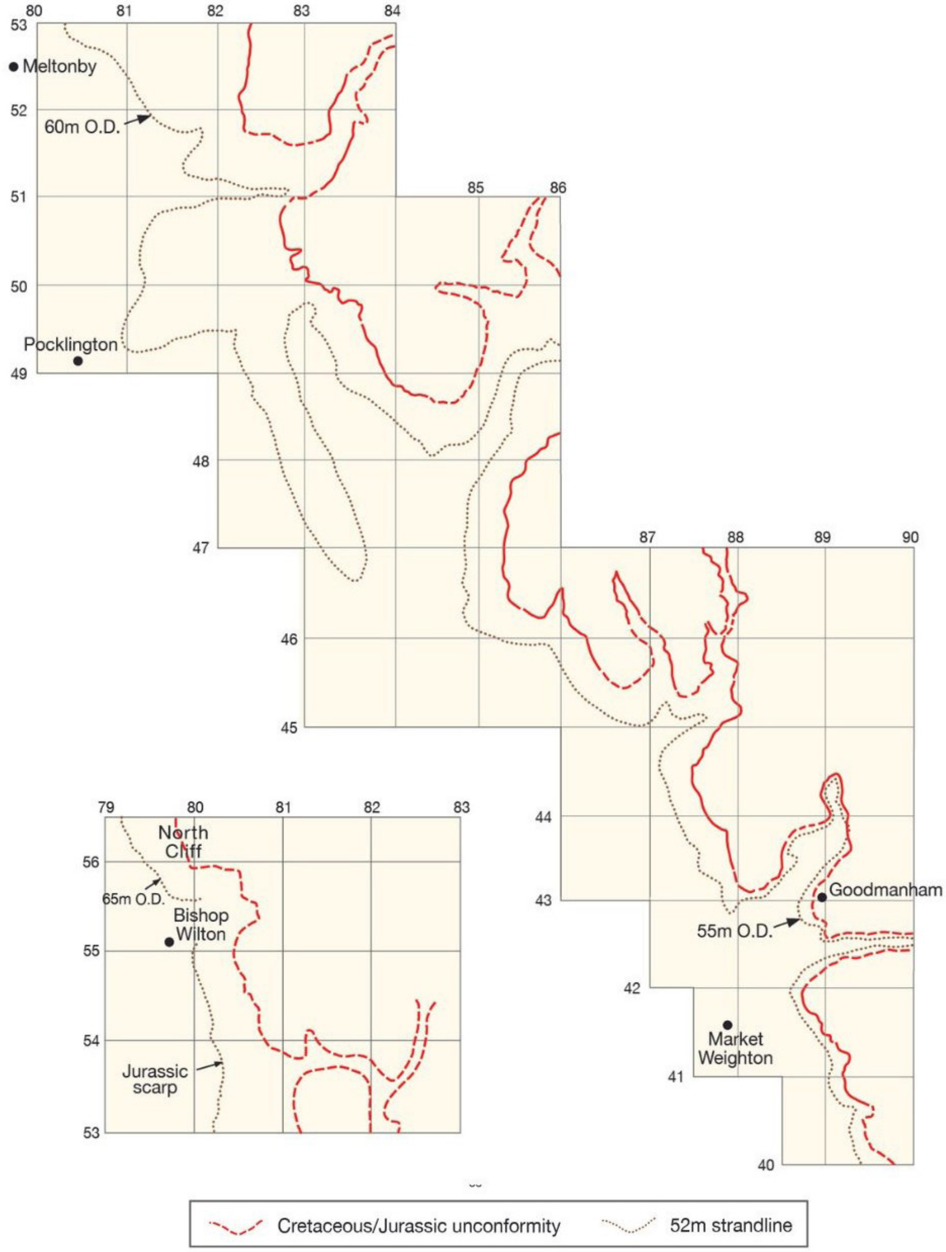

Figure 3. Plot of the 52 Metre Strandline and the Jurassic/Cretaceous unconformity along the western face of the Wolds between Goodmanham and North Cliff (from Fairburn, 2022, fig. 14). The inclusion of the British Geological Survey mapping is acknowledged: Permit Number CP21/022 British Geological Survey © UKRI 2021. All rights reserved.

Figure 4. Photographs of the 45 m O.D. strandline taken approximately 500m west of East Heslerton. The riser above the strandline is about 1.0m. The strandline is most clearly defined on the photo top left. The Yorkshire Wolds escarpment is visible in the background of all four photographs at c. 70 m O.D.

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Quaternary Newsletter
Report

A PALAEOECOLOGICAL PERSPECTIVE ON THE ECOLOGICAL IMPLICATIONS OF SEAWALL REMOVAL AT GIBRALTAR POINT, UK

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Background and Rationale

Coastal salt marshes are increasingly threatened by sea level rise, reduced sediment availability and anthropogenic activity (e.g. embankments) threatening crucial ecosystem services (Schuerch *et al*., 2018, Schuerch *et al*., 2013). Human activities including the construction of sea defences can have unintended consequences on coastal salt marshes. Gibraltar Point, a UK National Nature Reserve site, is a highly dynamic sand spit enclosing coastal salt marsh that hosts a significant number of migrant and wintering birds, unique flora, and biodiversity (Williamson, 1967, Morgan, 1974). The site includes a sea defence (Bulldog bank), built in the mid-19th century, north of the (old) salt marsh (Figure 1).

This embankment was constructed to protect local pastureland from saline incursions, thereby creating its own unique freshwater marsh, rich in sward flora and aquatic fauna (Wilkinson *et al*., 2019). Breaches occurred on several occasions threatening the diverse freshwater wildlife by saltwater intrusion (Wilkinson *et al*., 2019). While the embankment has created a valuable freshwater marsh, seawalls such as this can have detrimental effects on the extent and carbon sequestration capacity of salt marshes (Kroeger *et al*., 2017). This project is exploring the environmental

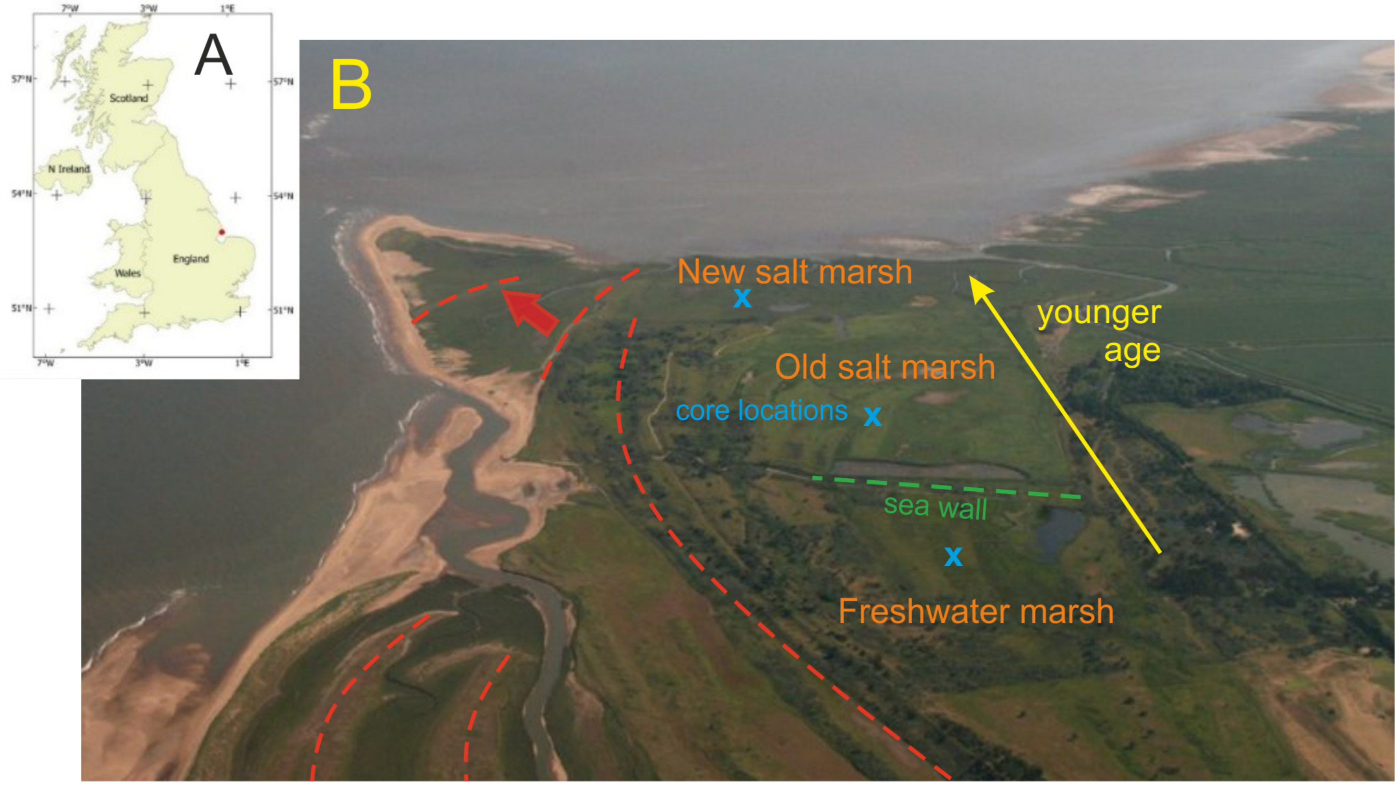

Figure 1. A) Location of Gibraltar Point, UK; B) the Gibraltar salt marsh system with recent over wash breaches, position of past sand barriers (red dashes lines), marsh ecological progressive units (in orange), Bulldog bank (dashed green line), and core locations (blue). Photo: https://www.geograph.org.uk/5837256

marsh history using a multiproxy palaeoecological approach to determine the past and future ecological trajectory of the marsh if the embankment is removed. The QRA provided the financial support for the lead-210 analysis to produce a chronology, key to determine the implications of the embankment on marsh development and if a possible removal is a viable restoration option.

Results

Lead-210 analysis was performed on the freshwater marsh core (GBHP0120 spanning 30 cm) and the old salt marsh core (GBHP0220 spanning 70 cm) using gamma spectroscopy (Table 1 & 2). Both Lead-210 profiles follow the expected exponential decline to a level comparable the Radium-226 values. Meanwhile Cs-137 shows distinct peaks for both profiles, likely

Table 1: Radiometric results for the old salt marsh core (GBHP0220).

Sample depth (cm)	Density (g/cm^3)	^{210}Pb (Bq/kg)	sd (^{210}Pb)	^{226}Ra (Bq/kg)	sd (^{226}Ra)	^{137}Cs (Bq/kg)	sd (^{137}Cs)
2-3 cm	0.6878	108.2	14.66	6.591	4.8995	5.946	1.916
6-7 cm	0.89208	90.44	18.05	19.84	5.914	26	2.619
8-9 cm	0.8492	69.37	13.84	15.655	5.2345	65.18	5.817
10-11 cm	0.89324	65.44	15.12	22.135	5.4575	51.55	4.378
12-13 cm	0.81552	42.26	15.46	18.395	5.408	31.59	3.197
14-15 cm	1.02348	41.99	11.51	26.445	5.612	16.56	2.149
16-17 cm	0.91956	26.78	12.5	25.57	4.4395	4.05	1.717
18-19 cm	0.85904	25.11	13.94	27.955	5.8685	3.917	1.393
20-21 cm	0.75804	29.45	14.31	29.65	6.733		
22-23 cm	0.8074	34.89	12.36	29.57	7.2675		
24-25 cm	0.86492	27.44	13.89	28.57	5.2855		
26-27 cm	0.88424	21.55	12.32	31.955	6.0645		
28-29 cm	0.82188	30.88	11.84	31.68	7.119		
30-31 cm	0.75112	25.5	13.36	18.575	6.284		
32-33 cm	0.84964	29.79	13.37	27.105	5.9885		
34-35 cm	1.05724	25.03	9.369	28.525	7.148		
36-37 cm	0.85332	27.66	12.7	21.975	6.009		
38-39 cm	0.8396	30.41	12.98	26.75	5.7915		
40-41 cm	0.90572	28.87	12.42	23.23	5.8245		
42-43 cm	0.9144	24.54	14.11	29.74	6.561		
44-45 cm	1.05988	22.59	9.682	32.54	6.0435		
46-47 cm	0.89552	35.77	12.48	26.52	5.785		
48-49 cm	1.14956	17.08	8.25	28.02	4.8355		
50-51 cm	1.12268	22.8	9.534	28.96	5.3265		
52-53 cm	1.30308	22.03	9.839	19.615	4.974		
64-65 cm	1.00168	31.12	11.73	32.14	7.54		
66-67 cm	1.1302	24.51	10.29	25.48	5.911		
69-70 cm	1.42828	14.6	8.794	16.815	2.73		

Table 2: Pb-210 results for the freshwater marsh core (GBHP0120).

Sample depth (cm)	Density (g/cm^3)	^{210}Pb (Bq/kg)	sd (^{210}Pb)	^{226}Ra (Bq/kg)	sd (^{226}Ra)	^{137}Cs (Bq/kg)	sd (^{137}Cs)
1-2 cm	0.47316	179.3	30.37	11.59	7.02	13.69	2.792
2-3 cm	0.78396	122	18.2	12.965	5.795	28.12	3.389
3-4 cm	0.92048	111.8	16.54	9.0435	4.6305	36.68	3.423
4-5 cm	0.91512	80.28	16.12	10.4725	3.826	41.32	3.667
5-6 cm	1.162	58.24	11.89	10.725	3.6195	43.7	3.92
6-7 cm	1.21344	34.38	10.73	13.995	3.5735	22.07	2.071
7-8 cm	0.99344	18.99	11.56	13.61	4.5215	10.59	1.653
8-9 cm	1.20792	21.55	9.127	16.325	4.3265	6.816	6.816
9-10 cm	1.0664	17.08	11.07	10.97	4.05		
10-11 cm	1.17104	15.89	9.515	10.955	4.0805	1.602	0.8959
11-12 cm	1.08212	16.9	8.245	11.52	3.786		
13-14 cm	1.37832	16.18	8.328	16.35	4.3525		
14-15 cm	1.3314	16.14	8.328	14.145	4.0275		
16-17 cm	1.40996	16.41	9.243	15.545	3.842		
18-19 cm	1.28232	16.36	9.206	12.53	3.528		
20-21 cm	1.28536	17.03	8.489	12.745	3.9545		
22-23 cm	1.46376	13.9	8.904	11.65	3.049		
23-24 cm	1.41684	13.23	7.877	11.78	3.969		

originating from the nuclear accident in Chernobyl in 1986 (Callaway *et al*., 1996).

These results were used to create the age-depth models (Fig. 2 & 3) using the *plum* package v. 0.2.2 in *R* v. 4.0.4 which utilises Bayesian statistical modelling to accurately determine age-depths from raw (supported and unsupported) ^{210}Pb concentrations (Aquino-López, 2018). Both habitats show linear accumulation with unsupported ^{210}Pb reaching background at 18 cm in the old salt marsh (Fig. 2) and 12 cm in the freshwater marsh (Fig. 3). The mean accumulation rate of the salt marsh is 0.2 cm/yr (Fig. 2) and 0.1 cm/yr in the freshwater marsh (Fig. 3).

Significance

The chronology will be vital for understanding the implications of seawall removal on Gibraltar point's salt and freshwater marsh habitats. Analysis and interpretation are still underway, but preliminary results suggest changes in grainsize and organic matter accumulation following the construction of the Bulldog bank. Pollen analysis will further assist in these interpretations contributing to the understanding of the habitat development and impacts to vegetation with breaches of the seawall. The outcomes of this work will allow for recommendations to the Lincolnshire Wildlife Trust on the ecological impacts of the seawall and the potential removal.

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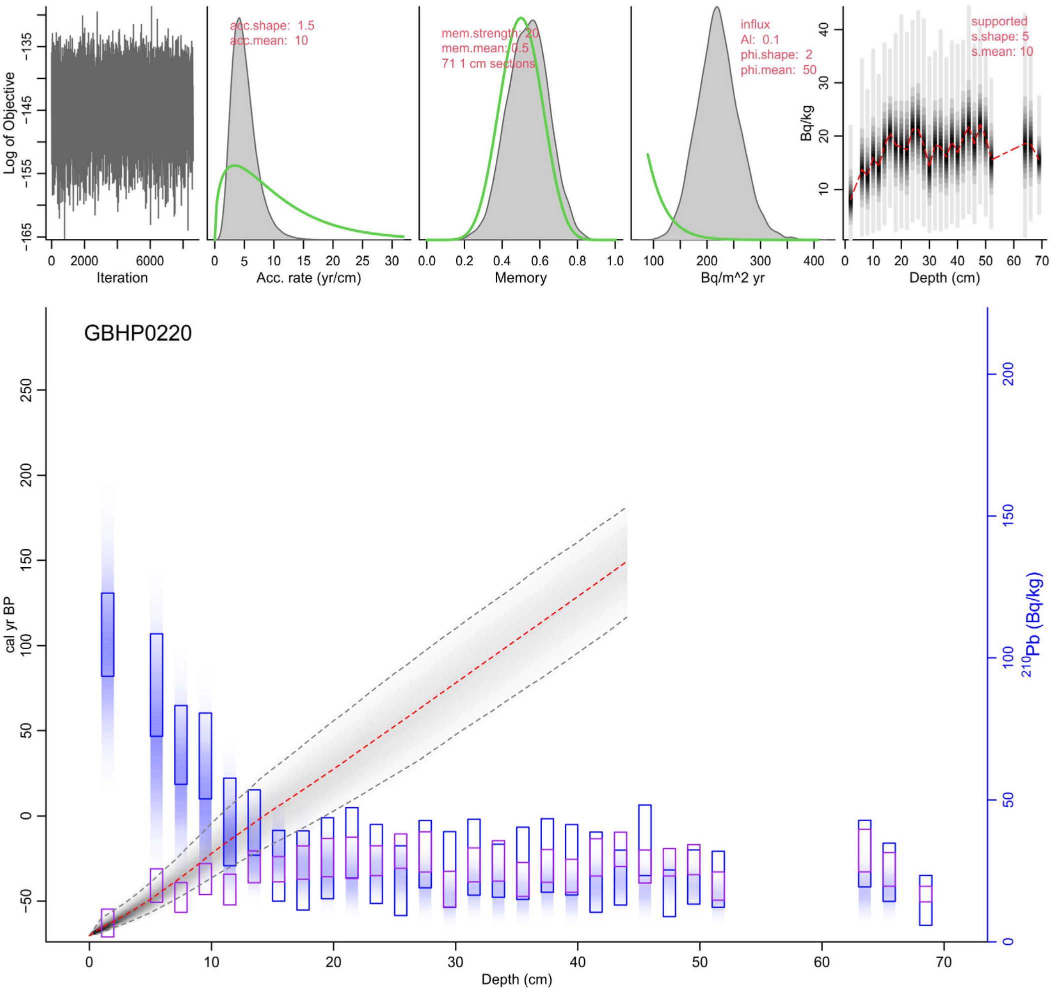

Figure 2. Age-depth model results for old salt marsh (core GBHP0220) performed using *plum* (Aquino-López, 2018) in *R*. Top panel from left to right: self adjusting Markov Chain Monte Carlo iterations, accumulation rates, age model memory, supply of ^{210}Pb, and supported ^{210}Pb by depth (cm). The bottom panel shows the results of the age-depth model with the blue squares indicating the trends in unsupported ^{210}Pb and the purple showing supported ^{210}Pb the black dashed lines show the bayesian iterations and the red dashed line the final age-depth model.

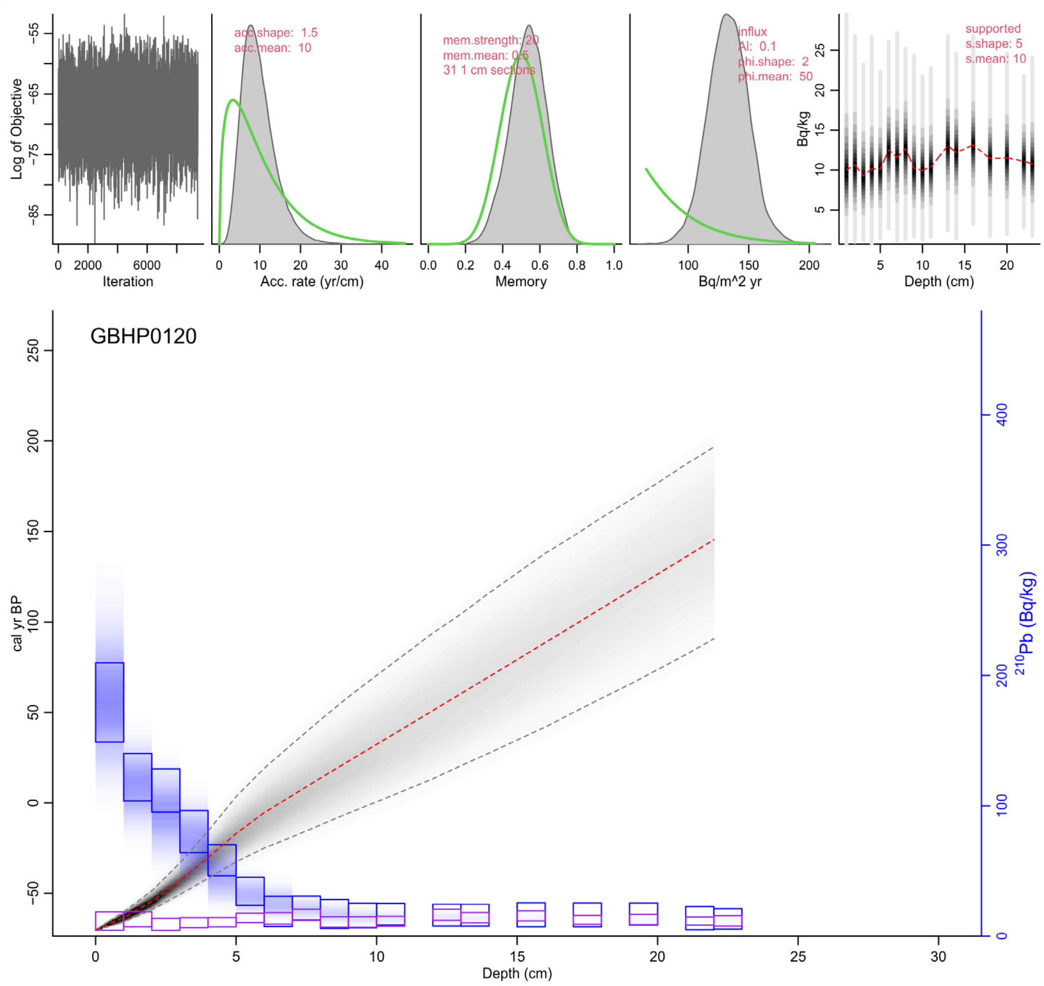

Figure 3. Age-depth model for the freshwater marsh (core GBHP0120) performed using *plum* (Aquino-López, 2018) in *R*. Top panel from left to right: self adjusting Markov Chain Monte Carlo iterations, accumulation rates, age model memory, supply of ^{210}Pb, and supported ^{210}Pb by depth (cm). The bottom panel shows the results of the age-depth model with the blue squares indicating the trends in unsupported ^{210}Pb and the purple showing supported ^{210}Pb the black dashed lines show the bayesian iterations and the red dashed line the final age-depth model.

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UNDERSTANDING THE IMPACTS OF DESILTING AGENT ON AQUATIC ECOSYSTEM HEALTH AND SUSTAINABILITY

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Background and Rationale

Human activity has had profound impacts on the functionality and structure of freshwater systems. Manipulating water courses has significantly impacted flow regimes and sediment connectivity, altering sedimentation (Schleiss *et al*. 2016). In the UK, excessive accumulation of organic matter in reservoirs is now widely mitigated by desilting agents. Previously used to alleviate the effects of acidification (Clair and Hindar 2005), these calcium carbonate-based agents were adopted to protect aquatic ecosystems by controlling water chemistry parameters such as pH and the acid neutralization capacity (Clair and Hindar 2005). Despite the consensus that calcium carbonate agents help mitigate the effects of acidification and eutrophication, there is a severe lack of research on the long-term consequences of specific applications of desilting. Studies have reported their role in liming total organic carbon (TOC), but usually as a by-product. Results generally show no change in TOC following liming (Simmons and Doyle 1996, Persson and Appleberg 2001), highlighting a gap in our understanding of the processes triggered by these desilting products. Therefore, this work will examine the ecosystem response to a desilting agent at Riseholme Reservoir.

Riseholme Reservoir, Lincolnshire, UK was formed from a dammed spring-fed tributary (Nettleham Beck) in 1779 CE (Carrol Planning + Design 2016). The site is surrounded by arable and pasture grassland for agriculture and has been quickly filling with silt over recent years; therefore, estate managers have recently used (December 2021) desilting agent to improve the water quality. We thus had the unique opportunity to determine the efficacy of a desilting agent, through assessing the reservoir's status before and after the treatment of a desilting agent. Palaeoecological

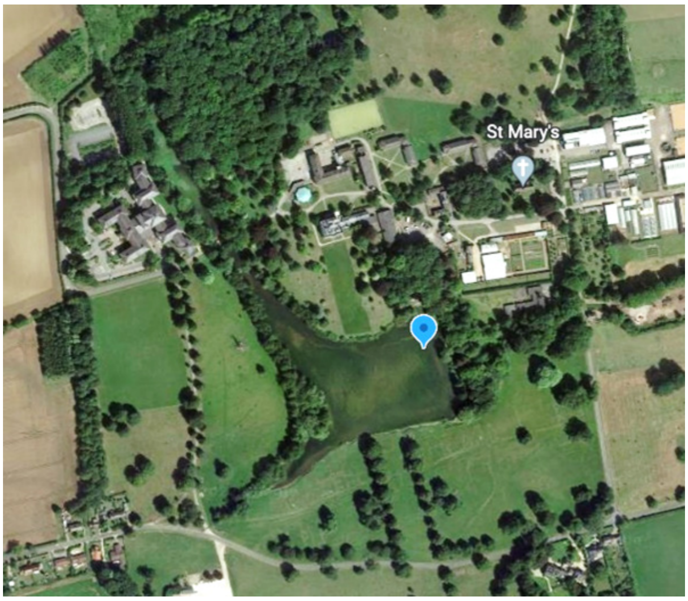

Figure 1. Riseholme Reservoir, Lincoln (53°15'59.9"N 0°31'44.8"W). Blue pin shows the location of core RSUN0420.

methods were used to determine baseline conditions and how sedimentation and environment has changed before desilting treatment was used. Sediment grab samples were used to investigate the reservoirs sediment and water conditions following the desilting treatment; however, this part of the project is not explored in this report.

A Universal core was collected from the deepest point in Riseholme Reservoir spanning 70 cm in length (RSUN0420) and analysed for aquatic pollen and algal pigments, to evaluate changes in primary producers and identify changes in aquatic community structure. Loss-on-ignition (LOI) and X-ray Fluorescence were used to investigate the organic matter and geochemical changes and ^{210}Pb was used to determine temporal changes in organic matter accumulation and the sedimentation rate.

Results and Interpretation

Lead-210 and pigment analysis were performed with the support of the QRA NWRA. The ^{210}Pb results reveal evidence of noisy total ^{210}Pb (Table 1), which could be due to low concentrations with high sedimentation load or mixing. However, results from other proxy data show no evidence of mixing (Figure 4). The age-depth model was produced using *Plum* (Aquino-López *et al*. 2018), an R package that uses Bayesian statistics to produce ages beyond the constant rate of supply model capabilities. The age-depth model results are in line with the expected age of the site (Figure 2). Lead-210 results can only date to 1800 CE, therefore, to retrieve basal dates the ages were extrapolated to the bottom of the core. This extrapolation suggests basal dates of 300 years ago consistent with the estimated date of damming, although these ages are to be interpreted with caution. The ^{137}Cs results do not show good alignment with the age-depth model. A ^{137}Cs peak from 36-38 cm suggests an age of c. 1945-1986 CE (Table 1) while the output from the age-depth model suggests ages from c. 1830-1900 CE (including confidence intervals). Therefore, more work needs to be done to improve the chronology.

Table 1. Lead-210 and Caesium-137 results for core RSUN0420 performed by gamma spectroscopy at Labor für Radioisotope, Georg-August-Universität Göttingen, Germany

Depth (cm)	Weight (g)	Ra 226 (Bq/kg)	+/- (Bq/kg)	Pb-210 (Bq/kg)	+/- (Bq/kg)	Cs-137 (Bq/kg)	+/- (Bq/kg)
0-2	14.87	13.46	3.08	36.00	12.92	4.25	1.50
2-4	14.61	17.46	5.56	44.99	15.01	3.67	1.50
4-6	14.73	8.78	2.94	35.64	13.36	3.77	1.44
6-8	14.42	18.58	4.31	52.66	8.57	4.44	8.57
8-10	17.4	15.19	4.75	32.11	12.13	2.63	0.93
10-12	17.19			43.77	13.87	5.19	1.42
12-14	17.94	14.29	3.18	42.48	7.94	3.71	1.11
14-16	16.37	18.74	5.09	29.34	10.71	3.93	1.25
18-20	19.61	9.24	5.88	37.70	12.04	3.31	1.84
20-22	19.64	12.99	4.30	34.21	11.77	5.46	1.28
24-26	19.37	18.77	4.73	31.95	12.45	5.17	1.38
28-30	16.99	15.51	4.68	27.07	11.10	5.63	1.49
30-32	18.08	15.48	4.71	27.13	11.86	8.93	2.01
32-34	18.07	21.30	27.63	21.95	10.66	8.82	1.37
34-36	18.47	22.35	5.05	30.02	11.33	12.70	2.04
36-38	18.75	21.68	5.06	25.63	11.07	16.30	2.06
38-40	22.1	21.91	4.48	22.01	9.89	16.17	1.83
42-44	22.27	15.22	4.14	<1,298E+01		<1,089E+00	
44-46	21.71	12.49	3.84	17.71	10.34		
46-48	22.78	14.82	2.64	11.48	4.68	<7,7877E-01	
48-50	23.24	14.22	3.85	14.82	9.73	<1,040E+00	
50-52	22.58	15.84	4.09	<1,342E+01		<1,077E+00	
52-54	23.29	12.12	2.58	10.43	4.62	<7,575E-01	
54-56	22.42	16.50	3.99	<1,431E+01		<1,061E+00	
56-58	22.13	13.53	2.743	12.61	5.76	<8,007E-01	
58-60	25.55	18.82	3.53	14.27	8.23	<9,992E-01	
60-62	25.41	21.17	2.53	14.00	4.91	<7,003E-01	
62-64	25.53	24.73	4.47	12.06	8.59	<9,649E-01	
64-66	25.23	23.43	2.87	20.94	5.48	<7,229E-01	
66-68	22.93	27.44	4.58	19.88	9.43	<1,223E+00	
68-70	25.06	27.03	2.94	18.85	5.391	<7,249E-01	

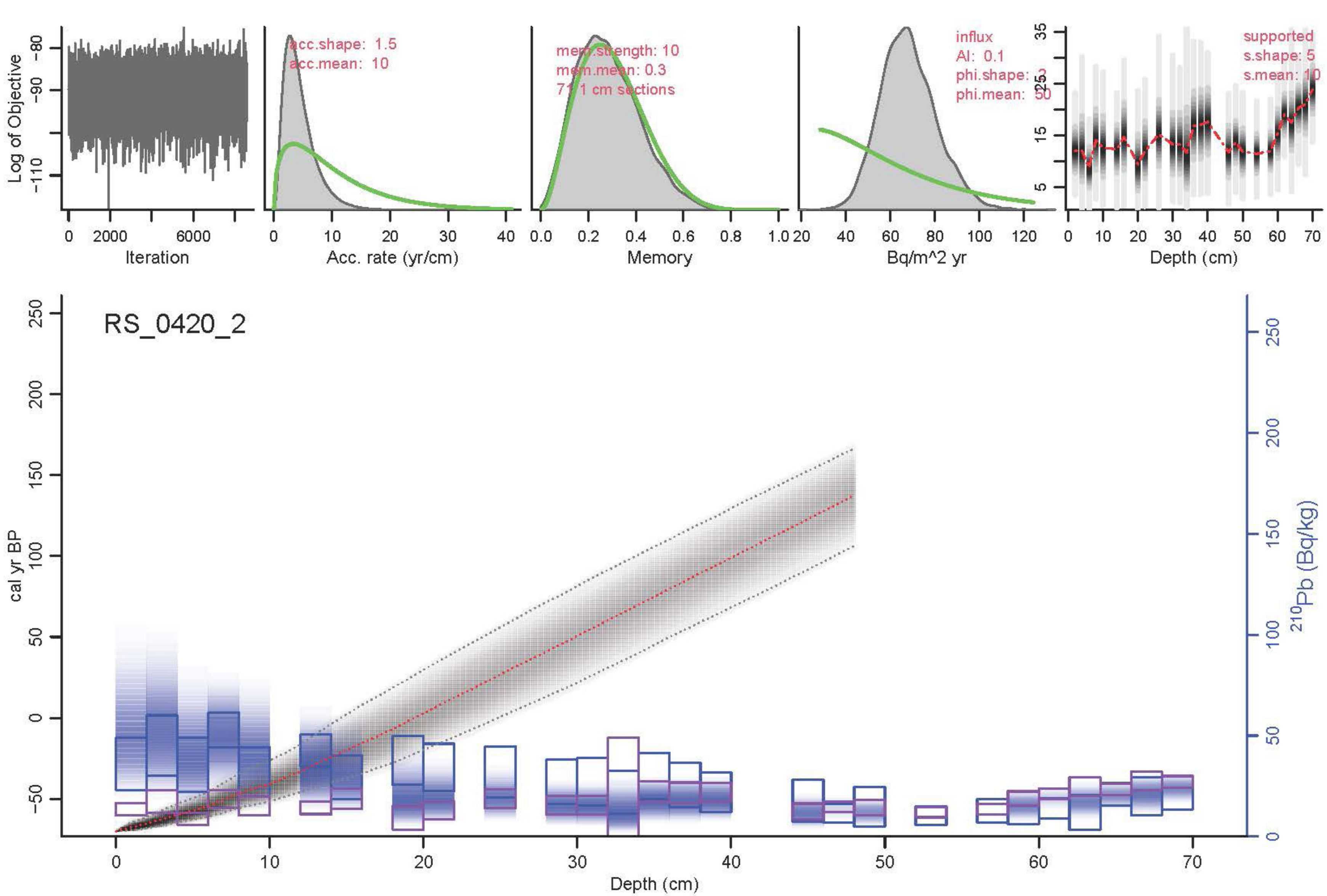

Figure 2. Age-depth model for Risholme Reservoir (core RS0420) performed using *plum* (Aquino-López 2018) in R. Top panel from left to right: self adjusting Markov Chain Monte Carlo iterations, accumulation rates, age model memory, supply of ^{210}Pb, and supported ^{210}Pb by depth (cm). The bottom panel shows the results of the age-depth model with the blue squares indicating the trends in unsupported ^{210}Pb and the purple showing supported ^{210}Pb the black dashed lines show the bayesian iterations and the red dashed line the final age-depth model, grey dashed lines represent upper and lower confidence interval of the age-depth model.

The calibrations for the pigments show good results for Lutein, Canthaxanthin, and Astaxanthin; however, there was a lack of data points for Diatoxanthin, Zeaxanthin, and Alloxanthin (Figure 3). Thus, concentrations cannot be determined at this point for the pigment data, and our interpretations will be based on the trends of the pigment results.

Preliminary results in the pigments show two transitions, at c. 1850 CE there is a drop in $\%LOI_{950}$ and Ca and an increase Lutein, Alloxanthin, and Zeaxanthin (Fig. 4), suggesting a decrease in calcium carbonate content and increased aquatic productivity. This transition coincides with the start of the Industrial Revolution, where increased land-use change, agricultural and human activity could have increased run-off, erosion and nutrient supply supporting more aquatic production (Anderson *et al*. 2013). At c. 1975 CE $\%LOI_{550}$, Ca and sedimentation increase, and all the pigments decrease (Figure 4). The decrease in aquatic productivity is likely due to increasing sedimentation at the site. High sediment loads can block out light in water bodies, important for primary producers causing unfavourable water conditions (Beck *et al*. 2020).

Significance

Our results show that the Industrial Revolution caused an increase in aquatic productivity at Riseholme Reservoir. Due to ongoing agricultural activity, the site began to experience an exponential increase in sediment loads causing a shift to low aquatic productivity (Figure 4). This site appears to be negatively impacted by high sedimentation and silt accumulation. However, it is still uncertain if desilting agents are a safe management strategy for freshwater environments. Next steps of this project are to uncover the efficacy of desilting agents on the aquatic system, improve the age-depth model and investigate the other proxy analysis.

Acknowledgements

We would like to thank the QRA for financially supporting this work, and University of Lincoln, Riseholme Campus for permission to perform this study at Riseholme Reservoir.

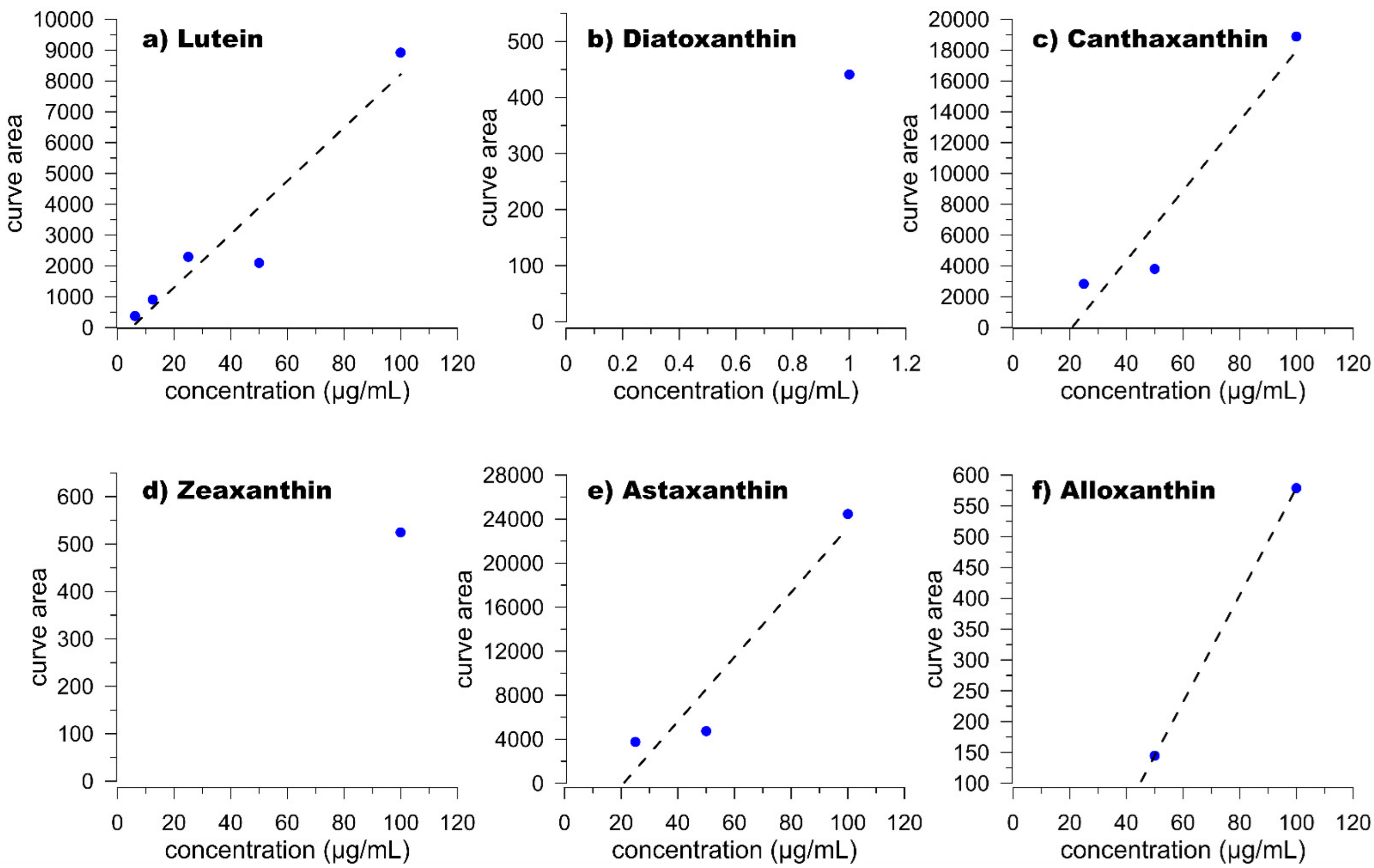

Figure 3. Calibration curves for the pigments: a) Lutein, b) Diatoxanthin, c) Canthaxanthin, d) Zeaxanthin, e) Astaxanthin, and f) Alloxanthin.

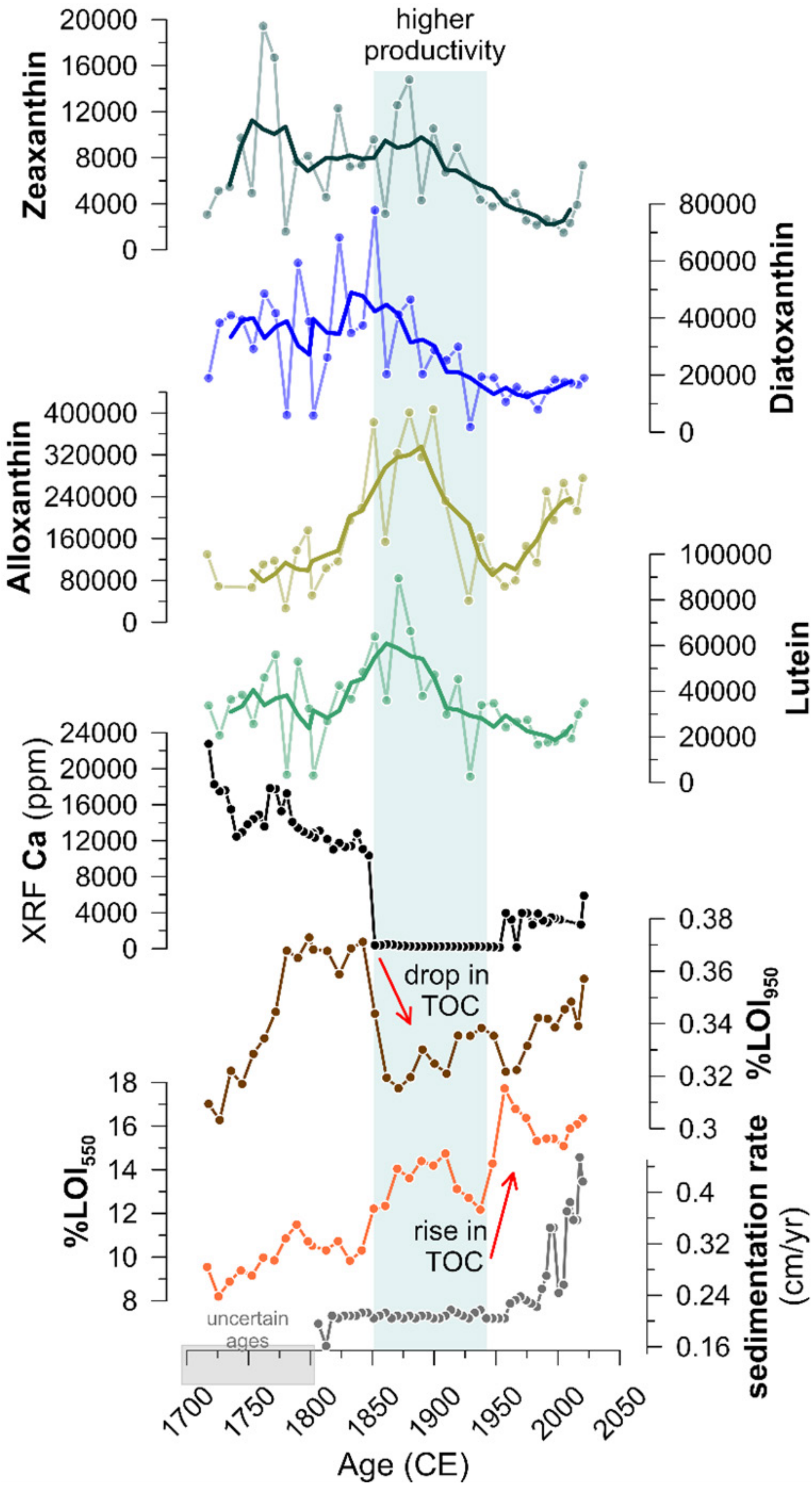

Figure 4. Proxy analysis of RSUN0420 by age (CE). Proxies from top to bottom: Zeaxanthin pigments, Diatoxanthin pigments, Alloxanthin pigments, Lutein pigments, XRF Ca (ppm), $\%LOI_{950}$, $\% LOI_{550}$ and sedimentation rate (cm/yr).

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QN Quaternary Newsletter
Report
QRA Quaternary Research Association

SMALL GLACIERS EXISTED ON BEN NEVIS DURING THE LATE HOLOCENE

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Background and rationale

In the past decade numerical simulations of former glaciers and dating of boulders on moraines in the Cairngorm Mountains has strongly suggested that small glaciers existed in the Scottish Highlands during the late Holocene, some 10,000 years after the generally accepted age of the last glaciers in Britain (Harrison *et al*, 2014; Kirkbride *et al*. 2014). Following this, we speculated that small glaciers may have existed elsewhere in Scotland (and possibly in other British mountain regions) during the Little Ice Age (LIA) and also potentially at other times during the Holocene. With colleagues (Ann Rowan, Adrian Dye and Karen Anderson) I identified the high corries of Ben Nevis and Aonach Mor in western Scotland as sites where Holocene glaciers might also have developed, and the QRA grant allowed two of us (SH and KA) to undertake fieldwork on Ben Nevis to test this hypothesis.

Study site

Ben Nevis in western Scotland (Figure 1) is, at 1345m, the highest mountain in the British Isles. Located close to the west coast means that annual precipitation is high (over 4000mm) compared with the Cairngorms where late Holocene glaciers have been reconstructed (Harrison *et al*. 2014). Its northeastern flanks contain well developed corries and these contain amongst the highest inland cliffs in Britain. It is likely that Ben Nevis was inundated by the Last Glacial Maximum

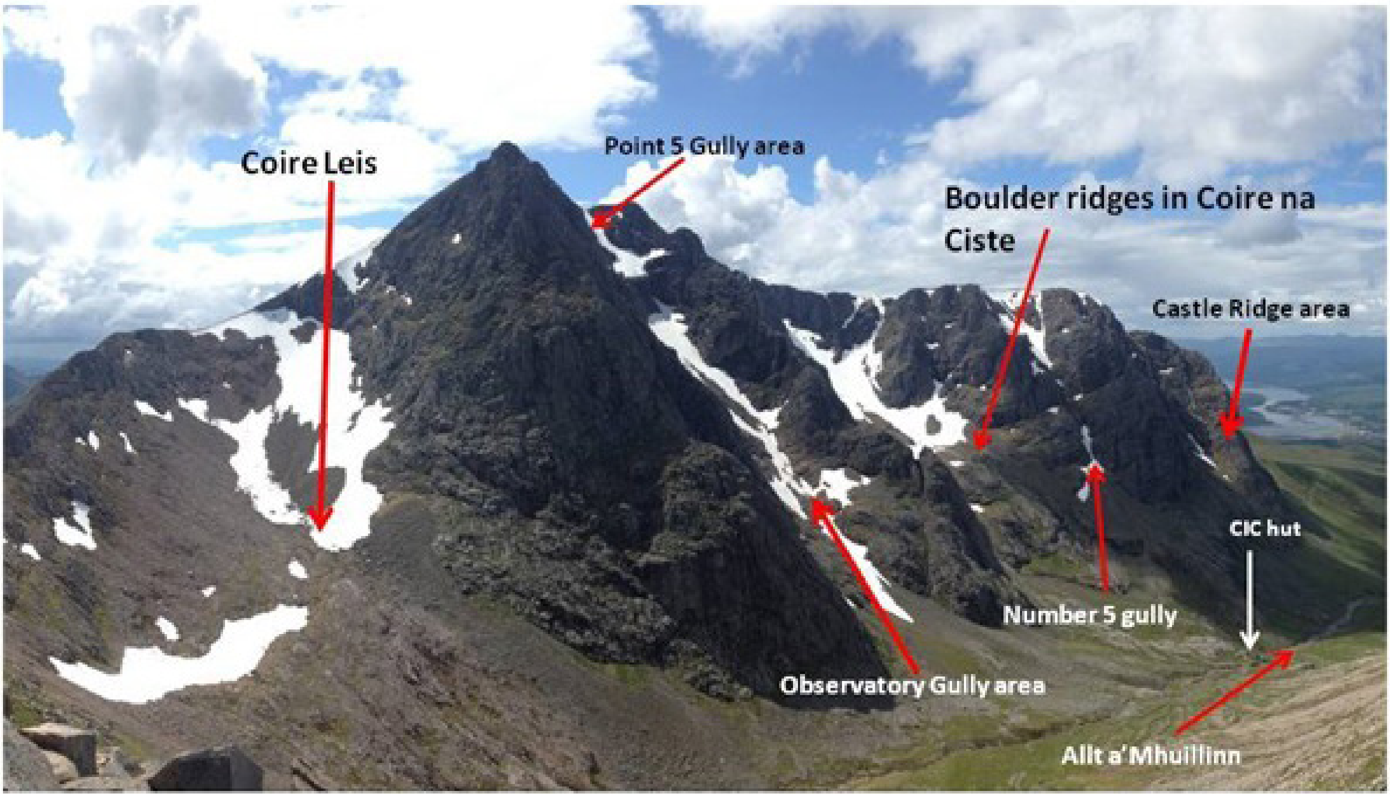

Figure 1. The north face of Ben Nevis showing the location of the study site (from Harrison *et al*. Geografiska Annaler 2022).

ice sheet (Clark *et al* 2004) and the Younger Dryas ice cap in the region probably existed up to 900m asl, in accordance with reconstructed upper ice limits from Rannoch Moor to the south.

On Ben Nevis moraines interpreted as having been deposited during the Younger Dryas occur above 300m asl occupying the Alt a'Mhuillin valley that drains the northeast flanks of the mountain. At higher levels, well-developed corries exist with valley floors over 900m OD. At Coire Leis, small ridges comprised of boulders occur on the north side of the coire below the North-East Buttress and similar features occur in Coire na Ciste (Figure 1). Late lying snow patches are common at the present day with snow regularly lying in sheltered locations on Ben Nevis throughout the year (especially in the Observatory Gully and Point Five Gully areas). On the northeast face of Aonach Mor (1130 m) some 2km to the northeast of Ben Nevis late-lying snow patches are also common and associated with well-developed protalus or pronival ridges. Our hypothesis is that these high elevation corries would have been sites where small glaciers developed during the cold periods of the Holocene.

Results

We used a numerical model to reconstruct small glaciers in the high corries under a range of climatic conditions (Figure 2). We showed that glaciers would probably have existed under a palaeoclimate equivalent to a difference in mean annual air temperature (ΔT) from present-day values of between –1.0°C to –2.0 °C with either no change in precipitation amount or a reduction of up to 30%. The response times for these simulations were 100–150 years, indicating that, from an unglaciated condition, a change to palaeoclimate conditions similar to those expected during the LIA was sustained for at least a century and was sufficient to form small corrie and niche glaciers. Small changes in ΔT and annual precipitation amount would have caused the glaciated area to fluctuate but would have sustained small glaciers for as long as mean annual air temperature remained at least 1°C colder than the present day.

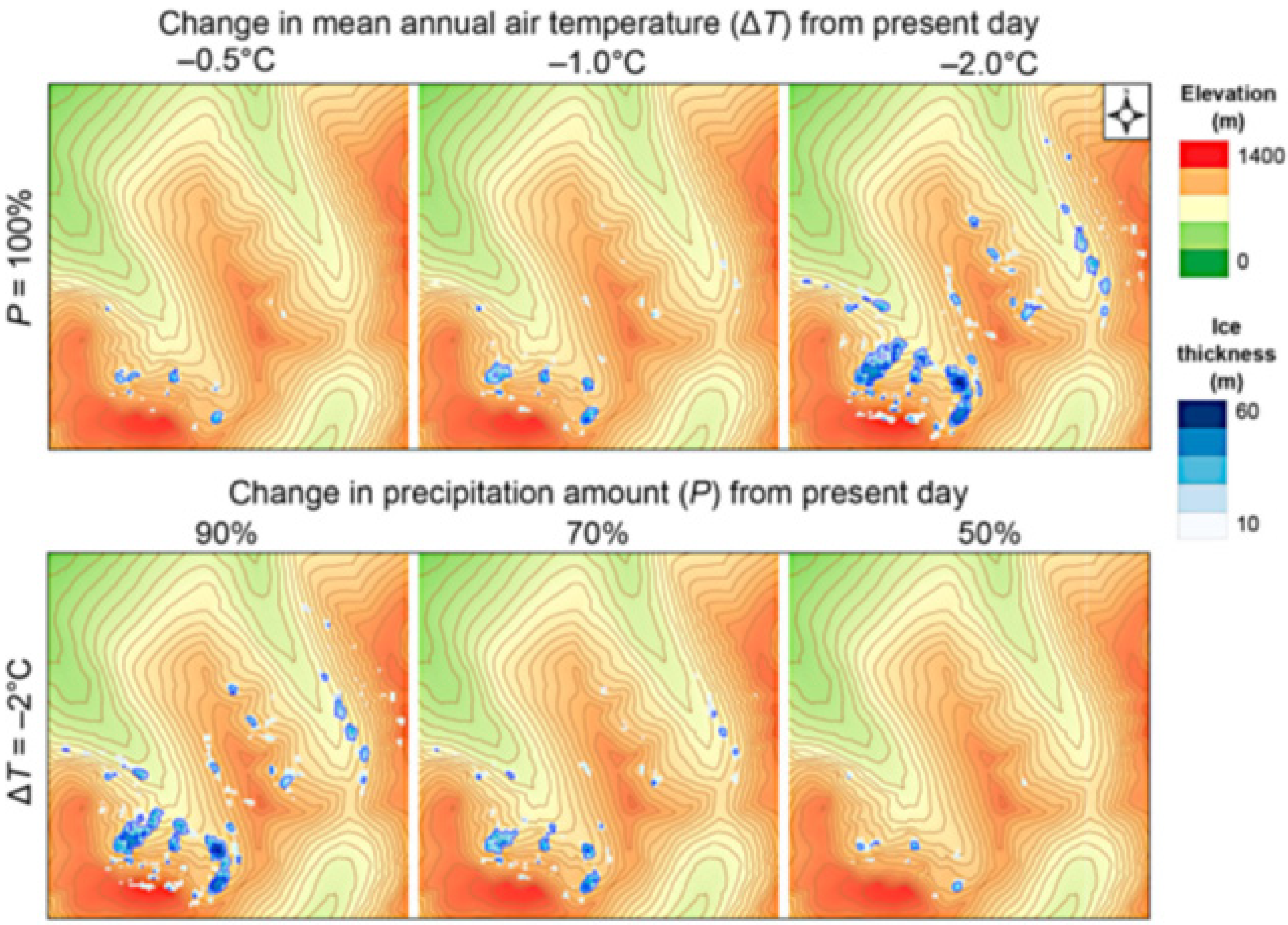

Figure 2. Numerical simulations of small glaciers and ice thickness under a range of cooler and drier climates on Ben Nevis and surrounding mountains (from Harrison *et al*. Geografiska Annaler 2022).

Although meteorological observations are not currently made at the summit of Ben Nevis, a historical dataset provides hourly air temperature and rainfall measurements between 1886 and 1903. Comparing the calculated present-day temperature at the summit with historical observations indicates that mean annual air temperature at the summit was around 2 °C colder between 1886 and 1903, which is consistent with the development of small glaciers on the mountain.

Significance

There are potentially numerous times in the Holocene when glaciers could have developed in Scotland. For instance, during the renewed cooling associated with the 8.2ka event temperatures dropped 6 ± 2°C at Summit in Greenland and this period of cooling may have lasted for over 160 years (Alley and Ágústsdóttir 2005; Thomas *et al* 2007). Other reconstructions suggest a reduction in temperature of 1–3°C across large parts of the Northern Hemisphere and, in northwest England, palaeoclimate reconstructions suggest a reduction in temperature of 1.6°C at this time (Lang *et al*. 2010). Given the likely sensitivity of Scottish glaciers to climate cooling, this might suggest that glacier limits currently described as having been deposited during the Younger Dryas were in fact also occupied during the early Holocene. Testing this hypothesis will be difficult. Accurate dating of boulders on moraines created by small glaciers will probably be affected by the problem of inherited ages, given limited subglacial transport paths of sediment. However, our results suggest that small glaciers may have existed in several locations in the highest parts of the Scottish mountains in recent centuries, and probably also during other cold periods in the Holocene. From this we argue that the current understanding of the glaciations of Scotland needs revision.

We have published a longer version of this report: Harrison, S., Rowan, A.V., Dye, A.R., Plummer, M.A. and Anderson, K., 2022. Late Holocene glaciers in western Scotland? *Geografiska Annaler: Series A, Physical Geography*, pp.1-13.

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Quaternary Newsletter
Report

EARLY MEDIEVAL TEPHRA LAYERS AND THE PROXIMAL IMPACTS OF THE ELDGJÁ FISSURE ERUPTION, ICELAND

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Introduction

The 939 AD Eldgjá fissure, a north-eastern extension of Katla Volcanic System, produced the largest Icelandic eruption after Settlement (c. 877 AD). It disgorged ~19.7 km^3 of lava (Sigurðardóttir *et al*. 2015), ~1.3 km^3 of tephra (E939; constituting ash, scoriae and bombs), and emitted ~232 Mt of sulphur dioxide (Thordarson *et al*. 2001), which formed a widespread atmospheric haze, confirmed by contemporary observations (Oppenheimer *et al*. 2018). Whilst lava flows represent most of the erupted volume, tephra formed thick deposits across southern Iceland (Larsen 2000). Despite the eruption's great scale, the impacts on the Icelandic environment and society are hitherto unknown, but likely profound. Detailed stratigraphic analysis, at various sites around Mýrdalsjökull ice cap, will address this by evaluating variations in tephra layer morphology and sediment accumulation.

Background, rationale and approach

After Iceland's Settlement, woodland clearance and pastoral farming enhanced erosion, and surviving soils began to thicken rapidly (Dugmore *et al*. 2000). Tephra deposits were buried rapidly so that even tephra layers from near-contemporary eruptions (e.g. Katla ~920 AD and Eldgjá 939 AD) are separated clearly within the stratigraphy. The resulting 'barcode' provides opportunities to track geomorphological change across landscapes and through time (Dugmore & Newton 2012). At present, aeolian soils are found in the highland margins, but an extensive network of erosion fronts have dissected the landscape and expose the stratigraphy.

Tephra layer morphology, created by depositional processes, selective preservation and reworking (Dugmore *et al*. 2019), provides evidence that can help to establish the impacts of, and responses to, volcanic eruptions. Woodlands and isolated shrubs can stabilise initial fallout from remobilisation by wind and precipitation (Morison & Streeter 2022). In addition to considering site altitude, topography and climate, we infer the former presence of woodlands through trace evidence of trunks and roots in pre-877 AD tephra layers. By contrast, deposits that fell on sparse, short-stature vegetation may have been largely reworked and redistributed.

The prime objective of our 2022 fieldwork was to determine whether settlement continued in areas impacted by the Eldgjá eruption. Fieldwork was conducted in June and August at forty sites in the Rangárþing Eystra and Skaftárhreppur municipalities. Selected farms contain archaeological evidence for early (pre-Eldgjá) occupation, where E939 thicknesses range from <1 cm to >1 m.

We recorded thicknesses of E939 (including its constituent phases; Moreland *et al*. 2019) as well as thicknesses and characteristics of younger (e.g. Hekla 1206 AD) and older (e.g. Veiðivötn 877 AD) tephra layers. Estimation of soil accumulation rates between other Settlement-period tephra layers will shed light on woodland extent and soil erosion before, during and after the Settlement period.

We sampled pre- and post-877 AD tephra layers, and also internal phases of E939. Geochemical analysis (major/minor oxides and trace elements) will be used to confirm our tephrochronology by distinguishing tephra from different volcanoes, and different eruptions of the same volcano (Óladóttir *et al*. 2011).

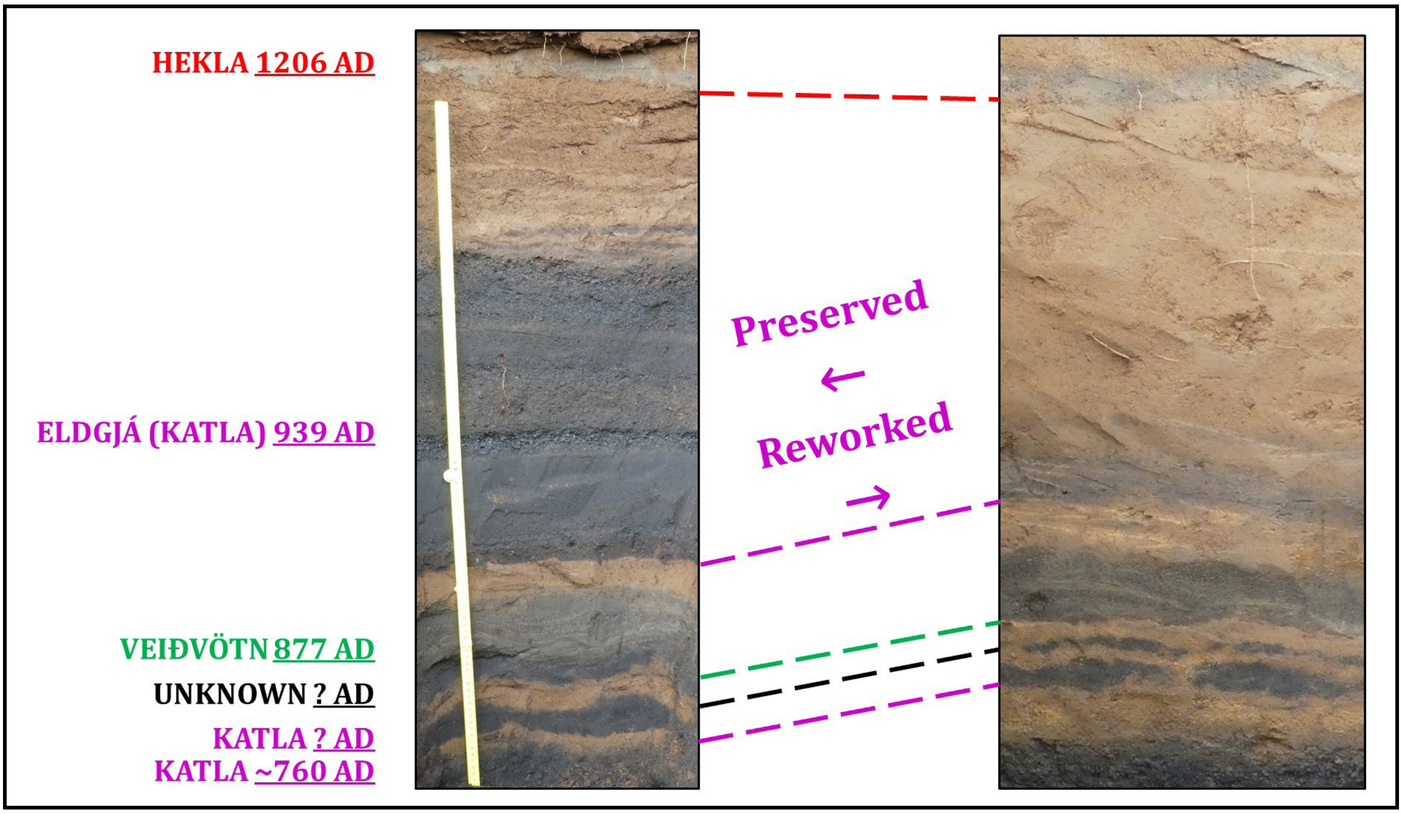

Figure 1. Comparison of two sections, showing the stratigraphy between the suspected Katla ~760 AD (lower contact is below field of view) and Hekla 1206 AD (top) tephra layers. Both sites are in the Skaftártunga area of southern Iceland.

Results and significance

At some sites, preservation of original E939 fallout and internal phases indicates rapid and effective stabilisation of the tephra, indicating the former presence of woodland. At other sites, only vestiges of original tephra fallout remain, its discrete phases having been obliterated by erosion and reworking (Figure 1).

We classify the stratigraphic profiles into three groups. Sites at altitudes greater than ~250 m probably lacked woodlands, even before 877 AD. Some sites had woodlands in 877 AD, but were cleared during the Settlement period to permit farming; thus forming 'occupied' clearings by 939 AD. Other sites had woodlands before 877 AD and after 939 AD.

Trace fossils and disturbance (or absence) of Early Medieval tephra layers imply continuity of human settlement after the Eldgjá eruption. Initial settlers cleared woodlands to establish farms in areas above coastal plains (Dugmore *et al*. 2000), resulting in poor preservation of E939 fallout thicknesses and individual eruptive phases there. Thus, pre-existing local conditions (e.g. short-stature vegetation) would have been ineffective at stabilising fresh deposits from wind erosion. Additionally, farmers may have cleared tephra from fields during the following decades. Lingering snow patches that were buried by fallout would, upon melting, have hindered its preservation further.

The decision not to abandon occupied areas is intriguing because settlement patterns elsewhere in Iceland did adjust during the colonisation period (Vésteinsson *et al*. 2002). Clearance of tephra from field systems may have been easier than creating new fields from surviving birch woodlands, which had stabilised thick tephra deposits. However, archaeological evidence of new structures, built directly on top of E939, suggests that some adaptation did occur in Skaftártunga (Hreiðarsdóttir *et al*. 2013). Woodlands that had survived both the initial 'land-taking' and contemporary eruptions would, if left undisturbed, have continued to stabilise E939. However, if disturbed by later generations in the pursuit of new land, these woodlands could have unleashed great volumes of unconsolidated tephra, perhaps decades to centuries after the eruption.

Acknowledgments

The lead author acknowledges financial fieldwork support from the *New Research Workers' Award*, Quaternary Research Association. This project was also supported by the *Geographical Club Award*, Royal Geographical Society (with IBG), and a grant from the Scottish International Education Trust. The *Geography Centenary Award*, School of GeoSciences (University of Edinburgh) supported airfare costs between the UK and Iceland. Martin Dugmore and the lead researcher's family assisted during fieldwork, whilst Elín Hreiðarsdóttir (Fornleifastofnun Íslands) provided logistical support. Finally, we appreciate the support of landowners at Fljótsdalur, Barkarstaðir, Heiðarsel, Búland, Snæbýli and Flaga.

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Quaternary Newsletter
Report

AN ULTRA-HIGH-RESOLUTION ISOTOPIC ANALYSIS OF THE MARKS TEY ABRUPT CLIMATE EVENT, MIS 11C

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Background and Rationale

Stable isotopes in lacustrine environments are widely used as tracers of past climate (e.g., Holmes *et al*., 2010). They are particularly useful in studying abrupt climate events (ACEs) given their rapid response to changing climate. The impact of ACEs can be seen within a human lifetime and may have severe economic and societal consequences (Alley *et al*., 2003). The Marks Tey, Essex, core contains an annually laminated record of an ACE during MIS 11c, the best available in a pre-Holocene interglacial (Tye *et al*., 2016). Subsequently, this site presents a unique opportunity to understand the dynamics of ACEs without anthropogenic input. A low-resolution oxygen isotope record at this site exists shows a link between vegetational and isotopic changes (fig.1); thus, infers a climatic response (Tye *et al*., 2016).

The tephra layer identified at this site links this event to a reduction in sea surface temperature in marine core ODP 980, allowing for North Atlantic Ocean dynamics to be confidently correlated to ultra-high-resolution terrestrial changes for the first time in MIS 11c (Candy *et al*., 2021, fig.1). This project aims to utilise oxygen isotopes from individual calcite laminations drilled from sediment blocks (e.g., Mangli *et al*., 2010) as a palaeoclimatic proxy by producing a minimum decadal resolution across ~ 2300 varve years and increase resolution to 5 years during the ecological event to fully extract the climate signal from the background noise across the depth interval. This will permit (1) a robust analysis of the structure of this ACE and any cyclicity within; (2) a detailed comparison to the 8.2 ka event, of which it is often seen as an analogue for (Koutsodendris *et al*., 2012).

Results and significance

Preliminary results indicate that the Non-Arboreal Pollen (NAP) phase at Marks Tey is the final oscillation of a period of a millennial-scale reduction in isotopic values spanning ~ 1500-2000 years. Within this, there are two distinct isotopic events separated by a centennial-scale increase in values (Oxygen Events (OE) 1 and 2). The NAP phase (here referred to as OE 2c) is part of a 3-step reduction in isotopic values within OE 2. OE 1 is ~ 400 years in length, whilst OE2 is ~ 865 years (averaged between 30/100-year smoothing), giving an overall length of ~ 1250 years. The temperature decline experienced between the onset and trough of OEs 1 and 2 is ~3.64 and 4.25 °C respectively, or ~ 5°C from the onset of OE 1 to the trough of OE 2c (averaged between 30/100-year smoothing). Both the duration and absolute reduction in temperatures exceed that of Western Europe during the 8.2 ka event (~300 years, ~1°C), indicating that this event is not an 8.2 ka analogue. Indeed, there is greater similarity to the Younger Dryas (~ 1200 years, 6°C temperature decline). Significantly, this is not something experienced at any point in the current warm phase and may relate to the substantial levels of ice loss in MIS 11c, which is yet to occur in the Holocene.

Acknowledgments

We are grateful to the Quaternary Research Association for the assistance in funding the isotopic analysis via the New Research Workers' Award to the resolution required for this study. We would also like to thank Dr Anne-Lise Jourdan for running these samples at the UCL BEIF Laboratory. Finally, we would like to acknowledge NERC for funding this PhD thesis as part of the London NERC DTP.

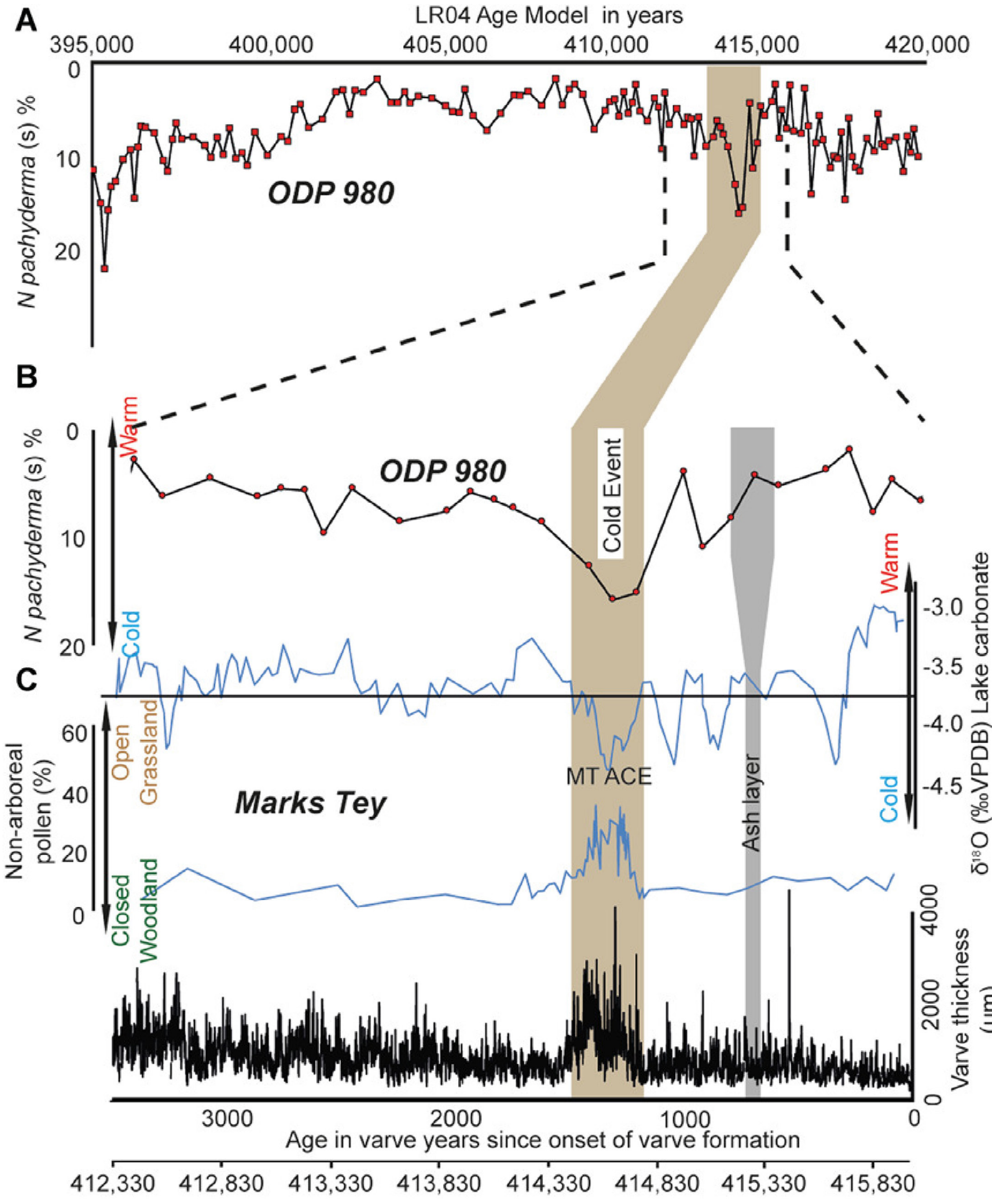

Figure 1. The correlation of key environmental proxies from Marks Tey (C, oxygen isotopes, non-arboreal pollen and varve thickness) with the N.pachyderma (s) (A and B) of ODP 980 (McManus *et al*., 1999 but using the timescale of Lisiecki and Raymo, 2005) on the basis of the co-located tephra layer. Both B and C are plotted on independent timescales but are aligned on the basis of the tephra layer. Taken from Candy *et al*., (2021).

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Quaternary Newsletter

Report

SURFACE EXPOSURE DATING USING COSMOGENIC ^{3}HE AT SKÁLAFELLSJÖKULL, SOUTHEAST ICELAND

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Background and rationale

Surface exposure dating using cosmogenic nuclide dating has become a well-known and accepted dating technique in glacial geomorphology, used for understanding issues such as timing and extent of glacial advances (Darvill, 2013), using a variety of lithologies at any altitude and latitude (Gosse and Phillips, 2001). Cosmogenic nuclides such as ^{3}He, ^{10}Be, ^{14}C, ^{21}Ne ^{26}Al and ^{36}Cl are the most used in surface exposure dating (Darvill, 2013), and are produced in surface materials as cosmic rays interact with the earth's surface (Licciardi *et al*., 2007). Cosmogenic ^{3}He is a stable, noble gas isotope (Darvill, 2013) and has received less focus compared to other cosmogenic nuclides in surface exposure dating (Blard, 2021). The use of ^{3}He requires specific lithologies, like mafic rocks such as basalt, which

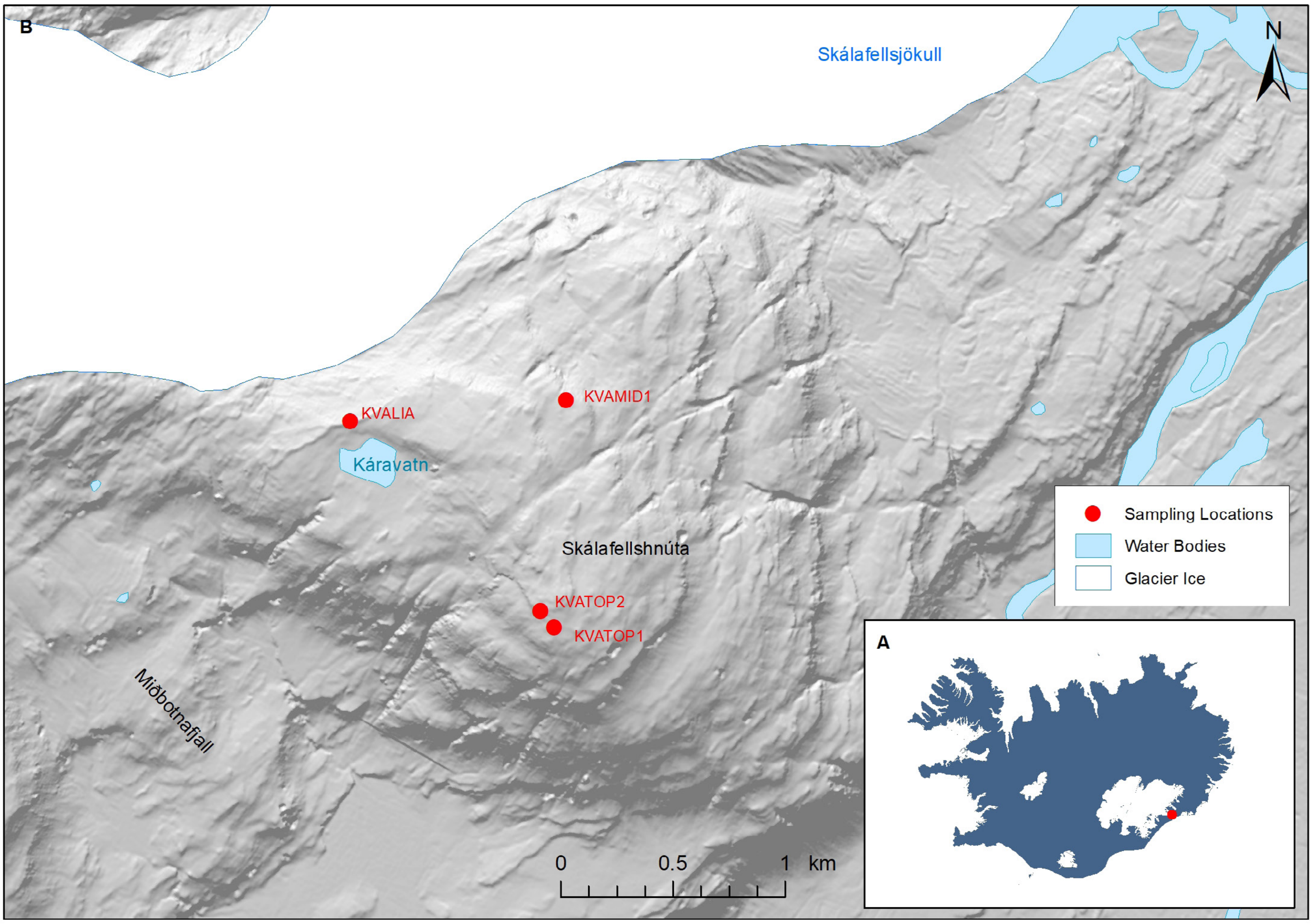

Figure 1. Map displaying the study area in southeast Iceland (A) and sampling locations (B). Hill shade from Arctic 2 m DEM (Porter *et al*., 2018). Based on data from the National Land Survey of Iceland (IS 50V | National Land Survey of Iceland (lmi.is)).

contain olivine and pyroxene (Blard, 2021). Surface exposure dating using cosmogenic ^3He has been used in a variety of applications in Iceland focusing on dating postglacial basalt flows (Licciardi *et al*., 2006), ice sheet surface elevation and thickness (Licciardi *et al*., 2007), extreme flood events (Baynes *et al*., 2015), and river terraces (de Quay *et al*., 2019). This highlights the potential for using cosmogenic ^3He to date glacial extent and ice thickness from glacial landforms such as glacial erratics and bedrock using basaltic lithologies in southeast Iceland.

Funding from the QRA New Research Workers Award (NRWA) was used for sample processing at the Palaeoenvironmental Research Unit at the National University of Ireland, Galway (NUI). Funding from the QRA NRWA will also be used for further analysis of the processed samples using an accelerator mass spectrometer (AMS).

Methods and Results

Skálafellsjökull is an outlet glacier from the southeast margin of the Vatnajökull ice cap in southeast Iceland (Figure 1). Samples for cosmogenic ^3He nuclide dating have been collected from boulders and bedrock at different elevations, ranging from ~480 to ~650, from Skálafellshnúta (~653 m a.s.l), south of Skálafellsjökull (Figure 1 and Figure 2A, B, C and D). Samples were processed at the National University of Ireland in Galway, following methods outlined in Bromley *et al*. (2014). Samples were crushed, pulverised, and sieved to 150-250 μm and 250-500 μm size fraction, before separation (Figure 2E, F, G and H). The samples were washed with water to remove dust and lichen before adding Hydrochloric acid (HCl) and heated using a hot plate to dissolve any metals. The HCl was removed, and the samples were washed using water before leaving to dry through completely. Heavy liquid, lithium sodium heteropoly tungstate (LST), was used to separate the pyroxene from the rest of the crushed samples. Measurements of ^3He will be carried out using an AMS.

Significance

Glacial reconstruction in southeast Iceland has mostly focused on the LIA (LIA; ca. 1250-1900 AD; Geirsdóttir *et al*., 2009), and retreat since this period. Dating techniques such as lichenometry (e.g., Bradwell et al., 2006), tephrochronology (e.g., McKinzey *et al*., 2005) and Schmidt Hammer dating (e.g., Evans *et al*., 1999) have been used in southeast Iceland to date LIA moraines in the forefield of southeast Vatnajökull outlet glaciers. However, no cosmogenic nuclide dating has been carried out in the southeast. The use of this method will be valuable for constraining ice thickness in southeast Iceland during the Holocene, which is useful for developing accurate models of the Icelandic Ice sheet (IIS) throughout the Younger Dryas and Holocene (e.g., Hubbard *et al*., 2006). This research will also be useful for assessing the application of surface exposure dating glacial landforms such as glacial erratic boulders and glacially polished bedrock using cosmogenic ^3He in southeast Iceland.

Acknowledgments

The QRA New Research Workers Award was used to fund travel and laboratory work at NUI Galway and will be used to fund further analysis using an AMS. Funding from the Department of the Natural and Built Environment at Sheffield Hallam University was used to fund accommodation in Galway. Thank you to Dr Gordon Bromley for his guidance in processing the samples at the Palaeoenvironmental Research Unit at NUI, Galway. Thank you to Dr Rob Storrar, Dr Tim Lane, Amy Lally, and Gwyn Rivers for support with data collection in September 2021, in a wet and windy Iceland! This project forms part of my PhD project titled Holocene climate and environmental change in southeast Iceland. Thank you to my supervisors Dr Naomi Holmes, Dr Rob Storrar and Dr Jon Bridge for their guidance and support throughout this project and my PhD.

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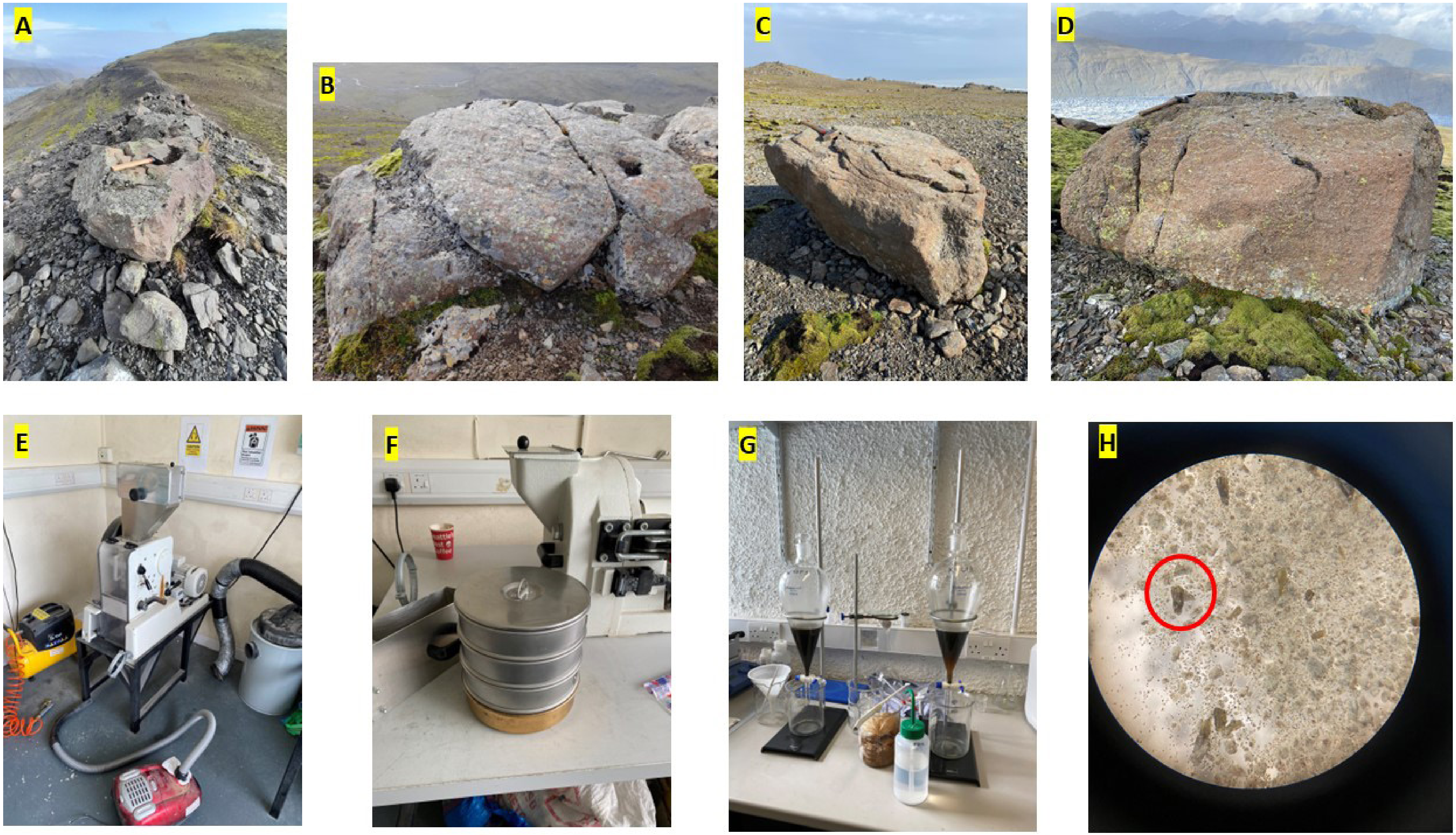

Figure 2. Images showing sample sites KVALIA (A), KVATOP1 (B), KVATOP2 (C) and KVAMID1 (D). Images showing lab work at NUI Galway, displaying rock crushing (E), sieving (F), heavy liquid separation (G) and pyroxene within the crushed sample under a stereo microscope (red circle) (H).

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QRA UNDERGRADUATE DISSERTATION PRIZE 2022

It is our great pleasure to announce that the winner of this year's QRA Dissertation Prize is Yuqiao Natalie Deng (University College London) for her dissertation on "A tephropalaeoecology study investigating volcanic eruptions and tephra depositions' impacts on a lacustrine ecosystem in Northeast China, using diatoms as environmental indicators".

The study concerns a highly detailed and thorough investigation of lake response (via diatom communities) to tephra loading. It is well written and clearly explained, and it represents an outstanding amount of work for an undergraduate dissertation. Significant strengths are the level of analysis, the critical evaluation, the quality of interpretation, and a very high standard of presentation. While the discussion is mainly focused on the results, the study also has a broader significance.

We wish to commend a second student for their high-quality research that demonstrated their command of their research investigation:

Duncan Russell (Plymouth University), "Using GIS and numerical modelling to test the influence of climate change on glacial lake outburst flood risk in the Dudh Koshi Basin, Nepal Himalaya".

Judges:

Mary Edwards
Geography and Environmental Sciences
University of Southampton
m.e.edwards@soton.ac.uk

Gill Plunkett
School of Natural and Built Environment
Queens University Belfast
G.Plunkett@qub.ac.uk

The QRA wishes to extend its thanks to Mary Edwards and Gill Plunkett who this year step down as judges of the dissertation prize after fulfilling the role excellently over the last three years. Needless to say that without the efforts of the judges we could not run the prize to recognise the excellent Quaternary undergraduate research that is being undertaken by students.

We are currently looking for two (or more) new people to take on the judging role for the dissertation prize for the period 2023-2026. Potential judges should have experience with the supervision and marking of UK undergraduate dissertation projects, and be prepared to review 5-10 dissertations between September-November each year. Anyone who is interested in volunteering for the role of judge should contact the Outreach Officer (James Lea, University of Liverpool) by email at j.lea@liverpool.ac.uk before 31st March, 2023.

A TEPHROPALAEOECOLOGY STUDY INVESTIGATING VOLCANIC ERUPTIONS AND TEPHRA DEPOSITIONS' IMPACTS ON A LACUSTRINE ECOSYSTEM IN NORTH-EAST CHINA, USING DIATOMS AS ENVIRONMENTAL INDICATORS

Yuqiao Natalie Deng
University College London

Tephra layers are commonly found in lake sediments around the world and have often been used as chronology controls in tephrochronology. Limited studies have investigated past tephra depositions' impacts on lake ecosystems. The use of palaeoecological analyses across tephra layers in sediment cores to infer volcanically-induced environmental change is termed 'Tephropalaeoecology'. A diatom-based tephropalaeoecological approach was adopted in the study to infer the impacts of five tephra depositions on a lacustrine ecosystem in northeast China during the past 30,000 years. The five tephra layers (including two micro-tephras) have varying thicknesses and were deposited in different time periods under different climatic conditions. Changes in diatom communities between samples pre and post-tephra were utilised to reconstruct changes in lake conditions due to tephra depositions. In general, thicker tephras induced larger degrees of change in diatom communities and lake conditions. Tephras deposited in more eutrophic and warmer lake conditions induced more dramatic responses from diatoms and the lake system. Water column phosphorous likely decreased dramatically from reduced sediment-water phosphorous loading as the tephra layers probably formed an impermeable layer at the lake bottom. This was supported by a decrease in overall diatom concentration and a decline in sensitive, high phosphorous requirement diatom taxa e.g. Discostella stelligeroides and Stephanodiscus minutulus. Contrastingly, tephra deposited in more oligotrophic and colder lake conditions induced a smaller degree of change. Because the lake condition was already low in phosphorous, diatoms did not respond to further decline in phosphorus but rather responded to the minor increase in silica from the dissolution of tephra particles in the water column. This was inferred from the slight increase in overall diatom concentration as well as opportunistic taxa. The results outlined the importance of lake background conditions in mediating tephra's impacts. In terms of recovery, none of the tephras showed complete recovery back to their background states, possibly suggesting the long-lasting effect of tephras and a shift to new lake ecosystem equilibrium.

USING GIS AND NUMERICAL MODELLING TO TEST THE INFLUENCE OF CLIMATE CHANGE ON GLACIAL LAKE OUTBURST FLOOD RISK IN THE DUDH KOSHI BASIN, NEPAL HIMALAYA

Duncan Russell
Plymouth University

For centuries, farming communities have occupied the valleys and foot slopes of the world's mountain ranges; living and working in a harsh environment that is defined by climate, hydrology and threat of natural hazards. Despite this history, and the lessons learned, the populations that occupy these spaces today are experiencing change to all three of those elements at a rate and intensity never seen before. Increasing global temperatures have caused glacial recession since the 1940s and will continue in doing so for the rest of this century, regardless of the emission pathway taken. For the people of the Himalaya, glacial ice is a resource that proves its value across all facets of life; providing, a store of freshwater that maintains flow through dry seasons, irrigation of crops, renewable energy and attractions for tourism. In this paper, I show that the loss of glaciers in the Dudh Koshi basin, as a result of climate warming, has caused the expansion of glacial lakes in the area and the creation of new ones. This by-product of glacier diminishment; along with growing pressures on food, energy and water; has increased the threat of glacial lake outburst floods (GLOFs) to a critical level. With over 500 glacial lakes covering an area of almost 4000 km^2, identifying which lakes pose the largest threats and which areas are most at risk is an essential first step in hazard management. Therefore, this study develops a multi-criteria hazard assessment on lakes within the Dudh Koshi basin, which remotely measures influences on both GLOF susceptibility and downstream vulnerability. The seven largest moraine dammed lakes in the basin were identified and ranked in order of hazard level. For the three most hazardous lakes, Imja tsho, Lumding tsho and Dig tsho; calculated volumes and GIS techniques were used to model inundation extent for three GLOF scenarios. The first represented a GLOF under a lake volume calculated for 2020. Two theoretical increases in lake volume, by 15 and 25%, provided future GLOF scenarios to be tested. The models were used to analyse the influence that climate change might have on future GLOF events and highlighted which downstream settlements will be impacted the most. Results found climate change scenarios to have varying levels of influence on inundation zone, with a major control being the topography surrounding settlements.

AN EARLY PLEISTOCENE HIPPOPOTAMUS FROM WESTBURY CAVE, SOMERSET, ENGLAND: SUPPORT FOR A PREVIOUSLY UNRECOGNISED TEMPERATE INTERVAL IN THE BRITISH QUATERNARY RECORD

Journal of Quaternary Science (2022), 37(1), 28-41
Neil Adams, Ian Candy and Danielle Schreve

Although fossil assemblages from the late Early Pleistocene are very rare in Britain, the site of Westbury Cave in Somerset, England, has the potential to address this gap. The mammal fossils recovered previously from the Siliceous Member in Westbury Cave, though few in number, have hinted at an age for the deposits that is as yet unparalleled in Britain. Here, we describe the first bona fide occurrence of Hippopotamus in the British Early Pleistocene, discovered during recent reinvestigation of the Siliceous Member. The hippo fossil indicates a refined biochronological age of ca. 1.5–1.07 Ma for the Siliceous Member and a palaeoclimate that was warm and humid, which accords well with previous palaeoenvironmental inferences. A synthesis of late Early Pleistocene hippo occurrences suggests that the Siliceous Member hippo may have been part of an early colonization of north-west Europe by these megaherbivores, possibly during MIS (Marine Oxygen Isotope Stage) 31. Alternatively, it evidences a currently cryptic northward migration during an even earlier temperate phase. In either case, the Siliceous Member is likely to represent a warm period that has not been recognized previously in the British Quaternary record.

QUATERNARY RESEARCH ASSOCIATION

The Quaternary Research Association is an organisation comprising archaeologists, botanists, civil engineers, geographers, geologists, soil scientists, zoologists and others interested in research into the problems of the Quaternary. The majority of members reside in Great Britain, but membership also extends to most European countries, North America, Africa, Asia and Australasia. Membership (currently ~1000) is open to all interested in the objectives of the Association. The annual subscription is £20 with reduced rates (£10) for students, retired and unwaged members and an institutional rate of £35.

The main meetings of the Association are Field Meetings, usually lasting 3–4 days, in April, May and/or September, and a 2-3 day Annual Discussion Meeting held at the beginning of January. Short Study Courses on techniques used in Quaternary work are also occasionally held. The publications of the Association are the *Quaternary Newsletter* issued in February, June and October; the *Journal of Quaternary Science* published in association with Wiley; and the QRA Field Guide and Technical Guide Series.

The Association is run by an Executive Committee elected at an Annual General Meeting held during the January discussion meeting. Current officers of the Association are:

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All questions regarding membership are dealt with by the Secretary, the Association's publications are sold by the Publications Secretary and all subscription matters are dealt with by the Treasurer.

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