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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. PhD 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 now available via the QRA webpage and from the editor.

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COVER PHOTOGRAPH

View from the north-facing slope of Galdhøpiggen mountain (Jotunheimen, Norway) with patterned ground visible on the foreground. *(Image H. Hallang)*.

OBITUARY

MICHAEL JOHN TOOLEY (1942 – 2022)

Michael Tooley died on June 11th 2022, and with his passing Quaternary Science has lost one of its leading and influential figures in sea level studies, both in the United Kingdom and abroad. He was born in Barnstaple, Devon, on December 17th 1942, the only child of Bill and Linda Tooley, but in his early years the family moved to Lytham St Annes in Lancashire. In 1961, he began a B.A. at Birmingham University, achieving an upper second class honours degree in Geography there in 1965. With a strong interest in biogeography, Michael Tooley won a Fulbright Scholarship to study for an M.Sc under Professor Pierre Dansereau, Professor of Botany and Geography at Columbia University, New York, in 1965. His interests had always lain in coastal research, initially on coastal dunes, perhaps reflecting his time at Lytham, and at Columbia his interests focused on sea level change when he met Professor Rhodes Fairbridge there. Fairbridge had already established himself in the field of sea levels with his seminal chapter on “Eustatic Changes in Sea Level” in the volume “Physics and Chemistry of the Earth”, edited by Ahrens et al. in 1961. When his scholarship at Columbia came to an end in 1966, Michael decided to work in the field of sea level change and returned to the United Kingdom to study for a PhD with Professor Frank Oldfield at Lancaster University on “Sea-level changes and the development of coastal plant communities during the Flandrian in Lancashire and adjacent areas”. During his PhD studies, in 1968 he was appointed to a Young Scientific Workers Exchange Scheme at the Geological Survey of the Netherlands, Haarlem, where he met Dr Saskia Jelgersma, who would remain a strong influence in his work.

In 1969, having completed his PhD, Michael was appointed Lecturer in Geography at Durham University, where he was to carry out most of his research on sea level. His work was characterised by a meticulous attention to detail, especially in his pollen and diatom analyses as well as in his recording of stratigraphic sequences. In the latter he was well in advance of his time, perhaps due to the influence of Dr J Troels-Smith, whom he met in 1976 and briefly worked with at the Danish National Museum, Copenhagen. At this time (1978), Michael published a monograph on “Sea-Level Changes in North-West England during the Flandrian Stage”, which remains today a bench mark study in sea level change.

As his research at Durham progressed, Michael authored a number of influential papers on sea level change. He identified in some detail variations in changes in relative sea level, documented the effects of sea level rise along vulnerable coasts, and identified evidence for a rapid rise in relative sea level, later to be associated with the Early Holocene Lake Agassiz discharge. Through this work, he developed and refined a now widely used methodology for coastal and sea level investigations, applying this not only to work in the United Kingdom, but also in Brazil, India, Bangladesh and China, and initiated the Durham Sea Level Database. Examples of several of his more influential papers are listed at the end of this obituary. He was promoted to a Chair at Durham in 1993. In 1995 he moved to the University of St Andrews as Professor and Head of the School of Geography and Geology and later in 2003 to Kingston University as Professor of Physical Geography and Environmental Science. In 2006 he was awarded a D.Sc. from Lancaster University in recognition of his research. He had been instrumental in establishing Durham University as the leading centre for sea level research in the United Kingdom.

A feature of Michael’s work has been his involvement in organisations concerned with climate and sea level change, notably the Working Group of UNESCO/IGCP Projects 61 and 200 “Sea-level changes” (as UK Representative and Secretary) and the INQUA Commission of Quaternary Shorelines (as Secretary and later President). Michael played an active and influential part in these organisations. He became widely travelled in the cause of sea level studies, and the many papers he gave at conferences and symposia were universally well received and contributed much to the understanding of sea level change. He was strongly committed to the Royal Geographical Society as a Member of the Council and of the Geographical Club.

Michael was an articulate and often entertaining lecturer and a dedicated PhD supervisor. He led a significant contingent of PhD students at Durham, with whom he published many papers. At conferences his presentations were well received. His humour was legendary, and his anecdotes – most told at the expense of himself - would brighten up the most serious of gatherings. In the field, whether with students or on conference excursions, he could be counted on to entertain, but not without serious purpose. Such talent is of great importance in furthering the business of scientific enquiry, since no facts are absolute, especially in the field of Quaternary Science!

Michael had many interests besides sea level change. In particular he was extremely interested in gardens and in the work of Gertrude Jekyll, the horticulturist and garden designer. Together with his wife Rosanna, an accomplished artist, he published several books on Gertrude Jekyll's work and travelled widely in the United Kingdom giving lectures on Jekyll and on garden design. He planted and cultivated his own garden in Fife, with avenues leading to views of the Highlands. He enjoyed entertaining and was no mean cook. Regular visitors will miss after dinner debate and discussion, not to mention good wine and the occasional malt whisky in the evening.

Michael married Rosanna Mellor in 1973 and they had two children, Nicholas (born 1976) and Anna (born 1978). Rosanna sadly died in 1996.

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David Smith
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RESPONSE LEWIS PENNY MEDAL

Introduction

I would like to begin by expressing my deepest gratitude to the QRA and my nominators for the honour of being awarded the Lewis Penny Medal. The QRA formed a key part of my early academic career through field meetings, ADMs, and funding. I am delighted to receive this award, and it represents the highlight of my career so far. In receiving the Lewis Penny Medal, I must acknowledge the inspiration, encouragement, and support that my former supervisors, collaborators, and colleagues have provided, which are summarised below.

My interests in glacial geology and palaeoglaciology were first developed during my time as an undergraduate student at Queen Mary University of London (QMUL), when I first encountered my future PhD supervisors, Sven Lukas and Clare Boston. I then went on to complete an MSc (by Research) at Durham University, which focused on moraine-climate linkages and glacier dynamics in Iceland. After completing my MSc, I returned to QMUL and undertook a PhD focused on Quaternary glaciations in the Gaick, Central Grampians, Scotland. This research in ancient and modern glacial environments laid the foundations for my early academic career, in which I have so far primarily specialised in glacial-process geomorphology and sedimentology.

Marginal Loch Lomond Stadial glaciation in Scotland

As an undergraduate student at QMUL, I chose to do a BSc dissertation on marginal Loch Lomond Stadial (LLS) glaciation in Scotland, under the supervision of Sven Lukas. This followed inspiring lectures, tutorials, and fieldtrips that first sparked my interests in glacial geology. Notably, these included a field day mapping hummocky moraine and discussing the glacial history of the Pass of Drumochter (during which it rained horizontally all day, in true Scottish fashion!). It was during this trip that I was first introduced to debates surrounding what was going on 'up there', on the plateau to the north of the Pass of Drumochter, with the glacial history of the Gaick much-debated at the time (for reviews, see Lukas *et al*., 2004; Chandler, 2018; Chandler *et al*., 2019a). And perhaps most significant was a second-year lecture by then-PhD-student Clare Boston on her PhD research in the Monadhliath (see Boston, 2012a, b; Boston *et al*., 2013, 2015; Boston and Lukas, 2017, 2019). Listening to Clare's lecture, I decided that I wanted to do research on the same theme.

For my BSc dissertation, I focused on the glaciation of Ben More Coigach in northwest Scotland. At the time of starting my dissertation research in 2012, there had been a considerable research effort to advance our understanding of the extent and dynamics of satellite icefields in Scotland (e.g. Benn and Ballantyne, 2005; Benn and Lukas, 2006; Lukas and Bradwell, 2010; Finlayson *et al*., 2011), but more marginal settings of glaciation had received far less attention. Although having less extensive and complex sediment-landform records, assessing sites of marginal (cirque) glaciation are important for assessing the influence of topoclimatic factors on glacier functioning and, crucially, the impact of these on glacier-derived palaeoclimatic reconstructions (e.g. Mills *et al*., 2012).

My research involved systematic assessments of snowblow and avalanching contributions, which were informed by modern analogues and tested using detailed palaeoglaciological reconstructions of three corrie glaciers on Ben More Coigach, north-west Scotland. A key finding of the research, later published in *Journal of Quaternary Science* (Chandler and Lukas, 2017), was that glacier-derived palaeo-precipitation estimates for Ben More Coigach did not conform with the expected regional precipitation gradient during the LLS. We argued that this discrepancy reflects topographically enhanced snow accumulation, which lowered the equilibrium-line altitude (ELA) from the 'true' climatic ELA.

Moraine-climate linkages and ice-marginal dynamics in Iceland

Following my BSc degree, I moved to Durham University to complete an MSc (by Research) under the supervision of Dave Evans and Dave Roberts. This saw a move away from palaeoglaciology to glacial-process sedimentology and modern glacial landsystems research, with my MSc focusing on the application of ice-marginal moraines in Iceland as climatic proxies. This introduction to modern glacial landsystems later became influential during my PhD research, in which I applied a glacial landsystems approach to understand the extent and style of former glaciation in the Gaick (see below).

For my MSc, I investigated the characteristics and formation of recessional moraines at Skálafellsjökull in Iceland, the location of the seminal study by Sharp (1984) on processes of annual moraine formation. The Skálafellsjökull foreland is characterised by sequences of striking sawtooth recessional moraines, which are a distinctive signature of the active temperate glacial landsystem (cf. Evans and Twigg, 2002; Evans, 2003). The aim of my MSc was to use these moraine sequences as geomorphological proxies to understand patterns, rates, and drivers of glacier retreat (see Chandler *et al*., 2016a, b, c, 2018).

Perhaps the most significant aspect of my MSc research was the serendipitous finding of 'sub-annual' moraines on the Skálafellsjökull foreland. Based on counting of the moraines, and cross comparison with aerial photographs and ice-front measurements, it appeared that multiple moraines were formed in some years

(Chandler *et al*., 2016a). At the time, we suggested that "grouplets of recessional moraines may form in the same year where submarginal processes active over a single seasonal cycle are recorded as multiple ridges, rather than as a single composite push/squeeze moraine".

After finishing my PhD (see below), I returned to this idea and my research in Iceland, and I led a project to investigate the controls on moraine-forming processes and the frequency of moraine formation at active temperate glaciers in southeast Iceland (see Chandler *et al*., 2020a, b). In collaboration with colleagues (including my brother and then-MSc-student, Samuel), we used a time series of repeat uncrewed aerial vehicle (UAV) imagery to test the sub-annual moraine hypothesis at Fjallsjökull. For the first time, to our knowledge, we captured and demonstrated sub-annual moraine formation on our repeat aerial imagery. Based on this dataset, and complimentary glacial-process sedimentological studies in the foreland, we proposed that the sawtooth moraine sequences comprise (i) sets of small squeeze moraines formed during melt-driven squeeze events and (ii) larger push moraines formed during winter re-advances (Chandler *et al*., 2020a, b). We suggested that the development of this process-form regime is linked to a combination of elevated temperatures, high surface meltwater fluxes to the bed, and an emerging overdeepening.

Extent, style, and dynamics of glaciation in the Central Grampians, Scotland

In 2014, I started a PhD in the School of Geography at QMUL, supervised by Sven Lukas and Clare Boston. My PhD marked a return to research on Quaternary glaciations in Scotland, with the focus of my PhD being on the extent, style, and timing of former glaciation in the Gaick, Central Grampians, Scotland. Although having offers of PhD studentships to stay at Durham University or to move to the University of Edinburgh, I ultimately decided that I wanted to tackle the question of "what was going on up there [on the Gaick]?", which I had first been introduced to as an undergraduate at QMUL. This also allowed me to indulge my interests in hillwalking and the Scottish Highlands, spending large amounts of time (>18 weeks) out on long walks (often >35 km) in the hills while working.

At the start of my PhD, the accepted paradigm for LLS glaciation in the Gaick had been one of extensive plateau icefield glaciation, as argued by Sissons (1974). And this idea was reflected in numerous compilation maps of LLS glacier extent in Scotland/Britain (e.g. Golledge, 2010; McDougall, 2013). However, the glacial geological evidence in the Gaick had been repeatedly contested and, during the previous ~100 years, several diverging and conflicting models had been put forward (e.g. Barrow *et al*., 1913; Charlesworth, 1955; Sissons, 1974; Merritt, 2004; Merritt *et al*., 2004). These debates remained unresolved, and thus the purpose of my PhD was to establish the extent, style, and timing of former glaciation in the Gaick.

During my PhD, I undertook a systematic assessment of the glacial geological record, involving detailed geomorphological mapping of the glacial sediment-landform assemblages and targeted glacial-process sedimentological studies (see Chandler, 2018; Chandler *et al*., 2019a, b, 2020, 2021). Based on these investigations, and using morphostratigraphic principles, a distinct morphostratigraphic signature was recognised in the upper parts of the western catchments in the Gaick. This signature differs markedly from sediment-landform associations in other parts of the area, and we argued that this provides a strong indication of spatially restricted LLS glaciation in the Gaick (Chandler *et al*., 2019a). Our interpretation was independently supported by glacierisation threshold analysis, which implied that the eastern Gaick was unable to nourish LLS plateau ice. A major outcome of my PhD research was thus the recognition that the Gaick experienced vastly more restricted LLS glaciation than previously envisaged by Sisson (1974), with the LLS Gaick Icefield being ~85% smaller than Sissons' reconstructed icefield.

My research also found sediment-landform signatures indicative of multiple glacier fluctuations prior to the LLS (Chandler, 2018; Chandler *et al*., 2019a). This includes evidence for (i) interactions of local and regional ice lobes following unzipping during deglaciation of the Last British Ice Sheet, and (ii) an extensive plateau icefield that existed following thinning and retreat of the Last British Ice Sheet, but prior to the Younger Dryas. We suggested that this most likely occurred at the end of the Dimlington Stadial (correlated with Greenland Stadial 2 (GS-2). The evidence for, and the reconstruction of, these glacial events will be the focus of a forthcoming publication.

Another important outcome of my PhD was a re-interpretation of some areas of 'hummocky terrain' in the Gaick (Chandler *et al*., 2021). A characteristic feature of many glaciated catchments in the Scottish Highlands is the striking sediment-landform association 'hummocky moraine'. Sedimentological evidence from across Scotland indicates that these landforms represent a continuum of undeformed to completely overridden and glaciotectonised terrestrial ice-contact fans, and hummocky moraine is largely interpreted as sequences of ice-marginal moraines formed during active, oscillatory retreat (e.g. Lukas, 2005; Benn and Lukas, 2006; Boston and Lukas, 2019). This is also the case in the Gaick, where there is sedimentological evidence for terrestrial ice-contact fans (see Chandler *et al*., 2020c). However, we have also identified areas of distinctive irregularly shaped mounds and ridges that occur outside the limits of the former LLS icefield (Chandler *et al*., 2021). These ridges and mounds are intimately associated with series of sinuous channels, and their planform shape mimics the form of the adjacent channels. Based on the forms and spatial arrangement of the associated channels, as well as sedimentological evidence, we interpreted the irregularly shaped ridges and mounds as erosional remnants generated by a combination of ice-marginal and proglacial glaciofluvial incision. This re-interpretation has important implications, as misinterpreting similar features elsewhere could lead to erroneous reconstructions of palaeo-ice margin positions and glacier dynamics (Chandler *et al*., 2021).

Recent and future work

After my PhD, my research interests diversified and went in a new direction, with my recent work focusing on the application of near-surface geophysical methods to glacial environments. I was awarded a Leverhulme Trust fellowship to undertake postdoctoral research at Stockholm University, where I worked with colleagues to test and develop integrated, multi-method geophysical and glacial geological approaches (e.g. Watts *et al*., 2022). Our ongoing research is using geophysical and glacial sedimentological data to understand the formation and glaciological significance of moraines in Sarek (northern Sweden), a project that has been undertaken in collaboration with the local Sámi community. My recent research has also extended beyond glacial environments, with involvement in ground-penetrating radar studies of peatlands as part of research to understand Holocene storminess in Sweden (Kylander *et al*., accepted).

Looking forwards, I am particularly interested in research on plateau icefield dynamics, with a focus on understanding the influence of thermal regimes and topography on plateau icefield response to climate change. I also maintain on interest in British Quaternary stratigraphy, and I am currently leading a project using single-grain luminescence dating to date glaciolacustrine sediments in the Central Grampians, Scotland (a project supported by the QRA Quaternary Research Fund). I look forward to continuing my research on both ancient and modern glacial environments in future, working with established and new collaborators. I also look forward to welcoming my first PhD student, Libby Pattison, to the University of Nottingham in Autumn 2022. I hope that Libby will also benefit from being an active member of the QRA community!

Acknowledgements

The research I describe above would not have been possible without the support and encouragement of numerous influential people, both during my time as a student and during the early part of my academic career. In particular, I would like to thank my high school Geography teacher, Helen Carty, who first inspired me to study Geography at university. As a lecturer and tutor at undergraduate level, Sven Lukas developed my enthusiasm for glacial geology through his teaching, and later contributed significantly to my research as a supervisor and collaborator. Over the years, numerous thought-provoking, motivating, and entertaining discussions with Sven played a substantial role in my development as a researcher, and I am very grateful to Sven for his enthusiastic guidance and friendship. I am also grateful to Clare Boston for inspiring me to pursue a PhD on Quaternary glaciations in Scotland, and for her support and encouragement throughout my postgraduate studies. I would also like to thank my MSc supervisors, Dave Evans and Dave Roberts, for all their advice during my MSc and their continued collaboration. The encouragement and guidance of a number of other former lecturers and collaborators have also contributed to my development as a researcher, including Geraldene Wharton, Simon Carr, Iestyn Barr, Harold Lovell, Marek Ewertowski, and Benedict Reinardy. To all of them: thank you.

This award, and my academic career, would not have been possible without all the emotional and practical support provided by my family. Thank you to Mum, Dad, Abigail, and Samuel ('Simon'). Lastly, I would like to thank Helen for indulging me and listening to my impromptu lectures about hummocky moraine, etc., as well as for her support during recent challenging times.

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ARTICLES

PALAEODRAINAGE RECONSTRUCTION OF THE RIVER TRENT: NEW EVIDENCE FROM GOOGLE EARTH IMAGERY

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Introduction

Allan Straw (2022) has recently revisited the contentious issue of the Middle Pleistocene diversion(s) of the River Trent in the East Midlands. In it, he restates the hypothesis previously set out by Posnansky (1960), Straw (1963) and Rice (1968). By so doing, he is critical of conclusions reached by the TVPP (Trent Valley Palaeolithic Project) team (Bridgland *et al*., 2014) regarding the origin of the Trent Trench and Vale of Belvoir. Essentially, the disagreement revolves around the course of the Trent at the post-Anglian stage, the direction and impact of the Wragby ice advance (MIS 8), and the timing of formation of the Trench. Their respective models propose routes at the post-Anglian stage either eastwards towards the Ancaster Gap or north-eastwards via the Trench. A split point between these two alternatives is near Long Eaton (Figure 1). From this junction however, there are no surviving deposits older than the Beeston and Bassingfield Terraces in the Trench, and the fluvial archive, such as it is, within the Vale of Belvoir is notably meagre. Understandably, without a satisfactory sedimentary record between Long Eaton and Newark, workers have placed more reliance on morphological arguments, but perhaps with insufficient regard to post-depositional processes of erosion, differential uplift and subsidence. One significant complicating factor is surface subsidence by gypsum dissolution, a process largely overlooked by Quaternary specialists, but widely recognised locally by engineering geologists (Charsley *et al*., 1990; Hobbs *et al*., 2002; Bell *et al*., 2009; Cooper, 2020).

Gypsum karst

Within the Mercia Mudstone Group (MMG) gypsiferous mudstones of the Branscombe, Edwalton and Gunthorpe formations and thick gypsum units in the Branscombe Formation (Tutbury and Newark) are particularly vulnerable. The Triassic MMG lacks the open hydrological geometry of the Permian Edlington and Roxby formations with their adjacent magnesian limestone aquifers that is responsible for hazardous gypsum karst in North Yorkshire (Cooper, 2020). Nevertheless, where unrestricted water flow paths do exist, or past fluctuations have occurred in groundwater levels, the potential for local ground subsidence could have been significant (Tony Cooper, *pers. comm.*).

Collapsed areas and natural cavities were observed in the construction of the Derby Southern Bypass at Aston Hill (Cooper and Saunders, 2002) (Figure 1).

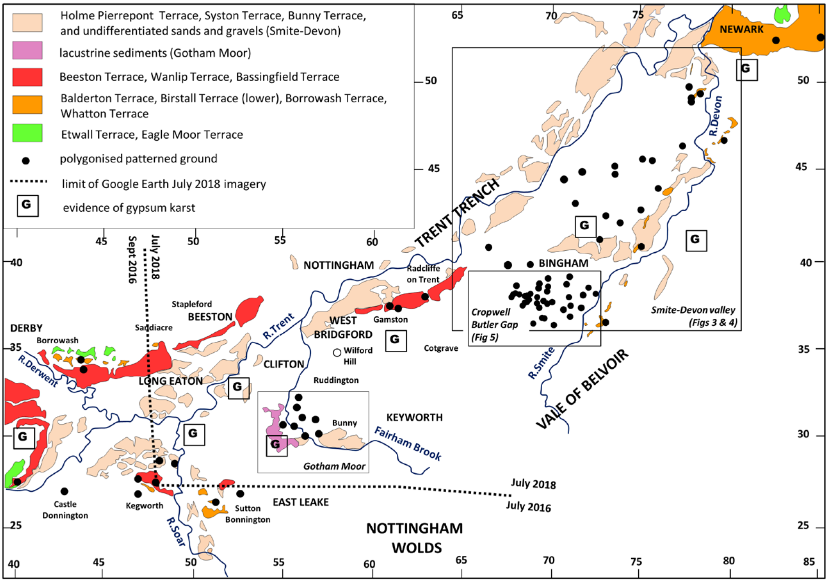

Figure 1. Distribution of polygonised ground, sites of gypsum dissolution, Trent river terraces (based on Charsley *et al*., 1990; Bridgland et al., 2014; and BGS 2021) and limits of Google Earth imagery.

Gypsum can make up to 50% rock mass (Young 1992; Hobbs *et al*., 2002), and dissolution depressions are reported in the Nottingham area (Howard 1989; Charsley *et al*., 1990). Core logs in connection with the Newark Southern Link Road (Soil Mechanics, 2013) have been examined and confirm about 10% rock mass at Hawton, in the Middle Beck south of Balderton, where a gypsum-free weathered profile up to 10 metres deep exists. This implies ground subsidence of about 1 m in response to dissolutional loss of gypsum, and this same gypsum-free regolith persists westwards underneath 5 m of Late Devensian Holme Pierrepont sands and gravels. Further south, contemporary ground subsidence is visible in the Orston area (Barnes and Firman, 1991), and Howard *et al*. (2009) estimate potential ground subsidence of 3 m at Bingham and Tollerton in connection with Holocene lake basins. Post-Late Devensian subsidence of 1-3 m is therefore likely, but over longer timescales the cumulative effect of continued subsidence may have been checked by repeated river adjustment. The depth of gypsum-free regolith depends in part on the rate of dissolution compared to the rate of erosion (Charsley *et al*., 1990). Firman and Dickson (1968) suggest that the bulk of dissolution of gypsum in the Vale of Belvoir was accomplished during and shortly after the ice age by acidified (soft) meltwater rising through frost-cracked ground, and more than one cycle of dissolution was implied by some selenite structures.

Google Earth imagery

Significant new evidence of aerial and satellite imagery has been reported recently (Baker *et al*., 2021), which greatly adds to previous knowledge of the periglacial record in the East Midlands (Baker *et al*., 2014). This may have some bearing on the palaeodrainage debate. Work has revealed widespread relict thermal contraction cracks throughout the region, including polygon-imprinted Trent valley terrace surfaces. It takes advantage of exceptionally clear crop markings and parched soil made visible in the dry summer of 2018. Methodology is outlined in Baker *et al*. (2021) and results can be viewed in Google Earth Pro at https://tinyurl.com/groundpatterning or via IceAgeInsights.org. Google Earth's tile mosaic optimisation, however, means that clear July 2018 images terminate west and south of Nottingham (Figure 1); beyond these limits, further historic imagery dating to July 2006, April 2007 and January 2009 is available in the Middle Trent, Soar valley and National Forest areas. Table 1 brings together all confirmed polygonised river terrace surfaces detected in the Soar, Middle and Lower Trent, Vale of Belvoir (Smite-Devon valley) and Lincoln Gap. Site locations are indicated in Figure 1, and a selection of three traces of polygonal networks is illustrated in Figure 2.

Polygonisation consists of more or less regular networks of low- and high-centred, secondary, unsorted ice-wedge polygons, many with clear borders and with diameters of 10-20 m, suggestive of mature ice-wedge formation. Some sites retain evidence of initial large primary rectangular networks (diameters 20-50 m), while tertiary reticulate meshes of diameters < 5 m (more cellular in appearance where possessing wide margins) indicate sites of prolonged and intense periglacial activity. Theoretical considerations of polygonal subdivision over time, based on contemporary thermokarstic drained lake basins, are discussed in Baker *et al*. (2021). It is assumed that the regularity and clarity of these relict thermal contraction features revealed in the summer 2018 images must have originated from silt-rich/ice-rich host deposits (alluvial, lacustrine or aeolian) that once overlaid the river terraces. Remnant patterning we see today may only be the truncated roots of past ice-wedge networks, with little evidence of former active layers or cover deposits that gave rise to them. Analysis of ice-wedge cast infill stratigraphy would be necessary to establish this firmly.

Chronology

Howard (1995) thought that relict ice-wedge polygons on the Balderton Terrace

Table 1. Proposed earliest age constraints (*terminus post quem*) for polygonal horizons in the study area.

	Soar	Middle Trent	Lower Trent	Smite-Devon	Lincoln Gap
Devensian	Syston Terrace	Holme Pierrepont (HPSG-A) Bunny Terrace			Holme Pierrepont (HPSG-A)
	Wanlip Terrace	Beeston Terrace	Bassingfield Terrace		Fulbeck Terrace
Pre-Devensian	Wanlip Terrace Birstall Terrace (lower)	Borrowash Terrace Egginton Common Terrace		Whatton Terrace	Balderton Terrace
					Eagle Moor Terrace Skellingthorpe Clay

at Brough was Late Devensian (MIS 2) in age, but there are many intraformational ice-wedge casts throughout the Balderton sands and gravels (Brandon and Sumbler, 1991) of assumed MIS 6 age in addition to Devensian structures. Baker *et al*. (2021) considered the possibility that polygonised patterning could all be MIS 2 in age, a relatively late imprint on Middle Pleistocene terraces, and that presence/absence in the distribution was merely an artefact of preservation, i.e. that patterned ground had been widely developed only once wherever favourable conditions allowed, and was subsequently broken up by erosion or concealed by burial. It was observed, however, that more recent Lateglacial surfaces appeared to lack visible polygonal imprint, suggesting that less severe periglacial conditions in that period had failed to produce the intensity and depth of ice-wedge growth more typical of the Last Glacial Maximum (LGM). It was also noted that recent researchers (Worsley, 2014; Bateman *et al*., 2014; Murton and Ballantyne, 2017) recognised periglacial episodes to have been polycyclic, so it is likely that older lines of thermal cracking could have been repeatedly reopened and reactivated during recurrent periglacial phases. Rice (1968) also recognised polygonal patterning locally, and alluded (ibid., p 352) to the likelihood of polycyclicity. A case can be made that the wide extent of polygonisation (80 locations in Figure 1) and the diversity of geometry, altitude, context and substrate all imply different episodes of formation and the potential for polycyclicity.

Chronologically, underlying surfaces provide the earliest possible date (*terminus post quem*) at which a given polygon could have been formed (Table 1). The *tpq* is the oldest date for an event determined by the youngest affected layer below the relevant horizon (pre-polygon). Table 1 therefore records only theoretical maximum time constraints for polygonisation. These extend the timeframe back to the late Middle Pleistocene interval (MIS 10-6), during some part of which Wragby ice advanced into the region. Patterning could span both Pre-Devensian and Devensian stages, and thus accords with Murton and Ballantyne's (2017) Periglacial Zone C. Gibbard *et al*. (2020) have assigned the Wragby glaciation to MIS 6, but this is contested by Westaway (2021) who reiterates the TVPP view that it must be MIS 8 based on biostratigraphic control.

The most firmly-dated terrace aggradation in the Lower Trent valley is that of the Holme Pierrepont sands and gravels, recognised as a diachronous formation (Howard *et al*., 2011), and here divided into HPSG-A (earlier) and HPSG-B (later). Its lower component (coincident with the Soar valley Syston Terrace) is dated to 28,875±205 BP (Brown *et al*.,1994) which adjusts after calibration to about 33,387 cal BP (Westaway *et al*., 2015), placing earliest aggradation towards the end of MIS 3 (MIS 2 commencing at about 29 ka). A few patches of HPSG-A appear to be polygonised (e.g. Swarkestone, Ratcliffe on Soar, Broadholme and Besthorpe), consistent with intense periglaciation throughout the LGM, but the majority of the Holme Pierrepont Terrace (Figure 1), occupying most of the floor of the Trent Trench, is probably younger comprising the upper and later HPSG-B component. Dating of three samples from the type site yields calibrated ages between 13,200 and 12,880 cal BP (Bayliss *et al*., 2008; Howard *et al*., 2011) placing aggradation of HPSG-B within the Lateglacial, at the close of MIS 2. Polygons are thus segregated, found on fragments of the older HPSG-A surface, but apparently absent on the more widespread younger HPSG-B surface, reflecting its more recent origin.

By way of comparison, eastern Essex provides a parallel case study of polygon-imprinted river terraces. Google Earth imagery from January 2009 confirms the presence of orthogonal and irregular primary polygons across much of the Tendring Plateau and Dengie and Southend Peninsulas, first described by Gruhn and Bryan (1969) and Sturdy and Allen (1981). Distributed on the low Kesgrave Sands and Gravels (Wivenhoe, Cooks Green and Holland terraces) (Bridgland, 1988; Allen, 2009), and imprinted on bedrock London Clay, these patterns widely underlie silt-rich fluvio-aeolian coverloams (brickearth) of presumed MIS 2 age. Eastern Essex falls within Murton and Ballantyne's (2017) Periglacial Zone 5, beyond the limit of Anglian ice. If we accept the assumption of polycyclicity and recurrent phases of periglaciation, these features have a *tpq* dating from the Middle Pleistocene, though with final reactivation within the Late Devensian beneath ice-rich coverloams.

Three specific areas within the Trent Valley will be described – Gotham Moor, the Smite-Devon Valley, and the Cropwell Butler Gap.

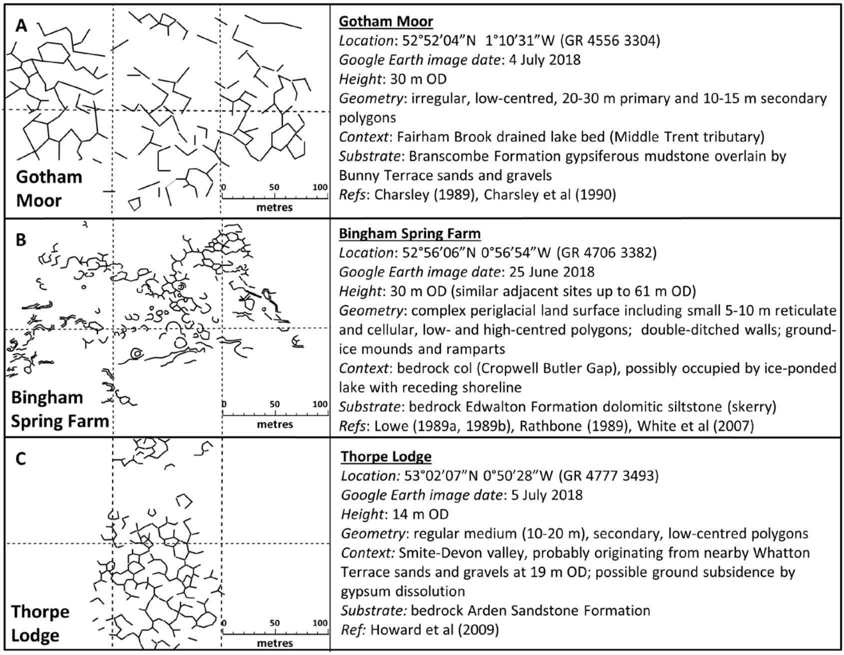

Figure 2. Outline traces of polygonal geometry at (A) Gotham Moor, (B) Spring Farm Bingham, and (C) Thorpe Lodge.

Gotham Moor

One of a number of unexpected discoveries in the summer 2018 survey was that of Gotham Moor (Figure 1) where a concentration of polygonised fragments exists across an area of about 8 km². Gotham Moor (and its extension into the Ruddington, Bradmore and Bunny Moors) is a broad expanse of once marshy ground (12 km² in area), drained by a small stream, the Fairham Brook, across a veneer of Holocene alluvial and lacustrine deposits up to 2-3 m thick (Charsley, 1989). At about 30-32 m OD, the stream's low gradient suggests frequent ponding with little evidence of fluvial incision to the local base level of 26 m OD. Evolution of these moors may be due in part to recent gypsum dissolution within Mercia Mudstone (as originally proposed by Lamplugh and Gibson, 1910), but Charsley (1989) also recognised earlier periglaciation, probably contemporary with adjacent Bunny sands and gravels (MIS 2). Current-bedded sub-alluvial gravels, exposed in a stream bank, overlie cryoturbated bedrock mudstone (Charsley *et al*., 1990, Plate 4) in which a single palaeocurrent analysis indicated a possible flow direction towards the ENE. The lake basin was accessed from the west via the Barton in Fabis gap at about 32 m OD.

Widespread subsurface polygonal networks imprinted in bedrock are very clearly visible in summer 2018 images. Patterning adopts diameters of 10-30 m (Figure 2A), though some is more reticulate and cellular in nature (diameters < 5 m), with circular raised walls around low centres, indicating a mature stage of development across a thermokarstic lake bed. In places, polygons are linked to palaeochannels, ridges and enclosed depressions. These widespread finely-subdivided meshes signify both long exposure and very cold conditions. Thus a suite of features (involutions, ice-wedge casts, patterned ground and palaeochannels) are preserved in bedrock, consistent with a Late Devensian (MIS 2) origin. Charsley (1989) thought that the very constricted channel of the Fairham Brook between Clifton and Ruddington was the final overflow route in a northerly direction from this lake basin, but an earlier outflow could have exploited a much easier open route to the northeast towards Bradmore and Tollerton (east of Wilford Hill) and Cotgrave, at elevations of approximately 35-40 m OD in the direction of the Cropwell Butler Gap. Such an outflow follows precisely the course of Straw's (2022) postulated proto-Trent palaeovalley, but he envisaged this as a drainage route rather earlier in the Pleistocene. This new evidence certainly supports the TVPP notion that the geomorphology south and east of the modern Trent course is relatively young (younger than any glaciation to have reached this area), but it provides a possible hint of an earlier antecedent, which could have been independent of the Trent Trench.

Polygonisation in the Smite-Devon catchment (Vale of Belvoir)

Most of the Vale of Belvoir is drained by the Smite-Devon catchment. This right bank tributary of the Lower Trent is clearly underfit and too small for the broad valley that contains it. The valley is noted for its very low drainage gradients (Lamplugh *et al.*, 1908) and significant overbank alluviation (Challis *et al.*, 2006), due in part to dissolution of gypsum within gypsiferous mudstones. Bridgland *et al.* (2014) draw attention to the fact that its sedimentary archive is distinctly meagre, and completely devoid of any evidence for glaciation (no till, no outwash gravels, no overdeepened channels). Its over-size is seen as a widened clay vale produced entirely by postglacial stream denudation across soft bedrock keeping pace with Trent incision. Straw (2022) on the other hand restates his belief that the Vale of Belvoir was fully impacted by powerful southward-flowing Wragby ice (the prime reason for re-routing the Ancaster-Trent to the Trent Trench), deepened by intense glacial erosion to form its broad character, and occupied by a northward-flowing Smite-Devon only after withdrawal of ice.

Figure 3 shows that patterned ground is very prevalent in the Vale of Belvoir, but that it is largely bedrock-based. Unlike polygonised terrace surfaces in the Middle

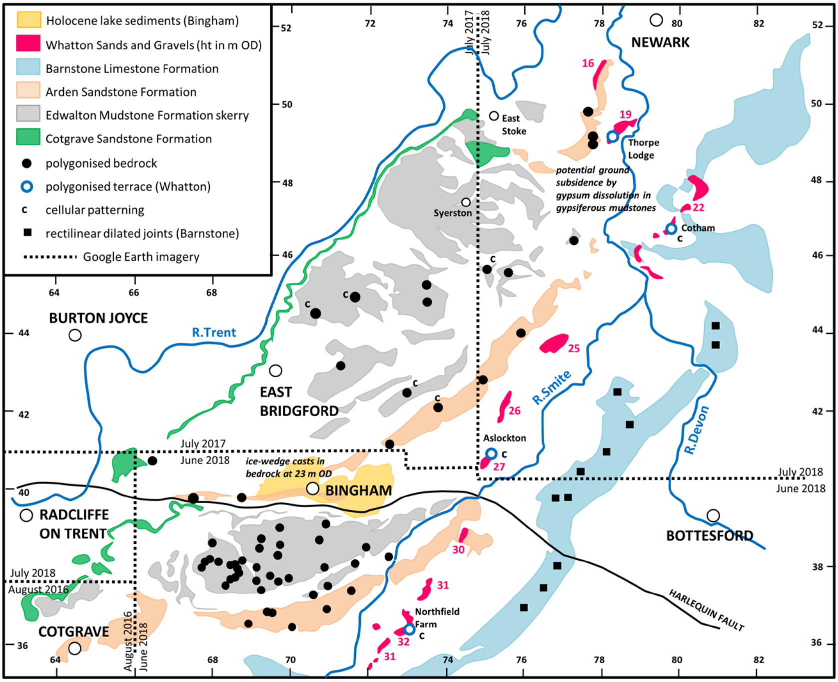

Figure 3. Polygonised terrace and bedrock surfaces in the Smite-Devon catchment, and limits of Google Earth imagery.

Trent and Lincoln Gap, this provides little or no clue as to date of periglaciation. To the east, Barnstone Limestone surfaces exhibit dilated rectilinear and irregular joints (probably frost-wedged) but without discernible polygonisation, while the predominant mudstone formations of the Mercia Mudstone Group (Gunthorpe, Edwalton and Branscombe) are notably lacking in any visible patterning. The central Edwalton Formation outcrop however is bookended by the Cotgrave Sandstone (to west) and the Arden Sandstone (to east), and repeated narrow bands of weakly-cemented dolomitic siltstone/fine sandstone (locally known as skerries) interbed frequently with mudstone. Distinct and widespread polygons are largely confined to the Arden Sandstone and the skerry outcrops, most notably south of Bingham. Just four localities (Northfield Farm, Aslockton, Cotham and Thorpe Lodge) retain traces of polygons on higher terrace remnants. Low terrace deposits (undifferentiated sands and gravels, Figure 1) do not possess patterned ground; they are assumed to be the equivalent of upper Holme Pierrepont Sands and Gravels (HPSG-B).

Lithological control

The skerries are a distinctive feature of the Mercia Mudstone Group in the Midlands

(Hounslow and Ruffell, 2006) and are sufficiently resistant to form gently-sloping low cuesta-like landforms within the Vale of Belvoir. Hydrologically, they may act as pathways for groundwater and can generate spring lines in places (Hobbs *et al*., 2002). They were first described by Lamplugh *et al*. (1908) and Lamplugh and Gibson (1910) who observed extended dipslopes south of Bingham and around Syerston. They were further described by Lowe (1989a, 1989b) and Rathbone (1989). Although only narrow, the skerry bands can broaden noticeably where surface slopes are very close to the value of regional dip (locally 1° to SE). The broad Bingham skerry dipslope surface is repeated at East Bridgford and Syerston by the Harlequin Fault with a downthrow of 40 m to north (Howard *et al*., 2009). In the BGS revision, Lowe (1989a) was aware that drainage across the Edwalton Formation around Bingham had been widely impeded in the form of shallow lake flats, due to a combination of skerry-mudstone alternations and gypsum dissolution subsidence, but these only appear in BGS mapping as alluvium. Extant lacustrine deposits do survive north of Bingham and are mapped as such (Figure 3); below them the skerry substrate is extensively disrupted by ice-wedge casts (Rathbone, 1989). Dolomitic siltstones appear to be, like Cretaceous chalk, significantly ice-susceptible.

Polygons are well preserved over a wide 7 km^2 area across the skerry dipslope south of Bingham (Figure 3). Around Flintham and Syerston the skerry horizon occupies a larger area of about 12 km^2 but displays fewer polygonal sites, certainly nothing like the density and clarity of the impressive network at Bingham. Only about 2% of skerry outcrop is polygonised at Flintham, compared with 50% at Bingham. Patterned ground here is unusual in two respects. First, geometry is one of reticulate, secondary, circular to hexagonal polygons, around 5-10 m in diameter, with walled, sometimes double-ditched, borders indicative of mature thermal contraction, together with what appear to be small ground-ice depressions and ramparts (Figure 2B). This is a complex relict periglacial land surface here, but with no evidence of host cover deposits. Second, polygons are traceable to high levels reaching a maximum of 61 m OD (the highest polygons within the region) extending down to 26 m OD. One possible explanation for this altitudinal range would be the existence of a former drained lake basin, with epigenetic ice wedges formed successively on retreating shorelines. Impounding during MIS 8 (Wragby glaciation) may have been involved, comparable with other sites of late Middle Pleistocene glacial ponding, such as at Skellingthorpe (Howard, 1992), and Uffington and Elton (Langford, 2018). The height of potential ponding at Cropwell Butler raises the level of a glacial barrier considerably.

An alternative Devensian interpretation for the Bingham patterned ground would be possible but would require invoking other cryostatic mechanisms for intense thermal contraction. Strong lithological control of patterned ground raises the question as to whether shallow skerry substrates could have been sufficiently ice-rich in themselves for cryostatic pressures necessary for intense and widespread ice-wedge growth, without the need for additional cover deposits. If so, polygonisation could well be of Late Devensian age, but studies of contemporary thermokarstic basins (Mackay, 2000; Kanevskiy *et al*., 2013; Ulrich *et al*., 2014) observe that bedrock areas without superficial deposits are rarely polygonised; and it is in the context of ice-rich and silt-rich alluvial flats and drained lake beds that large and extensive polygonal networks are best developed.

Central Smite-Devon

Further downstream, mature polygons are seen to be preserved across Arden Sandstone surfaces (Figure 3). These differ in terms of geometry, elevation and context. They are less concentrated, and consist of regular, secondary, low-centred forms with 10-20 m diameters and narrow borders (see Thorpe Lodge, Figure 2C). Again, it is thought unlikely that these networks were generated in ice-poor bedrock; rather they are believed to be truncated roots of deep ice-wedge casts, having originated within silt-rich cover deposits - alluvial or aeolian coverloams or drained lake sediments. Four sites retain evidence of a polygonised terrace surface. A.S. Howard *et al*. (2009) described the distribution of this terrace (their Whatton Sands and Gravels) in the Smite-Devon Valley, and demonstrated a graded profile compatible with the Balderton Terrace at Newark. Bridgland *et al*. (2014, Section 2.4.2.11) investigated this supposed correlation further; they re-examined sediments at various locations (Shelton Lodge Farm, Scarrington, and Aslockton) seen during the BGS resurvey, concluding that most of them were of a residual nature. *"These investigations suggest gravels are rather poorly developed within the Smite-Devon system, perhaps raising questions about the justification for their representation on the 1996 BGS map. Those traces of gravel that could be located were found to be thin and, where in situ, dominated by local rocks, mainly of low durability…. There is no reason to suppose that either the River Trent or glacial ice have occupied this lowland area since it was excavated, the latter process being attributable to the streams of the Smite-Devon system"* (ibid. p.106). Their final conclusion, however, is stated thus (ibid. p.322): *"Upstream equivalents of the Balderton Formation can be recognised …. in the tributary River Smite in which the Whatton Gravel represents a clear upstream continuation of the Balderton deposits of the main river…."*. The TVPP view therefore appears to be that the Whatton Terrace is correlatable with the Balderton Terrace (MIS 6) but may never have drained an area any larger than its existing catchment.

Plotted levels of polygonised bedrock in the Smite-Devon valley are illustrated in Figure 4. Patterned ground is not thought to relate to the low undifferentiated sands and gravels; however older and slightly higher Whatton Sands and Gravels are consistently located above the polygonised surfaces, showing that roots of former ice wedges could well have penetrated the Whatton Terrace surface by up to 5-7 metres. This is a measure of the potential ice wedge depth and thickness of host cover sediment and active layer that has since been lost to erosion.

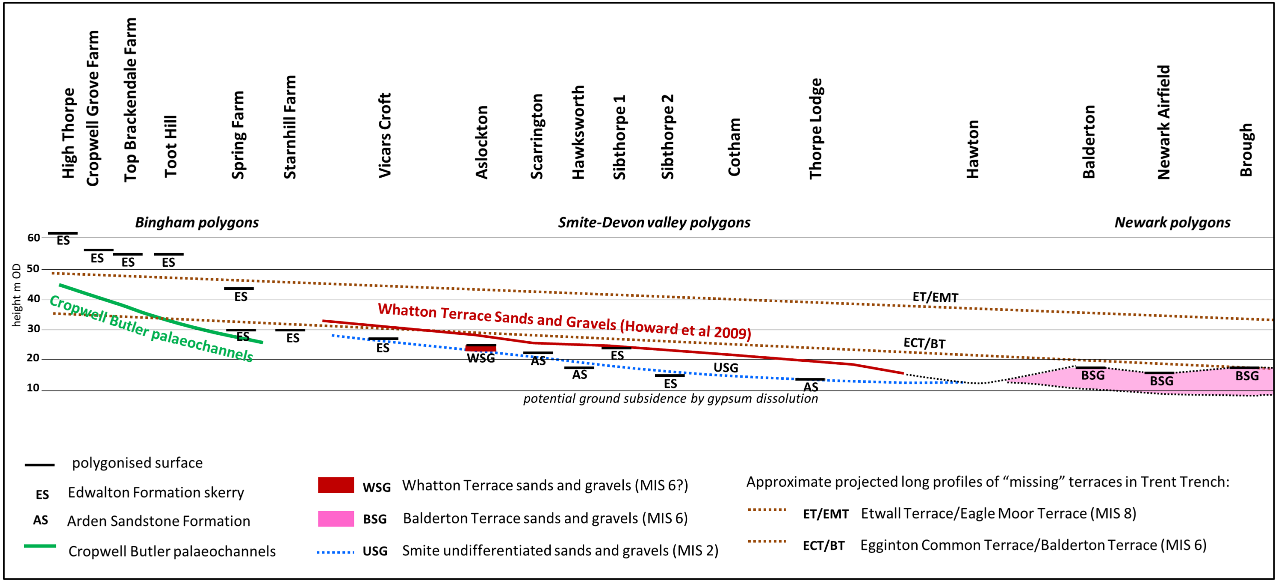

Figure 4. Long section from Cropwell Butler Gap to Brough illustrating elevations of polygonised surfaces, palaeochannels, Whatton and Balderton sands and gravels, and superimposed profiles of "missing" terraces in the Trent Trench.

Central areas of the distribution, however, are located across highly gypsiferous mudstones, so elevations may have been compromised by subsidence. The case for correlating the Whatton Sands and Gravels with the Balderton Terrace is not an unreasonable one, and both can be regarded as MIS 6. The fragmentary Whatton Terrace differs from the Balderton Terrace around Newark – with a very restricted narrow outcrop, rarely exposed, and with an impoverished suite of gravel. It lacks the armoured quality that ensured better survival at Balderton. Polygonal distribution however (Figure 3) points to a broad floodplain, perhaps 2-3 km wide, a terrace broader than previously imagined. Perhaps this substantial floodplain was swollen by glacial meltwater via the Cropwell Butler Gap. If not meltwater-driven, perhaps some other mechanism was involved in forming this expanded thermokarstic floodplain.

Figure 4 shows that Whatton Terrace levels fall below projected longitudinal profiles of the "missing" Balderton Terrace within the Trent Trench, due most probably to subsidence. There is a possibility therefore that the main Trent could have breached a low sandstone interfluve in the vicinity of East Stoke (location, Figure 3) with water backing up into a broad depression, creating a temporary flooded embayment across which thermal contraction then took place. Ensuing erosion (post-Whatton Terrace) flushed out most of this evidence, and exposed ice-wedge roots across planed bedrock surfaces. Such a scenario places polygonisation within MIS 6, but a more recent Devensian interpretation would be possible. This would require additional cover mechanisms to justify widespread ice-wedge formation. Bertran (2022), for example, has attempted to link polygonised terrace surfaces in the Lincoln Gap to the southerly extension of the putative Lake Humber, but his sites (Broadholme, Thorpe, Aubourn, and South Scarle) encompass different substrates, including Holme Pierrepont, Balderton and Scarle Terraces, that clearly predate Lake Humber. It is also worth noting that, like later Holme Pierrepont surfaces (HPSG-B), Google Earth imagery shows no polygonal imprint on Lake Humber sediments in the southern Vale of York (Hemingbrough Glaciolacustrine Silts and Clays).

Cropwell Butler Gap

At about 40 m OD the Cropwell Butler Gap lies between the Cotgrave Sandstone edge at Radcliffe on Trent to the north and the Cropwell Wolds to the south, breaching the Trent-Smite interfluve. It was visited by the Quaternary Research Association in 2007 (White *et al*., 2007), during which the authors stated their opinion that it could not have been occupied by a former Trent route. Straw (2022) however highlights this gap as a key element in his reconstruction of a proto-Trent palaeochannel. Employing an altitude approach, the TVPP view sees little significance in this col; it is too high to have carried Trent water (at the Balderton Terrace stage), and any drainage through it could not postdate the Etwall/ Eagle Moor Terrace (see projected downstream gradients, Bridgland *et*

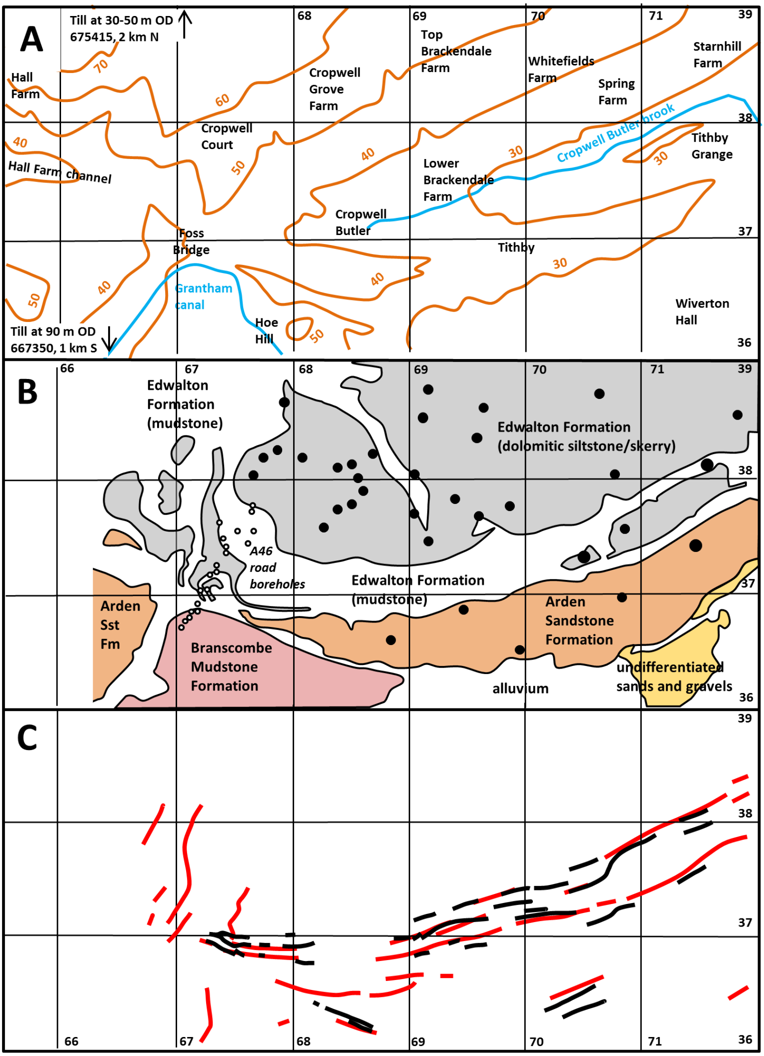

Figure 5. Context of the Cropwell Butler Gap. (A) topography, (B) selected geology (BGS 2021), A46 boreholes, and sites of polygonisation, (C) ridge alignments in black (Google Earth, July 2018) and red (LiDAR) (LiDAR data, copyright Environment Agency).

al., 2014, Fig 2.19 and Plate 4). This is stated explicitly (ibid, p 105) as follows: "*There is no direct evidence of Trent drainage through the Cropwell Butler Gap at any time, and any conjectured route would presumably have been on land surfaces considerably higher than those that presently exist*". Google Earth imagery provides fresh evidence to evaluate these views.

Initial investigation of the July 2018 images (Baker *et al*., 2021) seemed to suggest a series of palaeochannels passing through the Cropwell Butler Gap (Figure 5C) consisting of a number of parallel ridges, about 20-100 m apart, descending eastwards towards Whatton from about 45 m OD to 28 m OD. These follow the strike of Edwalton Formation mudstone with highlighted bands of more resistant interbedded skerries and sandstone. Straw (2022) comments on these lineations (ibid., p 35) ascribing them to glacial moulding. As noted by White *et al*. (2007) the gap is entirely rock-cut with no sedimentary record; indeed, no superficial deposits were encountered during A46 site investigations in 2009. Closer inspection, however, shows unusual patterning within skerry outcrops (Figure 5B). Lowe (1989a) noted these irregularities which were thought to be the result of minor faults (of which there are many), rather than sedimentary discontinuities. But narrow sinuous and curvilinear outcrops (Figure 5B) do not look like angular fault displacements. This is particularly noticeable at the entrance to the gap (Foss Bridge), picked out as clear ridges in LiDAR imagery (Figure 5C). Irregular water erosion may be a better explanation than differential weathering, but there is insufficient evidence to pinpoint how or when this might have occurred. The altitudinal range of these structures is problematic in terms of the TVPP terrace framework, for discharge, higher than a 45 m OD threshold, should be compatible with a terrace level no later than the Etwall/Eagle Moor stage. If palaeochannels are indeed present at about 40 m OD, rapid meltwater flow breaching the Trent-Smite interfluve during MIS 8 (Wragby advance) would seem to be the most parsimonious explanation. A problem then arises at lower elevations where palaeochannels continue to descend to about 28 m OD, and seem to grade directly into the Whatton Sands and Gravels (MIS 6). This leads to the contradictory conclusion that the Whatton Terrace (MIS 6) was fed by glacial meltwater (MIS 8). There is, in addition, a palpable lack of any supporting sedimentary evidence.

Glacial overdeepening?

The nearest mapped glacial deposits lie 3 km to the north and south-west at elevations between 30 m and 55 m OD. Lowe (1989a) identified an unmapped patch of till on the Cropwell Wolds 2 km south at a height of 90 m OD. At East Bridgford (Rathbone, 1989) tills consist of flint-bearing diamictites (probably decalcified Oadby Till, laterally equivalent to Wragby Till) with evidence of underlying glaciotectonism. An interesting site was reported by Lowe (1989a) at GR 655380 (Figure 5A); supposed glacigenic deposits were augered (Lowe, 1989a, section 6.4) but no firm conclusions reached. These occupied a W-E channel about 1 km long near Hall Farm, below 40 m OD, and were thought to be "*probably an important glacial drainage route*". This certainly merits further investigation, as it provides a small but not insignificant indication of glaciation within the immediate approach to the Cropwell Butler Gap. Its elevation suggests local overdeepening below the level of the Etwall/Eagle Moor threshold. The implication is that the gap could have been cut, not as a proto-Trent palaeochannel as Straw (2022) suggests, but as a subglacial channel during the Wragby advance. At present the gap lies at a relatively high level across the Trent-Smite interfluve, but this might once have occupied a topographic low within the Etwall/Eagle Moor land surface, perhaps the original source of its thermokarstic character. Channelling seen at Hall Farm and Foss Bridge would have predated the polygonal networks. It seems therefore that the Cropwell Butler Gap was an important focal point for MIS 8 glacial and periglacial activity.

Conclusions

Google Earth imagery has revealed widespread relict thermal contraction features across terrace and bedrock surfaces in the Middle and Lower Trent areas. These provide additional information to supplement the late Middle Pleistocene and Devensian sedimentary record, and to assess competing palaeodrainage hypotheses.

Patterned ground is well-preserved in the Middle Trent and within the Lincoln Gap, dating from recurrent phases of periglaciation during MIS 8, 6 and 4 but is largely absent from the Trent Trench, dominated as it is by upper Holme Pierrepont Sands and Gravels (HPSG-B). Gotham Moor is confirmed as a significant lake basin in the Late Devensian MIS 2, but provides only a slight hint that antecedent drainage may once have flowed north-eastwards in the direction of the Cropwell Butler Gap. Bedrock surfaces in the Vale of Belvoir (Smite-Devon catchment) are extensively polygonised, particularly on outcrops of ice-susceptible siltstone (Edwalton Formation skerry). A complex relict periglacial land surface is recognised south of Bingham, perhaps related to a former drained lake basin. In the central areas, polygonised surfaces of Arden Sandstone are thought to be truncated roots of ice-wedge casts superimposed from the Whatton Sands and Gravels and correlatable with the MIS 6 Balderton Terrace; a thermokarstic floodplain may have been temporarily enlarged by back flooding from the Trent Trench. The Whatton Terrace suffered considerable post-depositional erosion leaving little trace of its once 2-3 km wide floodplain. Land levels in the central Smite-Devon valley have clearly been influenced by gypsum dissolution subsidence. New evidence for an infilled channel at Hall Farm and ridge outlines near Foss Bridge demonstrate that the Cropwell Butler Gap could have been excavated by subglacial meltwater and glacially overdeepened, supporting the TVPP view that it was probably not occupied (at least in its present form) by a former course of the Trent. Lamplugh and Gibson observed in 1910 (p 67) that "*the scanty development of glacial drift over the district constitutes a problem which is not yet solved. It is still doubtful how much of the present valley system was in existence before glaciation and how much has since been excavated*". Over one hundred years later, this puzzle still awaits resolution.

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FINAL THOUGHTS ON THE LINCOLN GAP PROBLEM

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In their reconstructions of the development of the lower River Trent, White *et al* (2010), Bridgland *et al*. (2014) and Westaway (2021) assume that, following the Anglian (MIS 12) Glaciation and preceding the Wragby (MIS 8) Glaciation, the Trent pursued a course from Long Eaton through the 'trench' and thence from Newark to Lincoln across the wide Permo/Trias/Lias outcrop of the Vale of Belvoir. No relevant fluvial sediments survive, and in QN 155 the writer proposed that such a MIS 11 to MIS 9 course could be wholly speculative (Straw, 2022). It was also argued that the Trent 'trench' and a gap at Lincoln may not have existed during that time. Instead, Midland drainage passed E rather than NE, taking a course via the Ancaster gap to the Fens and the North Sea.

There is, however, substantial evidence (White *et al*., 2010, Bridgland *et al*., 2014) for the Trent flowing through the Lincoln gap during and after Wragby deglaciation in the guise of the Eagle Moor, Balderton and Holme Pierrepoint sands and gravels above the gap, and the Martin and Southrey deposits below it. It is not unreasonable to presume that, before the Wragby Glaciation, an earlier Trent would have left a similar train of sediments, albeit at a rather higher level, but to date none has been identified (Howard *et al*., 2009, White *et al*., 2010, Bridgland *et al*., 2014). A plausible reason is that they could have been reworked by Wragby ice when it scoured the floor of the Vale of Belvoir (Straw, 2020, 2022).

If a Lincoln gap existed before the Wragby Glaciation, the proto-Trent should have carried sands and gravels into the central Lincolnshire vale opened up on Upper Jurassic clays. This vale is overspread by Wragby Till composed largely of local rocks. To the N of Brigg, this till has been eroded from the lower Ancholme valley during subsequent low sea-level phases. S of Brigg it has been dissected into a group of W descending outliers. Mapping reveals that in these the till rests directly on the Jurassic clays. S of the Lincoln gap, the till sheet is largely intact and Trent gravels, transported through the gap, might have survived beneath it. Borehole evidence indicates that they do not, a circumstance that could be explained again by Wragby ice erosion which shaped the Jurassic rocks into a wide symmetrical vale, lowered the floor, and incorporated much bedrock clay into the Wragby Till (Straw, 1958, 1969; Westaway *et al*, 2015; White *et al*, 2017). Gibbard *et al*. (2018) record no gravels beneath Fenland till (Feltwell Formation).

If removal of fluvial sediment has been the case, then tills S of the Vale of Belvoir and S of the Lincoln gap in central Lincolnshire might be expected to contain much of the sand and gravel in their fabrics. These sediments would have been, like the Eagle Moor, Balderton, Martin and Southrey gravels, strongly quartzitic, and should have imparted a distinctive character to these tills. This does not appear to be the case (Kellaway and Hollingworth, 1953; Wyatt, 1971; Harrod. 1972; Perrin *et al.,* 1979; Langford & Briant, 2004; Carney, 2007; Gibbard *et al*, 2018; Straw, 2020; Rose *et al*, 2022). Incidentally, the survival of till in central Lincolnshire and its absence in the Vale of Belvoir probably reflects glaciological differences between the two ice streams. Among other factors, flow rate may have been important, the W ice moving faster. If pre-Wragby sediments did once exist both above and below the gap, two assumptions must be accepted – that glacial erosion was responsible for their total displacement and that they form at best only a minor component of the tills. No such assumptions are necessary if such Trent sands and gravels never existed in the first place, and no Lincoln gap was requisite.

The Midland drainage had to go somewhere. Straw (1963, 2022) suggests they passed through the Ancaster gap, and claims that part of the proto-Trent valley survives E of Long Eaton as the Cropwell Butler gap. It retains no early fluviatile sediments but it was subsequently glaciated and during deglaciation was occupied by wasting ice feeding meltwaters into the Trent 'trench'. The Ancaster gap per se is also devoid of pre-Wragby deposits, but it too would have been overrun by Wragby ice and meltwaters later coursed through it initiating deposition of the Belton Gravels that occupy its floor today. Before glaciation, waters and sediments would have issued from the gap into central Lincolnshire, the latter could then have been incorporated in the tills and outwash of the terminal zone of the Wragby ice toward Peterborough.

The case for the proto-Trent to have passed through the Ancaster gap may appear no stronger than that for passage at Lincoln, but whereas the Trent 'trench' can be plausibly regarded as a later MIS 8 deglacial feature and therefore not available to pre-Wragby Midland drainage, the Cropwell Butler and Ancaster gaps persist in the landscape as tangible features supporting an E route. Overall, the least speculative situation is that the Trent (Midland drainage) never passed across the Vale of Belvoir in pre-Wragby times, and that no sands and gravels ever needed total removal and/or incorporation into tills and outwash to account for their present absence. Until quartzitic fluvial sediments are found beneath the tills or can be shown to be included in them, a pre-Wragby Trent course to Lincoln and central Lincolnshire remains wholly speculative and invoking a Lincoln gap is unnecessary.

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THOUGHTS ON THE TRENT 'TRENCH' AND THE LINCOLN AND CROPWELL BUTLER GAPS

Discussions of contributions by Allan Straw and Colin Baker

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Recent QNs (including this one QN157) have included articles by Allan Straw, discussing aspects of the findings of the Trent Valley Palaeolithic Project (TVPP: Bridgland *et al*., 2014, 2015; see also Westaway *et al*., 2015), with a further contribution by Colin Baker in which he provides commentary on Straw's arguments. Straw wishes to return to the view (originating with Posnansky, 1960) that the wide low-level area know as the Vale of Belvoir was created glacially and that it owes its existence to occupation by an ice lobe, although he regards the glaciation involved to be that correlated with Marine Isotope Stage (MIS) 8, the Wragby glaciation (after the Wragby Till, a name that originates with Straw (Straw, 1966, 1969, 1983)). Straw also returns to another of his earlier suggestions: that, prior to the Wragby glaciation, the Trent flowed northwards to the Humber, much as it does now (Straw, 1979, 2011). The nub of the latter argument is summarized in a sentence from his conclusion in QN 155: "Because there is no tangible evidence for the proto-Trent flowing to Lincoln before the Wragby Glaciation, there is no requirement for a Lincoln gap at that time, nor earlier."

The TVPP interpretation of landscape and drainage evolution in the wider Trent valley has been based on what might be called the 'uplift paradigm'. This sees the modern landscape as representing progressive uplift of the terrestrial area over (at least) the latter half of the Quaternary, as evidenced by river terrace sequences in NW Europe and many other parts of the world (for recent summaries, see Bridgland and Westaway, 2008a, b, 2014). Although the original concept cannot be attributed to any current workers, the paradigm was perhaps most firmly established in a key contribution from Darrel Maddy (1997), who showed that height of sediments above valley floor can be a clear measure of age, and then followed up by the work of Rob Westaway, who put forward a potential mechanism to explain the phenomenon: inflow of lower crustal material acting as a positive-feedback mechanism to reinforce uplift (see Westaway *et al*., 2002), which means that uplift as an isostatic response to erosion has not been reversed, as happens with classic glacio-isostasy. If the uplift paradigm is accepted, then the Vale of Belvoir lies too low in the landscape to date back beyond the latest part of the Middle Pleistocene.

In terms of Straw's second point, the absence of evidence for a Lincoln Trent prior to the Wragby glaciation, the TVPP response once again invokes the uplift paradigm. There is indeed no such evidence between the 'Trent Trench' (the incised reach of the Trent between Nottingham and Newark; see Figure 1) and

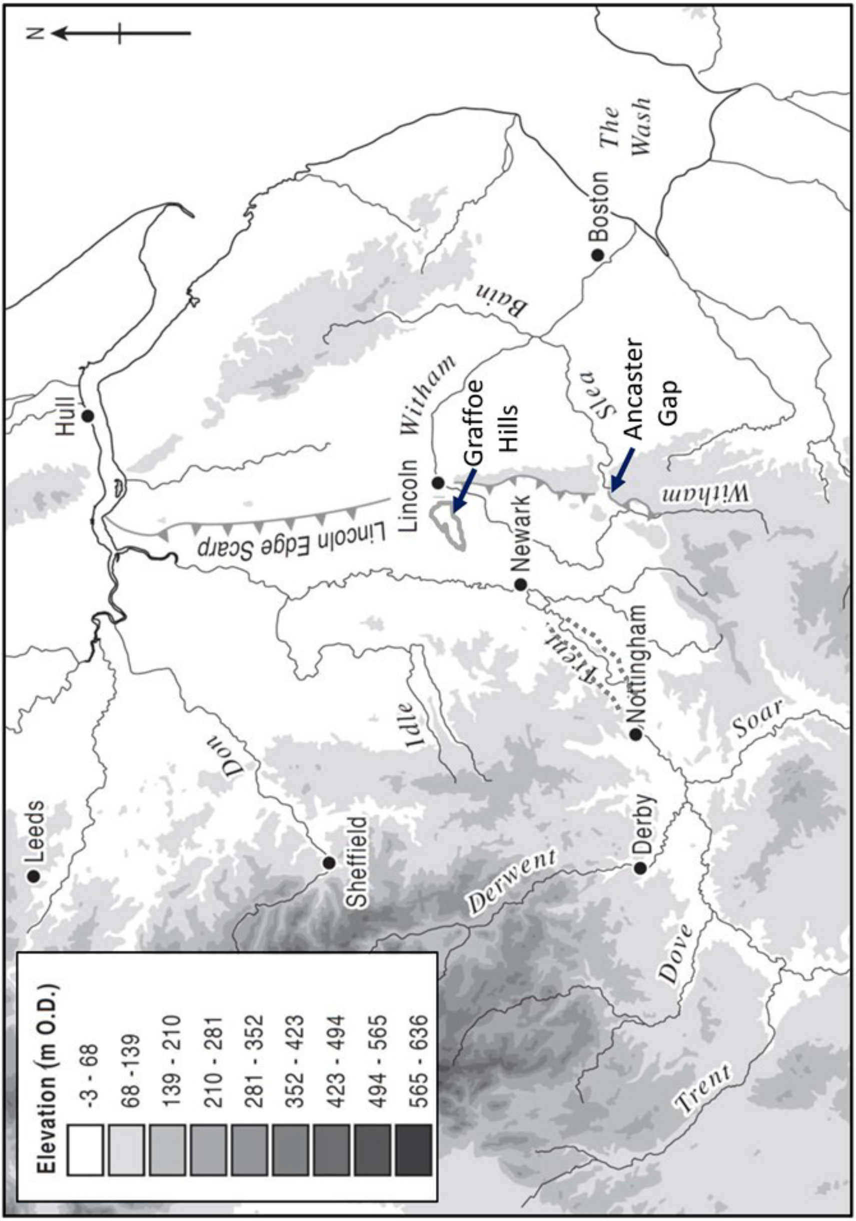

Figure 1. Topographical map of the River Trent showing the locations of the important tributaries, Lincoln, then Ancaster Gap and the Graffoe Hills. The edges of the Trent Trench, between Nottingham and Newark, are indicated by dashed lines. Modified from Figure 1.2 of Bridgland *et al*. (2014).

Lincoln, because the landscape is too low for such evidence to have survived; any terrace deposits that once existed have been removed by erosion. That also applies to deposits representative of a Trent flowing by any alternative route. The highest deposits in the fluvially generated landscape west of Lincoln form the Eagle Moor terrace as preserved in the Graffoe Hills (Figure 1), this now being regarding as dating from the MIS 8 glaciation and fed by outwash from the same. In the 'Trench' and in the Lincoln Gap, the constricted river has removed all evidence of anything as old as MIS 6, let alone older. Downstream of Lincoln, however, is found evidence for the existence of a major pre-Wragby valley that drained towards the North Sea, evidence in the form of the sediment geometry of the Wragby Till. This was interpreted by the TVPP as a sub-surface palaeo-Trent valley, now plugged with Wragby Till, extending from Lincoln to the Wash. The recognized terrace sequence of the Lincoln Trent has been emplaced above (and inset into) this body of till. This buried palaeovalley was steeper than that formed later in the Pleistocene because the pre-MIS 8 Trent did not yet incorporate those headwaters west of Derby, essentially comprising the Derwent and Soar, both inherited from the Bytham system (Rose *et al*., 1999, 2001, 2002; Carney *et al*., 2001; Lee *et al*., 2006). This meant that it had a lower discharge and catchment area than the modern-day Trent, with fluvial gradient being generally steeper for rivers with smaller catchments and discharge (e.g., Frasson *et al*., 2019; see Westaway *et al*., 2015). Thus the pre-MIS 8 Trent was flowing well below the modern land surface in its lowermost reach, as it approached the Wash. The existence of the Lincoln Gap prior to the MIS 8 glaciation is also required to explain the occurrence of glacio-lacustrine sediments to the west of the Jurassic escarpment, immediately upstream of the gap, in the form of the Skellingthorpe Clay, part of a complex of deposits attributed to MIS 8 (Figure 2). The Wragby Till, in contrast, is restricted to the eastern side of the escarpment hereabouts, suggesting that the MIS 8 ice was banked against the dipslope, blocking the contemporaneous Lincoln Gap and the downstream course of the Trent. The ice must be presumed to have entered the palaeo-Trent valley further north and flowed upstream through the area of the Trent Trench, since till of eastern facies (Oadby Till) is found in the Elvaston and Swarkestone channels in the Derby area (Brandon and Cooper, 1997; Bridgland *et al*., 2014, 2015).

In his discussion of the age of the Lincoln Gap, Straw alludes to the treatise by Harmer (1907) 'On the origin of certain cañon-like valleys …' [the accent on the 'n' is important, this being the Spanish originator of 'canyon'], but Harmer, a monoglacialist, sought to promote glacial-lake overflow as the normal explanation for gorges and gaps, with the main thrust of his discussions entirely at odds with the uplift paradigm. Thus he saw the Lincoln Gap as a recent feature and could not imagine it being older than the lower landscape to the west. His dismissal of the gravels capping higher points in that lowland as too low to have any bearing on the origin of the gap apply equally to the sedimentary evidence that would now be attributed to the Wragby glaciation (see Figure 2).

Turning to the origin of the Vale of Belvoir and the low-gradient valleys of the Rivers Smite and Devon, which drain it to the Trent at Newark, TVPP findings agree with the BGS (Howard *et al*., 2009), who envisaging this low country to have arisen from quite recent erosion and lowering of the landscape, these fairly minor tributaries having kept pace with downcutting by the Trent. A key point is that the latter was entrenched and laterally restricted in the relatively hard bedrock of its 'Trench', whereas the Smite and Devon achieved rampant denudation in the less resistant rocks underlying the 'low country', including the Vale of Belvoir, further to the SE.

In his contribution, Colin Baker (this issue) reports finding channels incised into the bedrock floor of the Cropwell Butler Gap, a col through which the Trent might have escaped from its Trench into the Vale of Belvoir. This gap was examined and considered at length during the TVPP, work that was presented during a visit there as part of a 2007 QRA field Meeting (White *et al*., 2007a). Its floor was explored for any Pleistocene sediments that could record drainage through it. Only bedrock was found. It was thus concluded that the floor of this gap is too high for Trent drainage to have used it (White *et al*., 2007b; Bridgland *et al*., 2014). This view is fully compatible with Baker's channels, which perhaps represent periglacial or glacial meltwater flow through an early version of the col.

An important part of TVPP argument about drainage evolution in the East Midlands is an old axiom of denudation chronology, which notes that a fluvial route through resistant rocks must be continuously occupied during downcutting or it will be left 'high and dry' and will no longer be viable as a drainage course. Thus the Trent Trench must have been continuously occupied from its inception to the present time or it would no longer be part of the river's course. The same applies to the Lincoln Gap. In the absence of surviving sediments, river occupation of constricted reaches is difficult to date, recourse being necessary to projection of datable terrace deposits from upstream and downstream, which is less of a problem in short 'gap' reaches than in more lengthy gorges. Richard Hey (1991) pioneered this method for the Wye Gorge in Herefordshire. If it is agreed that the Trent must have occupied its Trench from the time when its valley floor was at the height of the surviving gorge sides, then the age of terrace deposits at that height can give an indication of when the route of the Trench was first used, before becoming fixed. TVPP data links the 'top' of the Trench with the Wilford Hill gravel to the south of Nottingham, long regarded as fed by glacial outwash. This points to an Anglian age (Bridgland *et al*., 2014, 2015).

The Baker contribution (this issue) is largely based on newly observed remotely sensed evidence (from GoogleEarth) for periglacial, thermokarst and erosional features, much of this seemingly younger than the Trent-system palaeodrainage patterns onto which it is overprinted. Baker would seem to accept the TVPP argument that the entire Smite–Devon catchment area sits too low in the landscape to be significantly older than MIS 6. It can be reiterated that the highest points in that catchment, between the courses of the Smite and Devon (~37 m O.D.), are somewhat below the projection through the Trent Trench of even the lower level of the Eagle Moor Terrace (MIS 8) and so Anglian glaciation can have played no part in its formation (unless by overdeepening, for which there is no evidence). That assumes that the TVPP reinterpretation of the Eagle Moor as substantially younger than the Anglian, to which it was once attributed, is correct; that earlier attribution dates back to widespread adherence to a shorter Quaternary chronology and to argue for an Anglian age (MIS 12) for that terrace would reintroduce questions about the numerous missing isotope stages in the region (MIS 11–8 inclusive).

Baker also mentions evidence for gypsum karst in the area, something encountered by the preent author in another Aggregates Levy project in the Swale–Ure Washlands (SUW) of North Yorkshire (Bridgland *et al*., 2011). The Ripon area, central to the SUW, is a national gypsum karst 'hotspot'. Data from the project showed that large sinkholes can be formed by gypsum dissolution, with considerable potential as 'sub-base-level sediment traps, but that this process cannot be expected to influence drainage patterns and courses to a great extent (albeit that the sediemntary evidence from the SUW is entirely from the last climate cycle). Even if gypsum dissolution has been highly active in the Middle–Lower Trent, at the time of formation of each terrace the river would have adjusted to any subsidence that had occurred since its last 'rejuvenation', somewhat negating any influence over long timescales.

The Ancaster Gap, which is advocated by both Straw and Baker as part of a former Trent course, is an example of a constricted fluvial valley that is no longer a through drainage route, in stark contrast with the Lincoln Gap. It is hard to envisage formation of either of these gaps other than by rivers cutting their valleys from the level of the escarpment crest or higher (*contra* Harmer, 1907). The Ancaster Gap was considered by Swinnerton (1937) to represent the earliest of three Trent courses: in sequence via Ancaster, then Lincoln and then the modern-day Humber course. Harmer (1907), in contrast, had placed the Ancaster and Lincoln gaps in the opposite order of formation. The most recent through drainage in the Ancaster Gap was, according to sedimentary evidence (the Belton Gravel of Berridge *et al*., 1999), that of the 'Witham–Slea', a river system that incorporated the uppermost part of the present-day Witham catchment and flowed through to the gap to the Trent/Witham valley near Sleaford. This river would seem to have persisted until late in the Middle Pleistocene, when it was presumably captured by a right-bank tributary of the Lincoln Trent, leaving the beheaded Slea to drain eastwards from the middle of the gap. This diversion paved the way for the present-day Witham course via Lincoln, that river having maintained the Lincoln Gap as a through route, having inherited it at the end of the Pleistocene following the diversion of the Trent to the Humber.

Associated with the Ancaster Gap and in the area to the west of it there are sporadic remnants of high-level gravel that can be attributed to a pre-Anglian course of a

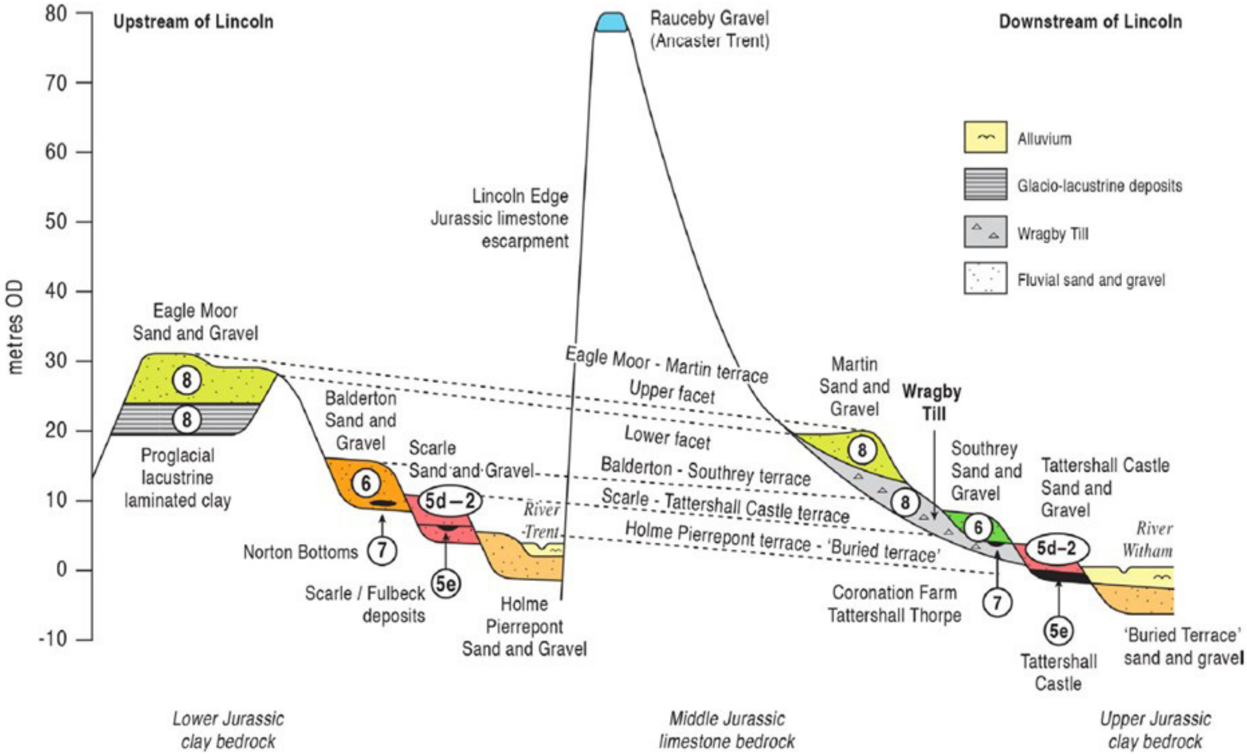

Figure 2. Section through the sequence upstream (west) and downstream of the Jurassic escarpment ln the vicinity of the Lincoln Gap. MIS correlations are circled. The Rauceby Gravel is projected northwards from Ancaster. From Plate 4 of Bridgland *et al*. (2014).

river routed along the approximate alignment of the gap, although at a level close to the present crest of the escarpment. These constitute the Rauceby Gravel, which records a pre-Anglian palaeo-Trent that was contemporary with, and potentially a tributary of, the Bytham (Bridgland *et al*., 2014, 2015). This then, is evidence for a river, an 'Ancaster Trent', flowing at escarpment-crest level, one that could subsequently have formed the gap. There are contemporaneous deposits that record a left-bank tributary of this Ancaster Trent: the Caythorpe Heath Gravel. This entire system must have been contained in the area to the east of the Derwent, which has been shown to have existed in the pre-Anglian as a left-bank Bytham tributary draining the southernmost Pennines (see above). Figure 2, a product of TVPP work, shows the relative disposition of the various deposits in the vicinity of the Jurassic escarpment, a further illustration of the importance of the uplift paradigm. The Rauceby Gravel, albeit projected from Ancaster to Lincoln, where the main sequence is preserved, towers above the landscape, twice as far above the valley bottoms as the MIS 8 suite of deposits. Survival of remnants of the Rauceby Gravel to the west of the Jurassic escarpment (e.g., at Hough on the Hill: Bridgland *et al*., 2014), was presumably aided by the fact that, as gravel, it armours the soft rocks of this predominantly lowland landscape against erosion, implying that, had any younger Trent course to Ancaster existed, it would also have left traces.

Returning to Allan Straw's statement that "there is no tangible evidence for the proto-Trent flowing to Lincoln before the Wragby Glaciation", according to the uplift paradigm the Lincoln Gap itself provides such evidence, since sediments related to that glaciation occur at a height above the valley floor that is less than half the depth of the gap (see Fig. 2). Assuming the gap to have been formed as a fluvial vally that has been progressively deepended in response to uplift, then a river has flowed through the gap since much earlier in the Middle Pleistocene, if not longer than that.

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LATE HOLOCENE ALPINE VEGETATION DYNAMICS, TEMPERATURE TRENDS AND SURFACE CO_2 EFFLUX IN JOTUNHEIMEN, NORWAY

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Abstract

Alpine permafrost regions are vulnerable to changes in climatic conditions. This study examined past changes in alpine vegetation assemblages on Galdhøpiggen mountain (Jotunheimen, Norway) based on palynological evidence, satellite-derived land surface temperatures, and surface 'greenness' (NDVI) in Jotunheimen. Additionally, the controls of CO_2 efflux from the ground surface were investigated across ascending altitudes. Throughout the 4350-year time period, the tree lines and the lower limit of permafrost have advanced and retreated in altitude in response to climatic changes. In the past six decades, air- and land surface temperatures and NDVI have increased the most over low- and mid-alpine heaths (1050-1500 m a.s.l.), which is attributed to shrubification. Higher soil moisture content and shrub cover result in greater CO_2 efflux from the surface The likely response to projected future warming in Jotunheimen will be continued permafrost degradation, increased shrubification and an elevated carbon release from the ecosystem.

Introduction

Alpine regions are highly vulnerable to present-day climatic changes (Biskaborn *et al*., 2019). Warming air- and surface temperatures result in the degradation of sub-surface permafrost and the subsequent release of carbon from thawed soil (Romanovsky *et al*., 2010; Serreze *et al*., 2000; Streletskiy *et al*., 2017; Turetsky *et al*., 2019). Warming can also create more favourable conditions for plant growth at higher altitudes, facilitating the altitudinal shift of alpine plants (Myers-Smith *et al*., 2011). Whilst such consequences of warming can affect the carbon- and nutrient cycling of alpine areas (Serreze and Barry, 2011; Schuur *et al*., 2015), the response to warming depends on the properties (topography, soil properties, vegetation cover, etc.) of the specific area.

To determine how the present-day warming may affect an alpine Jotunheimen region in southern Norway, the surface temperature trends, vegetation dynamics and surface CO_2 efflux were investigated over different time scales, spanning the Late Holocene. The study area covered north-east Jotunheimen (Figure 1), with specific focus on its highest peak, Galdhøpiggen (2469 m a.s.l.). Sub-surface permafrost occurs at higher altitudes in this region, ranging from continuous to sporadic. On Galdhøpiggen, the estimated lower limit of permafrost is approximately at 1450 m a.s.l. (Farbrot *et al*., 2011), and borehole monitoring provides evidence that permafrost has been warming and degrading (Etzelmüller *et al*., 2020). The altitudinal tree line, predominantly comprising downy birch (*Betula pubescens*) and Scots pine (*Pinus sylvestris*) can be found at c. 1100 m a.s.l. (Matthews *et al*., 2018). Above the tree line, several vegetational belts can be identified, including the low-alpine dwarf shrub belt (~1025-1350 m a.s.l.), mid-alpine belt dominated by grasses (~1375-1600 m a.s.l.) and the high-alpine belt that is sparsely vegetated and dominated by lichen and grasses (~1600-2200 m a.s.l.) (Matthews *et al*., 2018). Jotunheimen provides a setting where thermal, vegetational and sub-surface conditions change over short distances, making it suitable for studying the effects of climatic changes.

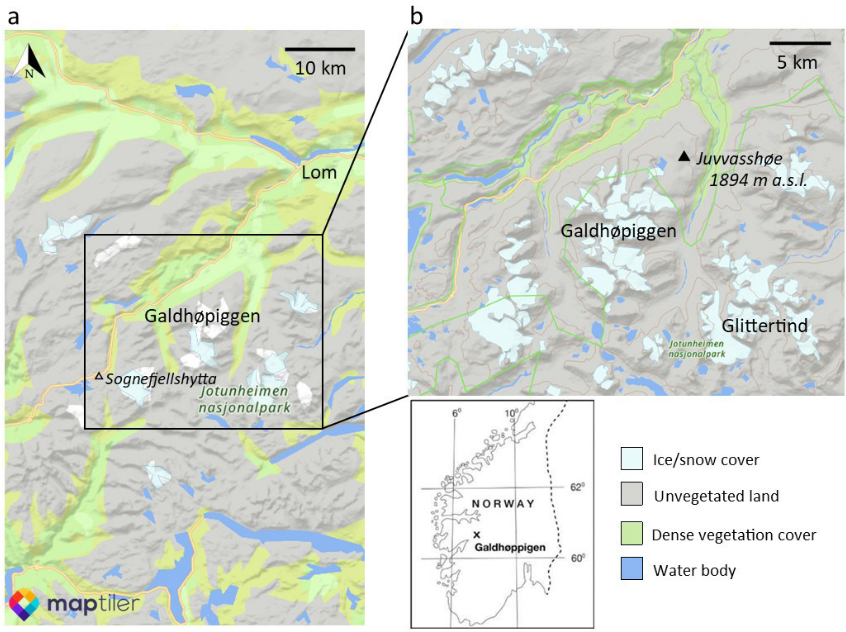

Figure 1. (a) A map of the study area in north-eastern Jotunheimen, Norway, (b) close-up of Galdhøpiggen. Maps reproduced and modified with permission from MapTiler (2021).

Aims and methods

The present study combined palynological analysis with remote sensing and field-based measurements of CO_2 efflux from the ground surface, allowing the thermal and vegetational properties and processes to be examined at various time scales. The aim of this study was to reconstruct past vegetation assemblages on Galdhøpiggen to detect any changes over millennial time scales, and to combine this information with remotely sensed vegetation – and temperature data to observe more recent, decadal-scale changes. Due to the nature of this article summarising three projects, methods will be outlined briefly. Detailed methods and results can be found in the publications that are referred to in the following paragraphs.

Past vegetational assemblages on Galdhøpiggen were reconstructed from fossil pollen preserved in a peat core collected from a mire at 1000 m a.s.l., the altitude at which the present-day tree line can be found (see Hallang *et al*., 2022a). The base of the 46-cm core was radiocarbon-dated to c. 4350 BP, and the top of the core at 10 cm was radiocarbon-dated to 2000 AD (calibrated using 'clam' (2.2) package (Blaauw, 2010)). The core was sampled at 1 cm resolution (n=46), and 500 total land pollen (TLP) grains and spores were counted and identified per depth level following the protocol by Bennet and Willis (2001). The 5-cm moss polster covering the top of the core, which was also analysed for pollen and assumed to represent 4-5 years of pollen accumulation (Lisitsyna and Hicks, 2014) served as a modern reference. The reconstruction of past vegetation assemblages at 1000 m a.s.l. was largely based on the relative fossil pollen and modern pollen abundance of each identified species throughout the core (Huntley and Birks, 1983; Lisitsyna and Hicks, 2014). To further characterise past vegetation, pollen accumulation rates and the presence of pollen from indicator species (species indicating a particular type of environment) were used (Hicks, 2001; Pardoe, 2006).

In recent decades, surface temperatures and vegetation dynamics can also be inferred from remotely sensed satellite data. MODIS-derived land surface temperatures (LSTs) were modelled back to 1957, which is the start of the continuous observed air temperature record from a nearby meteorological station. These observed air temperature records were used to investigate temperature dynamics over the past decades (see Hallang *et al*., 2022b). NDVI, a proxy of surface greenness (Pettorelli, 2013), was similarly modelled back in time, allowing to detect changes in vegetation between the periods 1957-1976 and 2000-2019. Each of the two periods covers 20 years, which is sufficiently long to establish meaningful averages fit for comparison, yet they are still far enough apart to allow to contrast the conditions between 1960-70s and the previous two decades.

Surface CO_2 efflux was measured across ascending altitudes on Galdhøpiggen during a single peak growing season (see Hallang *et al*., 2020). The study was based on the ergodic principle, assuming that the change in alpine vegetation from lower to higher altitudes reflects temporal changes (i.e., the vegetation composition and/

or abundance at lower altitudes represents the possible future vegetation cover at higher altitudes as warming continues). This approach allowed the investigation of how ecosystem respiration during the peak growing season may change with altered vegetation cover and patterns of cryogenic surface disturbances driven by continued warming. Several ecosystem (soil properties, vegetation type and cover) and geomorphological (cryogenic disturbance) factors were investigated, and CO_2 efflux was measured with a portable LI-COR (LI-8100A) infrared gas analyser (Virkkala *et al*., 2018). Seven most influential variables were identified using a Least Angle Regression technique. The results provide additional insight into possible future scenarios of change in response to continued warming.

Results and Discussion

Alpine vegetation dynamics on Galdhøpiggen (c. 4350 cal. yr BP-present)

Two tree species – Scots pine (*Pinus sylvestris*) and downy birch (*Betula pubescens*) –dominated the pollen profile throughout this period. The possible altitudinal limits of their respective ranges were estimated based on the reconstruction of the past local presence and abundance of each species at the coring site (1000 m a.s.l.). Using knowledge of the minimum growing season temperature requirements for *Pinus sylvestis* and *Betula pubescens* in this region (minimum July mean temperatures of 11°C and mean June-September temperatures of at least 7°C, respectively - see Paus, 2010; Nesje and Kvamme, 1991), past fluctuations of their altitudinal limits can be used to infer warmer and colder periods in Jotunheimen during the Late Holocene.

The palynological record indicates a much greater abundance of Scots pine at 1000 m a.s.l. during the period between 4350-3400 cal. yr BP compared to present day modern pollen data. This indicates that warm and mild conditions suitable for the establishment of a dense pine-dominated woodland prevailed at this altitude. The warm period was likely followed by cooler conditions between 3400 and 1690 cal. yr BP, as the pollen record shows a drop in the relative abundance of pine pollen in the profile and the simultaneous increase in the pollen of shrub- and herbaceous species. This could indicate the altitudinal depression of the pine tree line and the low-alpine shrub-dominated vegetation belt. whilst downy birch abundance at 1000 m a.s.l. increases. The relative abundance of pine pollen continues to decline, indicating a possible continuation of the downslope retreat of the pine tree line from c. 1690 to 170 cal. yr BP, with downy birch becoming dominant at 1000 m a.s.l. From 170 cal. yr BP onwards, vegetation belts advanced upslope and pine re-established at the present-day tree line at 1000 m a.s.l. in response to warming temperatures. The palynological evidence therefore reveals that the birch- and pine tree lines on the north-facing slope of Galdhøpiggen have fluctuated in altitude in response to climatic changes over the past 4350 years (Figure 2).

The modern pollen record also indicates the dominance of downy birch at 1000 m a.s.l. and suggests an increase in the abundance (and/or stature) of the species, as the relative abundance of birch pollen increases slightly between 2000 and 2014. This is supported by comparing several aerial photographs of Jotunheimen (Kartverket, 2021), which date back to 1981, and illustrate the upslope movement of the birch tree line by tens of meters over the past decades. Although the movement of the tree line since 2000 is not immediately evident on satellite imagery due to the coarse pixel resolution (250 m), the NDVI at 1000 m a.s.l. has significantly increased during the past six decades.

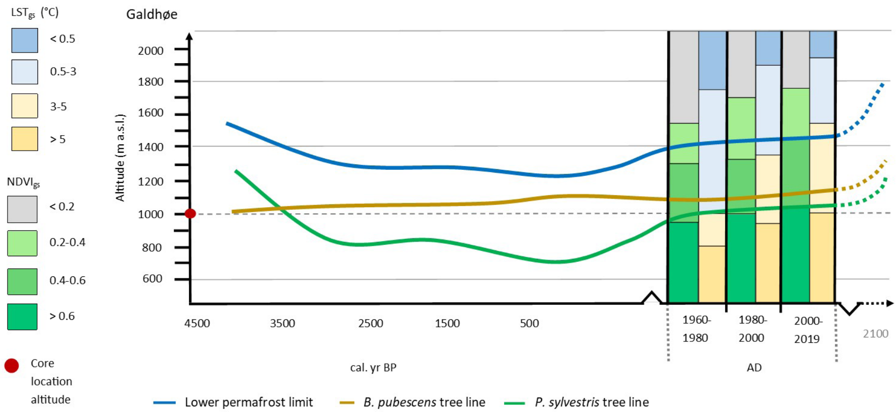

Figure 2. The reconstructed possible past and present dynamics of the birch- and pine tree lines and the lower limit of permafrost on Galdhøpiggen, and future projections (indicated by dotted lines). The approximate estimation of the past lower limit of permafrost is based on the environmental reconstruction, staying within the limits of the permafrost extent modelled by Lilleøren et al. (2012) for the late Holocene. The future projection for the lower limit of permafrost is modelled by Hipp et al. (2012), following the A1B (IPCC, 2007) warming scenario. The period between 1960-2019 has been divided into 20-year periods, and the mean growing season land surface temperature and NDVI, based on remotely sensed data, are indicated for each altitude.

A comparison of satellite-derived growing season NDVI between the periods 1957-1976 and 2000-2019 reveals the largest increase of surface greenness over the dwarf shrub- and grass dominated low- and mid-alpine vegetation belts between 1000-1500 m a.s.l. (Figure 3a). The comparison of growing season NDVI values of the two periods indicates that there has been a shift from dwarf shrub tundra to low shrub tundra in that time (based on Raynolds *et al*., 2008). The increase in NDVI suggests that the vegetation at these altitudes has increased either in stature or abundance, or shrubs have expanded at the expense of other types of vegetation, as the NDVI of deciduous shrub assemblages is often higher compared to other alpine species.

The upslope movement of alpine vegetation, especially shrubs, in response to climatic warming has been documented over the recent decades in Europe and elsewhere (Anthelme *et al*., 2007, Cannone *et al*., 2007). There is evidence of this occurring in Jotunheimen, where shrubs have established at higher altitudes above 1800 m a.s.l. This was detected in a vegetation survey conducted in the summer of 2018 along an altitudinal transect on Galdhøpiggen mountain. The survey (see Hallang *et al*., 2020) revealed that whilst the number of shrub species decreased with increasing altitude, dwarf species like *Salix herbacea* were present across the transect from the tree line to the predominantly barren, boulder-rich surface at 1950 m a.s.l. Moreover, the abundance of *Salix herbacea* was high at altitudes between 1850 – 1950 m a.s.l., demonstrating that the species is already able to establish at these altitudes.

Late Holocene permafrost limits and contemporary temperature trends in Jotunheimen

Combining the trends in vegetation dynamics in the pollen profile with past studies on glacial fluctuations and climate in the Jotunheimen area (e.g., Matthews and Dresser, 2008; Lilleøren *et al*., 2012), inferences can be made about the climatic conditions and past movements of the lower limit of permafrost on Galdhøpiggen during the Late Holocene.

During the warm period around 3450 cal. yr BP, with temperatures likely higher than today, it could be speculated that the lower limit of permafrost was also higher at the time, possibly between 1500 and 1600 m a.s.l. In response to the climatic cooling between 3400 and 170 cal. yr BP, permafrost aggradation likely occurred, with the lower limit reaching lower than today. However, based on previous model estimates, it is unlikely that the lower limit of permafrost on Galdhøpiggen ever reached below 1200 m a.s.l., or above 1600 m a.s.l. during Holocene (Lilleøren *et al*., 2012). From 170 cal. yr BP, permafrost degraded rapidly at its lower limit and eventually reached the present-day position of approximately 1450 m a.s.l. This is consistent with modelled borehole temperatures, which indicate that the permafrost limit advanced upslope by c. 200 m since 1860 (Hipp *et al*., 2012), illustrating the rapidity of the response to recent warming.

The warming of observed air- and modelled land surface temperatures from 1957 to 2019 is considerable with respective mean increases of 1.36 °C and 1.2-2 °C between the periods 1957-1976 and 2000-2019. The largest temperature increases have occurred in the winter (up to 2.4-2.6 °C), whilst spatially, some of the highest growing season (April-September) surface temperature increases have been recorded over altitudes of c. 1000-1500 m a.s.l. (Figure 3b). These increases can also be attributed to increased shrub growth, as the albedo over shrub-dominated ground is generally lower than that of other tundra vegetation (graminoids, lichens) (Juszak *et al*., 2014), which ensures more solar radiation is absorbed, leading to increased surface heating.

Although the remote sensing approach cannot be used to directly measure sub-surface temperatures, the air-, ground surface and ground temperatures have been found to be highly correlated at higher altitudes on Galdhøpiggen (Isaksen *et al*., 2003). Therefore, the applicability of land surface temperatures for mapping areas suitable for continuous permafrost occurrence was tested by identifying areas where mean growing season LSTs remain below 0 °C, providing suitable conditions for permafrost formation and preservation. The modelled LST data revealed a significant decrease in the extent of land with growing season land surface temperatures below 0 °C between 1957-1976 and 2000-2019 (Figure 4 a and b), providing further evidence that the climatic conditions in Jotunheimen are becoming less suitable to support the widespread occurrence of permafrost. Although the rate of warming in Jotunheimen has slowed during the past two decades, reflected by the finding that the temperature increase has not been statistically significant, the modelled mean land surface temperatures at the

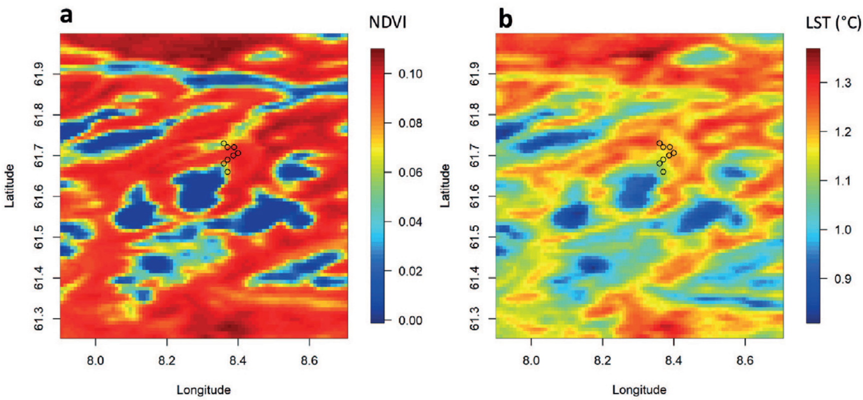

Figure 3. (a) Difference in mean growing season NDVI values and (b) difference in mean growing season land surface temperatures (LST) (°C) between the periods 1957-1976 and 2000-2019. Circles indicate the altitudinal transect on Galdhøpiggen, which was used in this study to extract LST and NDVI values across altitudes. From north to south, the circles indicate the following altitudes: 600, 800, 1050, 1450, 1550, 1750, 1850 and 1950 m a.s.l.

altitude of the present-day discontinuous permafrost limit (1450 m a.s.l.) have increased by 1.2°C since 1957. This further suggests that the warming is creating conditions suitable for continued permafrost degradation, and the upslope shift of the lower limit of permafrost. Other studies have created models based on borehole temperatures and predict a 55-75% probability of complete permafrost degradation at 1561 m a.s.l. on Galdhøpiggen before 2050 (Hipp *et al*., 2012), and further degradation at higher altitudes. The movement of the lower permafrost limit to above 1800 m a.s.l. would be unprecedented since the early Holocene (Lilleøren *et al*., 2012), and would lead to the transformation of this alpine ecosystem at higher altitudes.

Controls of CO_2 emissions from the ground across high altitudes on Galdhøpiggen

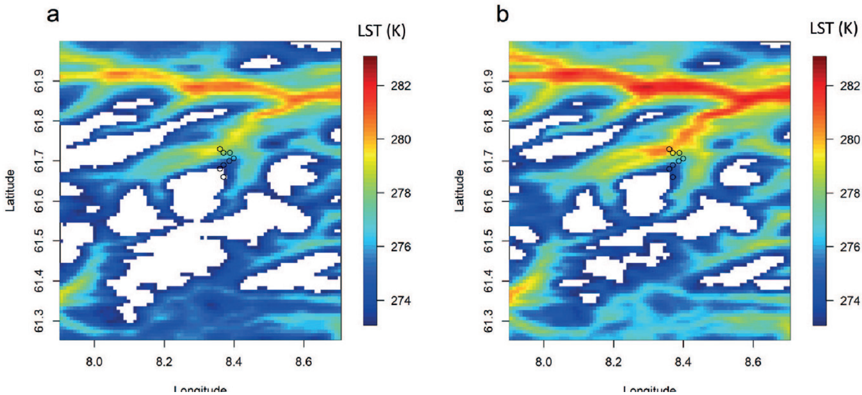

Figure 4. Mean growing season (April-September) land surface temperatures (LST) (K) above 0 °C for (a) 1957-1976 and (b) 2000-2019. The white areas indicate temperatures below 0 °C.

Higher temperatures, permafrost degradation and changes in vegetation patterns can affect local biogeochemical cycles in several ways. Increased soil temperatures in cold alpine regions can stimulate soil microbial activity, which accelerates carbon cycling and release (Donhauser and Frey, 2018). Increased winter warming, which was also identified in Jotunheimen, has been found elsewhere in Europe to lead to higher increases in soil respiration compared to summer warming (Kreyling *et al*., 2019). Permafrost degradation makes previously frozen soil organic carbon available for decomposition, which can increase the rate of CO_2 release from the soil. A more abundant shrub cover increases plant productivity and litter input rates and provides an additional source of CO_2 output from root respiration (Ge *et al*., 2017; Phillips and Wurzburger, 2019; Raich and Tufekcioglu, 2000).

Although higher shrub cover does facilitate the increased uptake of carbon during the growing season, the uptake can be offset by increased ecosystem respiration during autumn and winter (Mekonnen *et al*., 2018).

In the summer of 2018, a field study was conducted to determine the main controls on CO_2 efflux from the ground surface (i.e., ecosystem respiration) between altitudes of 1550 – 1950 m a.s.l. on Galdhøpiggen. The output of the regression indicated that the strongest controls on ecosystem respiration were soil microclimate (moisture content and temperature) and plant growth forms (vegetation abundance, presence of shrub species) (Figure 5)

Higher soil moisture during the dry peak growing season led to increased ecosystem respiration at all altitudes. Vegetation cover, particularly the presence

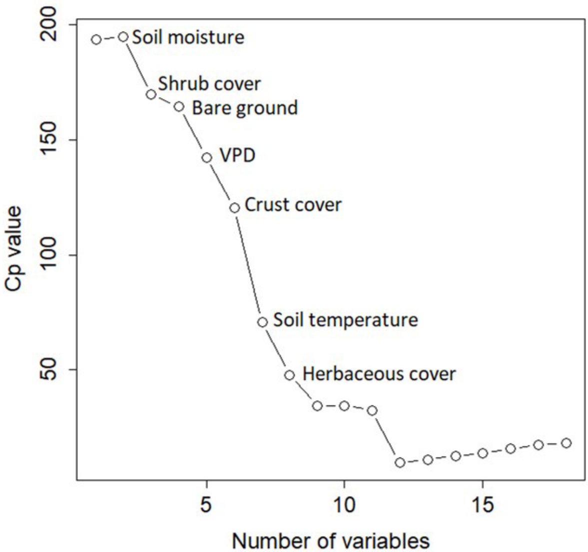

Figure 5. The Least Angle Regression model ranking the predictor variables according to their importance in explaining variance in CO_2 efflux rates.

of shrub species, also enhanced CO_2 efflux, whilst high proportions of bare ground or cryptogamic crust on the measured surface led to reduced CO_2 efflux. The findings suggest that shrub encroachment onto previously unvegetated surfaces at altitudes above 1500 m a.s.l. leads to elevated CO_2 efflux from the ground surface. However, the exact magnitude of the carbon efflux and whether this alpine ecosystem will be a net source or a sink of carbon remains uncertain, as further estimates of carbon uptake by vegetation and year-round measurements of respiration would be required to make such inferences.

Conclusions and future implications

Palynological evidence suggests that whilst climatic conditions in Jotunheimen demonstrate a general cooling trend from 4350 -170 cal. yr BP, the trend from 170 cal. yr BP to the present day indicates warming. Further evidence of this warming trend is found within the recorded air temperatures and modelled land surface temperatures from 1957 to 2019. Although the results indicate that the local warming trend in air- and surface temperatures has slowed in the area since 2000, temperatures are predicted to continue to increase in Jotunheimen (Hipp *et al*., 2012) and across the northern hemisphere (Biskaborn *et al*., 2019).

The pollen record suggests that during past warmer periods, altitudinal tree lines were likely tens of meters higher on Galdhøpiggen than they are today. The response to the more recent warming is evident from modelled NDVI and aerial images, which illustrate the advancement of the tree line and an increase in the stature and abundance of green vegetation over the mid-alpine heath over the past decades. With continued warming, the likely response scenario in Jotunheimen will be the continued upslope advancement of tree lines and increased shrubification at higher altitudes where soil conditions are suitable. Such transformation at higher altitudes will have implications on the local carbon cycle in this alpine ecosystem, as the abundance of vegetation cover was identified as one of the main controls on the efflux of CO_2 from the ground. Therefore, following the scenario of warming-driven continued permafrost thaw and increased shrub encroachment at higher altitudes on Galdhøpiggen, the release of carbon from the land surface is expected to increase.

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REPORTS

THE GLACIAL GEOMORPHOLOGY OF THE SCĂRIȘOARA PLATEAU, GODEANU MOUNTAINS, SOUTHERN CARPATHIANS, ROMANIA

Background and Rationale

Reconstructing the extent, style, timing and drivers of past mountain glaciation is crucial in understanding past atmospheric circulation and predicting future climate change (Li *et al.,* 2016). However, less is known of past glaciation in mid-altitude mountains, situated in transitional, temperate-continental climates, such as the Southern Carpathians, Romania (Figure 1). While previously identified and acknowledged (de Martonne, 1900; Niculescu, 1965), the glacial geomorphology therein has not been systematically mapped according to morphological diagnostic criteria (e.g., Giles *et al.,* 2017; Chandler *et al.,* 2018), nor has been confidently related to former styles of glaciation and glacial landsystems (Evans, 2003). Focusing on the Scărișoara Plateau, Godeanu Mountains, Southern Carpathians (Figure 1) the aim of this research is to map (remotely, and in the field) and interpret glacial landforms, to help infer the former style of glaciation.

Results

Several glacial, periglacial, and paraglacial landforms were identified in the area of the Scărișoara Plateau and the surrounding four valleys (Figures 2 and 3). The first category of mapped features includes depositional glacial landforms (terminal moraines and drift limits, recessional, and medial moraines), which were recognised based on their linear, or arcuate (Figure 3A) profiles, situated in the centres or sides of valley floors. (Evans, 2013). They signal the former presence of ice in the valleys. The second category comprises erosional glacial landforms (ice-moulded bedrock and ice-marginal meltwater channels). The former (Figure 3B) were identified as bedrock bumps showing evidence of subglacial rounding, while the latter (Figure 3C) by their appearance as undulating bedrock incisions and occurence at the edge of moraine ridges. They signify a warm-based thermal regime enabling glacial erosion underneath the ice (Glasser and Bennet, 2004), respectively high subglacial water pressures at the ice-margin (Dyke, 1993). The third set of mapped landforms shows depositional periglacial landforms (pronival ramparts, rock glaciers, and protalus lobes). The first (Figure 3D) were recognised by their linear or semi-circular profile at short distances from valley walls, indicating snow, rather than ice activity. (Hedding and Sumner, 2013). The second were identified by their lobate ridges (Figure 3E), showing evidence of postglacial creeping, through furrows and inner ridges(Harrison *et al.,* 2008). The

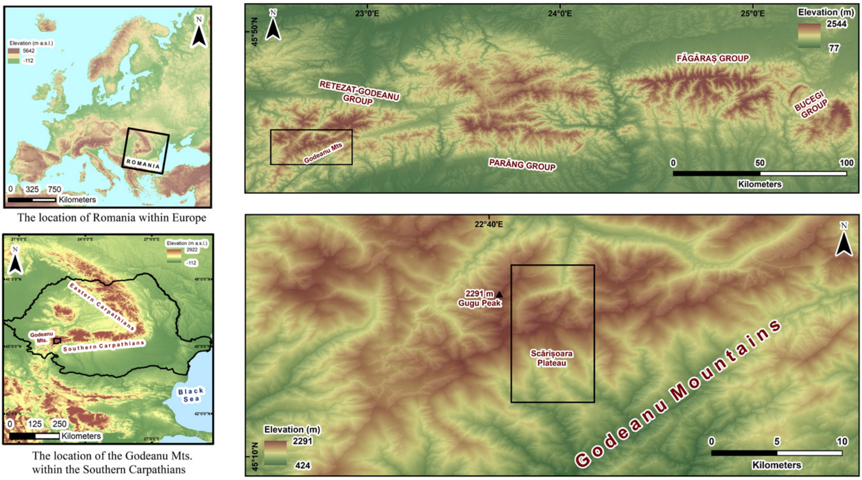

Figure 1. Locational maps of the study area: upper left - the location of Romania within Europe; lower left – the location of the Godeanu Mountains within the Southern Carpathians; upper right – zoomed in view of the Southern Carpathians, showing the location of the Godeanu Mountains within the Retezat-Godeanu group; lower right - the location of the Scărișoara Plateau within the Godeanu Mountains.

third are present on the central parts of some valley floors. as arcuate, moraine-like ridges that show evidence of creeping, alike rock glaciers (Whalley, 2009; Leigh *et al.,* 2021) (Figure 3F). The final mapping category includes rock slope failures, which were recognised by their chaotic planform at slope foots, their former source being traceable at valley heads and walls. These signify postglacial debuttressing upon deglaciation (Ballantyne, 2002; Jarman, 2006) (Figure 3G). Although no glacial landforms were identified on the surface of the Scărișoara plateau, occasional erratics were observed on its surface (Figure 3H). This might denote the possible existence of a former plateau icefield, with the transition from the low shear stresses of the plateau surfaces to the higher ones of the surrounding slopes triggering erosional processes (Rea *et al.,* 1998).

Significance

The geomorphological map of the Scărișoara Plateau has enabled us to differentiate between glacial, periglacial and paraglacial landforms, so that we could carefully target glacial landform samples for cosmogenic nuclide dating during the field expedition associated with the QRA NRWA award. Once fully processed, both the geomorphological map and the absolute ages will spatially- and temporally-constrain a numerical model reconstruction (PISM) of glaciation in the wider

Godeanu Mountains, so as to understand the Quaternary palaeoglaciology and palaeoclimate of the region.

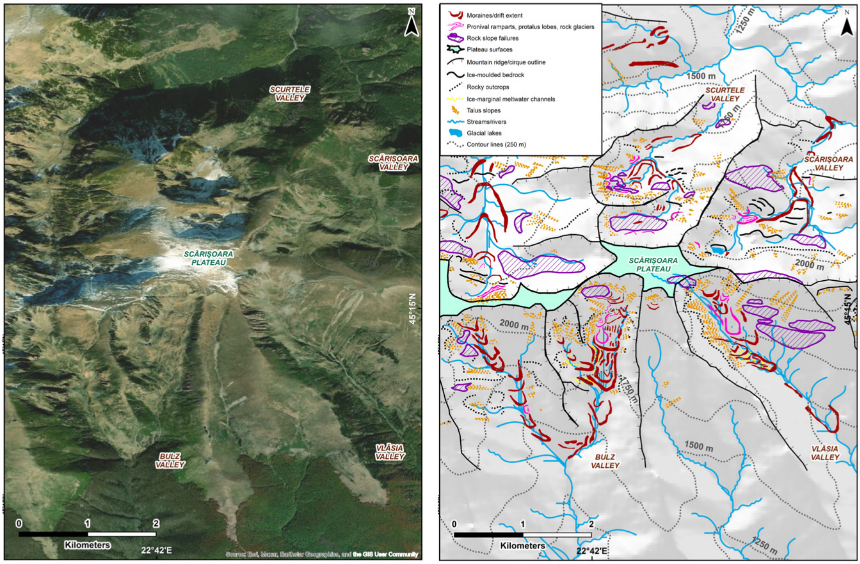

Figure 2. Aerial photograph (ESRI) – geomorphological map pair of the Scărişoara Plateau. This illustrates the approach of remote mapping, which entail visualising the photograph and then map over it in ArcGIS. Interpretations are based on morphological criteria from the literature (e.g. Giles *et al.,* 2017; Chandler *et al.*, 2018). Upon fieldwork, ground-truthed observations were made, and the geomorphological map was updated according to these.

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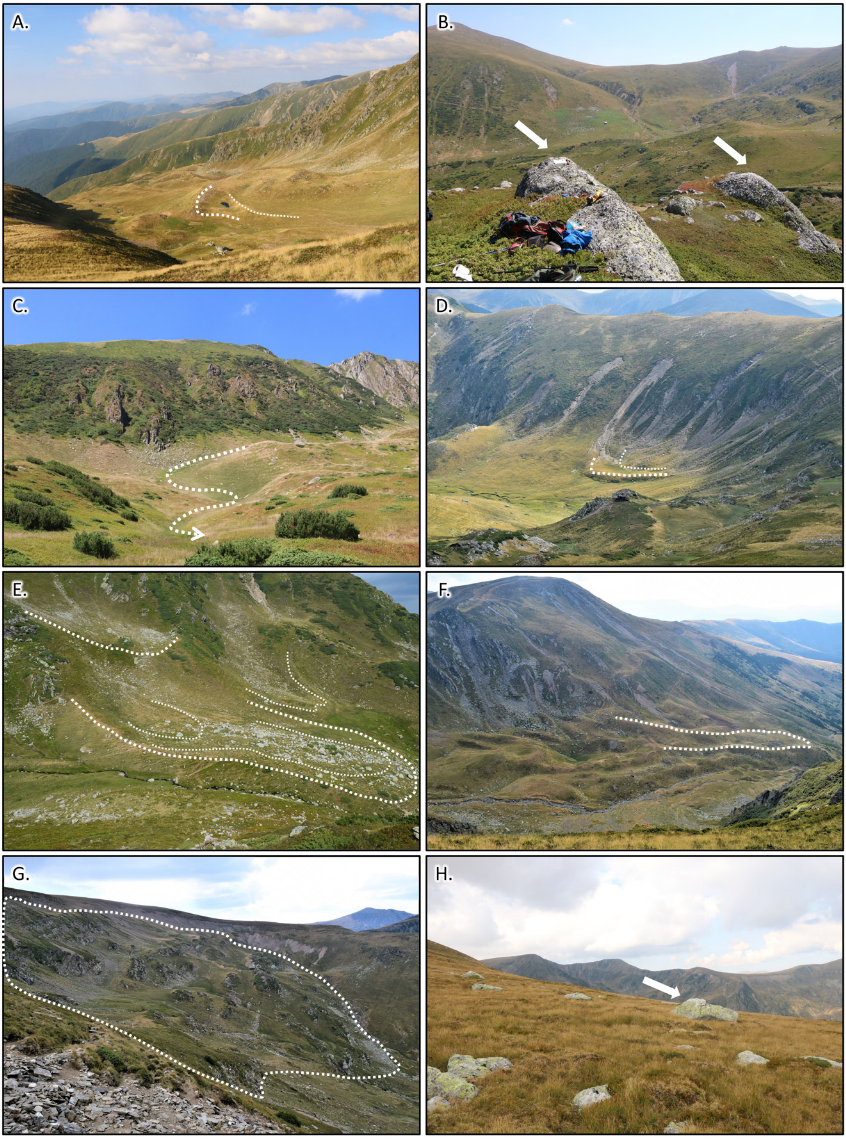

Figure 3. Photographic examples of ground-truthed landforms/ features. A. Recessional moraines in the Bulz Valley. B. Ice-moulded bedrock in the Scărișoara Valley. C. Ice-marginal meltwater channel in the Vlăsia Valley. D. Pronival ramparts in the Scurtele Valley. E. Rock glacier in the Scărișoara Valley. F. Rock-glacierised moraine in the Vlăsia Valley. G. Rock slope failure in the Scurtele Valley. H. Erratic boulder near the northern edge of the Scărișoara Plateau.

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WETLAND SURVEY IN NORTHERN ATLANTIC PORTUGAL: NORTHWESTERN AREA OF PARQUE NACIONAL PENEDA-GERÊS

Introduction

Wild fires have, in recent years, become a global threat to biodiversity and human societies alike, driven by climate change and shifts in land-uses. The composition of the native deciduous woodlands of Atlantic Europe is naturally fire resistant however the demise of Atlantic forests, changes in climate and land-use contribute to the increase in fire risk currently faced. Driven by climate change, shifts in land-uses can have catastrophic consequences not least by increasing ecosystems vulnerability to wild fires. In areas were wildfires were a relative rare occurrence, such as Sweden and the Artic Circle, fire frequency has increased in the last decade (Pinto *et al*., 2010; Witz, 2020). In this century, wildfires will increase in the UK as a direct consequence of climate change (Arnell *et al*. 2021). In 2017, and as a result of the Lucifer heat wave (Guerreiro *et al*., 2018), fires destroyed an area of 442,000 hectares of forest and caused the death of 114 people in Portugal.

Rationale

Fire history merits a dedicated study given its impact on ecosystems and long-term effects. Palaeoecology, and palynology in particular, plays a fundamental role in defining and understanding long-term ecosystem dynamics by determining ecosystem fragilities in response to both human and climatic inputs, elucidating the drivers of taxa and biodiversity decline. Owing to the scarcity of palaeoenvironmental studies in Portugal (cf. Sá Ferreira *et al*., 2020), it is not possible to evaluate how land-use has evolved in the Atlantic uplands of Portugal or the dynamic between the different drivers of change. Furthermore, in the absence of a long-term fire record fire frequency cannot be determined nor how shifts in land-use change and climate factors affected fire regimes.

The Parque Nacional Peneda Gerês (PNPG) (Figure 1) is the only area in Portugal, and one of the few in the Atlantic European biozone, where areas of natural vegetation still survive. It is also part of the European Network of Biogenetic Reserves and bogs are one of the habitats found in the PNPG. Despite wetlands in the PNPG being rare, there is no information regarding their extent, distribution or potential to contribute to the reconstruction of the regional palaeoenvironment or to elucidate past human activities in the area. The establishment of a long-term palaeoecological sequence in the PNPG is particularly relevant when the long history of human occupation of this territory is considered. Such a sequence would elucidate similar dynamics within the European Atlantic uplands which now face similar challenges. Without locating possible suitable study sites within the PNPG it is not possible to evaluate the potential for establishing palaeoenvironmental sequences in the region.

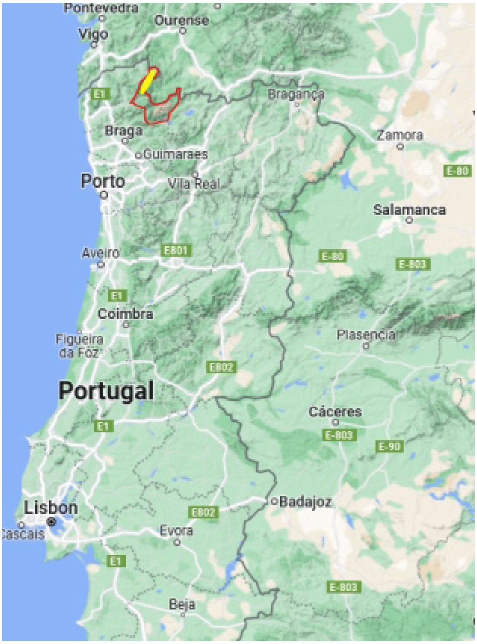

Figure 1. PNPG location in northwest Portugal. Survey area highlighted in yellow. Source: Google Maps.

Sites

Field survey of the NW area of the PNPG took place between September 20th and 24th 2021 with the aim to identify existing wetland deposits within the Park's special protection area. Five sites potentially suitable for palaeoecological investigation have been identified. Surface samples were collected at each location and processed for pollen analysis at the Division of Biological Sciences, University of Stirling, Scotland. Samples will be analysed for pollen and compared to local vegetation maps in order to define Pollen Source Area. Depth was assessed by testing with metal rods.

1. Nascente do Vez

This deposit (Figure 2) corresponds to a small area of blanket peat bog and is located at the source of the Rio Vez (41˚57'11"N, 8˚17'19"W) on a mountain plateau. It has an average depth of 1.5m. The vegetation on the deposit's surface is composed mainly by mosses and the surrounding vegetation is dominated by *Erica tetralix*, Erica spp. and, to the west by *Cytisus* spp.

Figure 2. Nascente do Vez.

2. Cabana do Bogalho

The Cabana do Bogalho deposit is located on a gentle southern valley slope (41˚49'24''N, 8˚13'15''W). This site (Figure 3) corresponds to a small flush with the ground being dried at the time suggesting the soil water saturation varies seasonally.

Figure 3. Cabana do Bogalho.

The deposit is surrounded by *Betula pendula*, mainly to the west, *Pteridium* spp., *Cytisus* spp, *Erica tetralix*, *Pinus* spp. and *Cedrus* spp. The average sediment depth is 0.70 cm at the time of testing. The depth however could be greater when soil is waterlogged. There is a booley hut on site probably dating from the 17th/18th centuries.

3.Turfeira do Fieiral

This deposit is the remnant of a larger existing ombrotrophic peat bog and is located on a large summit plateau (42˚06'91''N, 8˚13'52''W). Its depth varies between 1.10m and 2m. Local vegetation is mainly shrubland with Erica spp., Calluna vulgaris, Baccharis trimera and mosses, mainly Spaghnum spp., on the deposit's surface (Figure 4).

Figure 4. Turfeira do Fieiral.

5. Turfeira da Lama Redonda

This deposit's (42˚07'34''N, 8˚13'39''W) depth varies from 1.4m to 1.6m and is surrounded by Calluna vulgaris, Erica spp. Ulex spp. and sedges (Carex spp.). The site corresponds to a small deposit of ombrotrophic bog (Figure 5).

Figure 5. Turfeira da Lama Redonda.

6. Turfeira do Porto dos Bois

The deposit is located within the area of one of Iberia's larger megalithic necropolis (Figures 6 and 7)(42˚06'64''N, 8˚09'87''W). The average sediment depth is 1.6m and the local vegetation is composed of shrubland namely Erica spp. Calluna vulgaris and Ulex spp. This site corresponds to a flush with areas of degraded peat.

Figure 6. Turfeira do Porto dos Bois.

Figure 7. Megalithic tomb, northwest of the deposit.

Future work

This work's aim was to identify wetland sites with the potential to yield long-term palaeoecological data on this sensitive area of northwest Portugal. Future work will entail the analysis of the sedimentary sequences and new surveys will be undertaken in order to identify new deposits. This will form one of the bases of a multidisciplinary and multiproxy research project aimed at delineating vegetation dynamics and fire histories in vulnerable Atlantic uplands.

Acknowledgments

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REPORT ON 'EXPLORING POLAR ENVIRONMENTS DAY' 22ND JUNE 2022

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'Exploring Polar Environments' was designed to build on the significant work carried out by British Antarctic Survey, the Polar Regions Department of the FCDO and Polar community including UK Polar Network in encouraging greater equality, diversity, and inclusion. It was generously funded by the FCDO and supported by the Quaternary Research Association amongst others.

Representation of BIPOC (black, indigenous people of colour), women, and other minority people in geoscience is severely lacking, and is most apparent in polar sciences. Despite representing 16% of the UK population, only 3% of polar scientists are BIPOC[1]. Polar sciences have a poor history of inclusivity, with examples of research being dominated by white males until as late as 1960, when the first British female scientist conducted research in Antarctica. A 2018 study by Bernard and Cooperdock suggests that increased diversity benefits scientific advancements greatly, as different life experiences often spark unique approaches to research[3]. If we want to broaden the ethnic and racial range in polar science, we need to increase involvement in polar sciences from school age students by encouraging them to pursue further education on polar and environmental sciences. Underrepresentation is apparent from undergraduate level to research staff and beyond including at professorial level. In the UK, black people account for 1.2% of research staff, despite making up 3.4% of the UK population2. Similar statistics appear for research students, where 6.5% of black people who begin research, discontinue before graduating, compared with only 3.8% of white students[2].

Rationale for "Exploring Polar Environments"

In order to combat the lack of diversity in polar science from the bottom up, we hosted a free schools outreach event at Royal Holloway, University of London on 31st March 2022. With core funding from the FCDO, additional funding was provided by the Quaternary Research Association (funding of speakers' costs and 10 QRA volunteers), the UK Polar Network (funding of volunteer costs), Royal Holloway University of London (funding of goody bags). In addition to this funding, several organisations provided free educational materials for 'goody bags' which were provided to each attending child (including Royal Geographical Society, British Antarctic Survey, Geographical Association).

This event was firmly grounded in an ethos of widening participation and engaging with school children who may not have previously considered a career in polar science. We worked with targeted schools in Surrey and West London with diverse or disadvantaged cohorts and a high percentage of students receiving free school meals. These schools were identified by discussion with our university Widening Participation team, and through discussion with our partners.

The event was designed to accommodate Year 9 (13-14) and year 12 (16-17) students, as both age groups represent pivotal point in education, where the students select option courses and begin to consider further study and future careers. These two key age groups were strategically chosen, because: (1) Widening Participation action needs to target younger age groups to make meaningful change in career paths; and (2) A-Level students are deciding on higher education choices, and this is a second point at which students are lost from the pipeline.

The outreach event had three key aims:

1. To increase participation of underrepresented groups in polar science at a young age
2. To challenge the lack of gender and ethnic diversity in polar sciences
3. To showcase the diverse and exciting range of careers that polar end environmental sciences have to offer.

Targeted and invited schools

Our goal was to have 150 year 9 (13-14 years old) and year 12 (16-17 years old) students plus their teachers from specific schools in the South-East of England with diverse or disadvantaged cohorts. When identifying schools to invite to the Polar Environment Day, we used the following criteria:

- state funded schools;
- high percentage of students receiving free school meals;
- large number of first languages spoken by students;
- ethnically diverse cohorts.

When inviting schools, we first contacted the head of the Geography department by email, giving details on the event and requesting to meet online to discuss further. We worked with existing relationships between the university's Widening Participation team and local schools, and developed new connections through contacts such as the Royal Geographical Society, Geographical Association, and high champions of Diversity in STEM subjects such as Dr Anjana Khatwa and Professor Chris Jackson. We did not advertise the event more widely on social media, and did not encourage students to sign up themselves. Rather, schools were encouraged to sign up their students, and for teachers to attend the day along with their students.

Students and teachers from two year groups from seven schools ultimately attended the Exploring Polar Environments Day. Of these, several were local, from the Staines and Berkshire area, while others arrived from London or Southampton. Several other schools were also contacted, but either did not respond or could not attend. Once 150 students were registered, we stopped contacting schools due to capacity. These schools all attended as expected but some students were unfortunately unwell with Covid-19 and were unable to attend.

Outline of the Exploring Polar Environments Day

The Exploring Polar Environments Day included talks from our inspirational speakers, a free and interactive exhibition, interactive StoryMap computer practicals, a free goody bag for every participant, and a free lunch and morning and afternoon snacks.

The students were split into two streams based on age and completed a speaker session and computer based StoryMap activity either in the morning or afternoon. 20 minute morning and afternoon breaks were provided with free drinks and snacks, along with an hour long free lunch. During these times, the students were able to explore the exhibition area and speak with the polar experts. Each participant was provided with a printed schedule in their goody bag.

Volunteers

The Exploring Polar Environments Day was only able to run due to a large number of volunteers. In total, 30 volunteers helped with either the exhibition or the StoryMaps practicals. These volunteers included 4 external speakers (costs covered by the QRA), postgraduate students and staff from Royal Holloway University of London, 2 volunteers funded by the UKPN (from University of Liverpool and BAS), 2 postgraduate students from Sheffield (funded by their RTSG), and visiting artist Abi Spendlove (self-funded).

Invited speakers

Five strategically invited speakers from a range of backgrounds and disciplines within polar sciences gave 20 minute talks on their experiences and careers in polar and environmental sciences, engineering, and geopolitics. We deliberately ensured that we had a diverse range of speakers and topics, with expertise in the Arctic and Antarctic. We ensured that we had speakers from the LGBTQ+ community, women, different socio-economic backgrounds and people of colour within our speaker list.

Our speakers were:

Dr James Lea (University of Liverpool and Quaternary Research Association Outreach Officer)
Dr Shasta Marrero (Cardiff University)
Dr TJ Young (Scott Polar Research Institute)
Rad Sharma (British Antarctic Survey)
Professor Klaus Dodds (Royal Holloway University of London).

Figure 1. Speakers at the Exploring Polar Environments Day. Clockwise from top left: Dr Bethan Davies, Professor Klaus Dodds, Dr Shasta Marrero, all the speakers, view of the auditorium, Dr TJ Young, Rad Sharma.

Talks focused on the speakers' careers and practical aspect of their work e.g. fieldwork in polar regions, with the aim to enthuse and inspire the students, as well as showcasing the methods used in polar science (Figure 1). Having a role model to identify with is key to fostering a sense of belonging in the science community. Therefore, we invited speakers from a range of ethnic and socioeconomic backgrounds, which we hope the students were able to identify with and will therefore be able to envisage themselves pursuing a career in polar science.

Storymap sessions

In the StoryMap Practicals, students worked through two Antarctica themed award-winning StoryMap exercises, which were developed by the AntarcticGlaciers.org team. Age appropriate StoryMaps were selected, with the year 9s working through "Introduction to Antarctica: where is Antarctica?" and "People in Antarctica: discovery of Antarctica", and the year 12s working through "Climate change in Antarctica: Antarctica as a time machine" and "Climate change in Antarctica: current climate change in Antarctica". The StoryMap sessions were run by a large team of volunteers consisting of polar science PhD students from universities across the UK (funded by the UK Polar Network), who worked with the students in small groups to guide them through the activities and answered any questions. The aim of this session was to deepen engagement and ensure that many opportunities arose for discussion between the students and experts. This session also allowed students to explore the content at their own pace and discover something new about polar sciences and Antarctica in particular.

Feedback

Feedback from the year 9 students was overwhelmingly positive. 92.9% rated the speakers as a 4 or 5 out of 5 (5 = amazing 1 = bad), and 88% rated the StoryMap sessions as the same. 76.2% or year 9s said that they would maybe like to have a career in the polar sciences. Feedback from the year 12 students was similar to that of the year 9s, with 91.5% rating the speakers as 4 or 5 out of 5, 74.5% for the StoryMaps. 63.6% would maybe consider a career in the polar sciences. The year 12s favoured the speaker session over the StoryMap session, as 21 students mentioned that they enjoyed the university style lectures in their freehand comments. The Geopolitics lecture by Klaus Dodds was a particular favourite, highlighted by 11 students. 12 students praised the StoryMaps practicals. The most common suggestion for improvement was for there to be more interactive features.

Reflections and guidelines for best practice

As a guideline for best practice, we would recommend that in any future events considerable care is taken to ensure that invited schools reflect closely the intended target demographic. It is critical to develop a close working relationship with the schools and their teachers. We found that cold emails rarely worked. Finally, schools are busy and to ensure that they remained engaged, we sent regular emails in the runup to the event.

We made sure to work closely with a wider group of school, polar and science educators while in the planning stages of the event, and we explicitly asked teachers what would be useful to them. These discussions highlighted the need for widening participation activities to start young, before students select subjects for GCSEs and A levels and begin to plan future careers.

All of which informed our overall approach which was to make sure we had a host of interactive activities, with plenty of opportunity for informal discussions, exhibits that could be touched and examined, and task-orientated activities. Speakers were encouraged to present in a way that encouraged Q and A and live interaction. We found that the exhibition area contributed greatly to the success of the day as it kept the students engaged in the subject during the breaks, and allowed many opportunities for informal and friendly discussions (Figure 2).

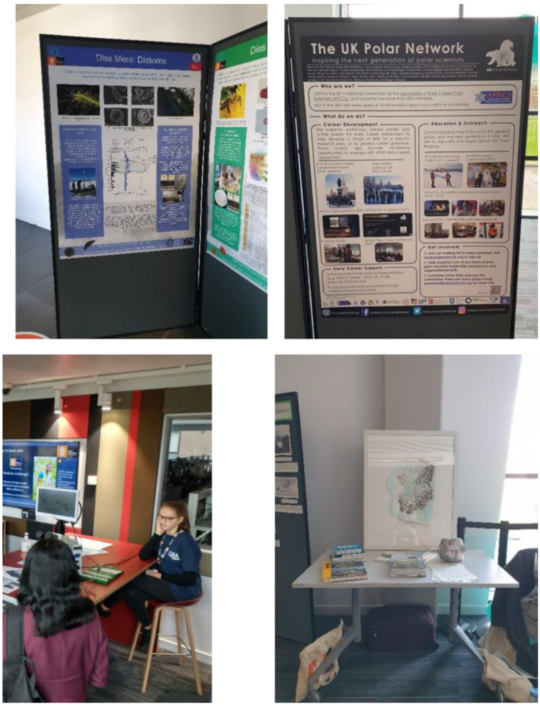

Figure 2. Exhibition area of the Exploring Polar Environments Day.

Lectures and talks are more suitable for older audiences and work less well for younger age groups. We found that year 9 students became restless in the talks. Future widening participation events would benefit from shorter and more interactive talks with longer breaks, especially for younger students.

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ABSTRACTS

ABSTRACTS FROM THE 27TH ANNUAL QRA POSTGRADUATE SYMPOSIUM, 2ND AND 9TH SEPTEMBER 2022 ONLINE

USING A PORTABLE LUMINESCENCE READER TO INVESTIGATE THE HOLOCENE DUNE ACTIVITY IN THE THAR DESERT, INDIA

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Sand dunes in the densely populated Thar Desert, India are a valuable proxy for the Indian summer monsoon (ISM) winds that dominantly control their development. Understanding the response of dune activity to future changes in the seasonal monsoonal regime is informed by a landscape-scale investigation of the dune accumulation history. These palaeodata are used to validate simulations by numerical climate models, and can be used as time-series for machine learning algorithms that are also employed in climate prediction. However, establishing dune accumulation chronologies using traditional dating techniques is time and resource intensive. This study overcomes these limitations by using rapid-age estimates derived from portable luminescence signals (port-OSL), calibrated via a regression against existing laboratory-based luminescence ages. The study focuses on arid western Thar, a region that lacks robust dune chronologies. Fieldwork was conducted in two seasons and a total of 222 samples were collected from ten linear dunes along a 100km transect. Calibration of port-OSL measurements was carried out using ages of samples with previously established chronologies from central Thar (n=40)[1] as well as newly dated samples collected as part of this study (n=4) and showed a good fit using a linear regression model approach[2] (R2=0.84). Palaeo-dune activity was then reconstructed by using the port-OSL age estimates. All investigated samples dated to the Holocene period, ranging between ~11ka to ~0.5ka, corresponding to port-OSL blue light stimulated luminescence totals of 14 million and 0.2 million counts. The spatio-temporal patterns of accumulation suggest that eastward migration of the dunes. A period of high accumulation between ~8ka and ~6ka in six of the dunes corresponds

to the Holocene warm period during which the ISM was stronger[3]. This study demonstrates the utility of the port-OSL reader for determining the spatial variability in dune accumulation at large spatial scales within the Thar desert and beyond.

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DID THE LAST BRITISH-IRISH ICE SHEET HAVE FLOATING ICE SHELVES?

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The recent 6th IPCC Assessment Report projects global sea–level rise of 0.5 to 0.9 m before 2100, but due to inherent instabilities pertaining to marineterminating glaciers (MTG's) in Antarctica and Greenland, a rise of 1.5 m by 2100 cannot be ruled out. This uncertainty in MTG dynamics comes from a lack of long- term (centennial to millennial) observations of how glaciers in Antarctica will respond to internal changes such as the collapse of their floating margins (ice shelves). The collapse of ice shelves has been observed to cause significant increases in ice-sheet velocity (2 to 8-fold), however, direct observations of iceshelf collapse only span the last ~20-30 years. This research is examining the sediment and landform record of the palaeo-British-Irish Ice Sheet (BIIS), to generate a longer- term record of MTG and ice shelf behaviour. This presentation investigates whether the BIIS had ice shelves by studying sediments and landforms from the seafloor in The Minch, NW Scotland – which hosted a large MTG (palaeo-ice stream) during the last glacial cycle. This study combines geomorphological, sedimentological and micropalaeontological evidence to reconstruct the paleoenvironmental and palaeoglaciological conditions at the former ice-sheet margin in the NW sector of the BIIS. Quantitative analyses of sediment cores include traditional (X-radiography, grain counting, Itrax XRF, laser diffraction particle–size analysis) as well as newer more refined methods (X-ray computed laminography, and sediment characterisation using automated greyscale image analysis). Initial results suggest a characteristic ice shelf sediment stratigraphy is observed within certain cores: with stratified diamicton grading into finely laminated mud with limited dropstones followed by clast-rich ice-rafted sediment indicative of ice shelf collapse and subsequent glacier retreat. Despite advancements in understanding of sedimentary signatures and associated processes, uncertainty persists regarding the diagnostic features for identifying ice shelves from multiyear sea ice in the marine-geological record. To resolve this uncertainty and to better understand the ingredients required to reconstruct past ice shelves, a suite of interval-specific biomarker tests are currently being undertaken.

USING TRANSVERSE RIDGE MORPHOMETRY TO UNDERSTAND ICE SHEETS IN HIGH SPATIOTEMPORAL RESOLUTION

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Ice sheets are a core component of the climate system and palaeo-ice sheets are effective climate-proxies. Reconstructions of such can provide important information regarding past environmental changes and interrelationships between different earth systems (i.e., cryospheric-atmospheric-oceanic-land systems). Typically, ice sheet reconstructions aim to capture the rates of ice margin retreat, as well as ice configuration and flow dynamics. Critically, this information can then be extrapolated to inform numerical modelling of contemporary ice sheets and thus assist in predicting cryospheric changes in response to a rapidly warming climate. For any reconstruction, spatial and temporal resolutions are critical and underpin the quality of our understanding. Ultimately, reconstructions are only as valuable as input observations, and any misinterpretations or gaps will be propagated and magnified at the largest scale. Increasing spatial and temporal resolutions of ice sheet reconstructions presents a difficult challenge to overcome, with solutions often pertaining to absolute dating and numerical modelling methods. Given the reliance on a geomorphological framework, two additional solutions would be to 1) increase the input geomorphological dataset (increasing spatial resolution) and 2) to seek out alternative landforms that may be able to delineate ice margin retreat at more regular time intervals (increasing temporal resolution). This project aims to address the challenges surrounding spatiotemporal resolutions of palaeo-ice sheet reconstructions by investigating high-resolution geomorphology (De Geer Moraines and Crevasse-Squeeze Ridges). Research efforts will focus on attempting to constrain the spatiotemporal properties of these 'high-resolution' geomorphology and subsequently integrate these landforms into palaeo-ice sheet reconstructions to increase ice-marginal retreat resolutions.

RECONSTRUCTING THE EVOLUTION OF THE SUBGLACIAL DRAINAGE SYSTEM OF THE LAST FENNOSCANDIAN ICE SHEET

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Recent climate warming has had significant impacts on ice masses around the world, particularly the Greenland Ice Sheet which has seen widespread accelerations in ice flow, furthering its contribution to global sea level rise. This speed is the result of increased surface meltwater production which, when transported to the bed, lubricates basal sliding (Zwally *et al*, 2002). Temporal and spatial variations in the subglacial drainage system as efficient (low pressure) or inefficient (high pressure) determines the extent to which meltwater influences ice flow. Thus, with surface melting expected to propagate further inland into the accumulation zone under a warming, it is imperative to understand how the ice sheet's subglacial drainage system will adapt to increasing meltwater inputs and its long-term impact on ice flow velocities. Observing the subglacial meltwater system in contemporary settings is near impossible and limited to few visible and rarely accessible outlet channels. Therefore, the geomorphological record of past glaciations provides the ideal opportunity to study subglacial meltwater evolution. The present-day landscape of Finland reveals the changing subglacial characteristics of the last deglaciation of the Fennoscandian Ice Sheet following the Younger Dryas when global temperatures rose and Eurasian ice sheets experienced widespread retreat, a potential proxy for today. A selection of large eskers from the former Baltic Sea Ice Lobe intersecting with the distinctive Salpausselkä ice marginal deposits will be examined in detail via 2 m LiDAR remote sensing, ground-penetrating radar, and sedimentological analyses. Constrained by multi-proxy reconstructed ice margin isochrons (Stroeven *et al*, 2016), and with reference to contemporary geomorphological research (e.g., Storrar *et al*, 2019), a spatial-temporal comparison of meltwater system evolution during post-Younger Dryas climate warming will be produced. This study will contribute to the wider efforts seeking to better represent the influence of meltwater in future ice sheet projections.

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IN SEARCH OF SEISMIC AND SEDIMENTARY EVIDENCE FOR PROGLACIAL NORTH SEA LAKES: INSIGHTS INTO THEIR DISTRIBUTION AND ROLE DURING THE ELSTERIAN, SAALIAN AND WEICHSELIAN GLACIATIONS

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During the Middle and Late Pleistocene, ice sheets occupied parts of the North Sea during three major glaciations, the Elsterian (MIS 12), the Saalian (MIS 10-6) and the Weichselian (MIS 4-2). Since there is no ample offshore evidence, the limits, dynamics and chronology of the ice sheets that occupied the southern North Sea are less precisely defined. Nevertheless, offshore studies often support the idea of the presence of proglacial North Sea lakes in front of the ice sheets, despite the lack of solid geomorphological and sedimentological evidence [1,2,3,4]. The existence of a proglacial lake is also used in the argument that glacial outburst floods created the erosional features preserved in the Dover Strait [5]. As part of the WALDO project ("Where are All the (proglacial) Lake seDiments in the NOrth Sea Basin?"), this study aims to test the hypothesis that proglacial lakes were important landscape features in the southern North Sea during the Elsterian, Saalian and Weichselian glaciations, based on the analysis and interpretation of marine geophysical and sedimentological data. In the framework of this study, three field surveys with the RV Belgica have been planned. During these surveys, high-resolution geophysical data (bathymetry, backscatter, acoustic and seismic data) and sediment cores from different areas in the southern North Sea will be acquired. By looking for geomorphological and sedimentological evidence of proglacial landforms and other associated sediment deposits, we aim to determine the location, distribution, and extent of the proglacial lakes during the last three glacial maxima. If such evidence is found, it will lead to a better understanding of the Pleistocene glacial landscape evolution and lithostratigraphic framework of the southern North Sea basin, ultimately resulting in updated regional palaeo-geographic and palaeo-environmental reconstructions. If insufficient evidence is found, then the proglacial lake hypothesis needs to be reassessed.

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This study is part of the WALDO project (Where are All the (proglacial) Lake seDiments in the NOrth Sea Basin?), a 4-year BELSPO-funded research project, which supports two PhD programs (more information: https://waldo.ugent.be/).

ASSESSING THE STRATIGRAPHIC SIGNIFICANCE OF NOVEL CRYPTOTEPHRA HORIZONS FROM THE MIS 5 SEDIMENTS OF THE SCOTIA SEA

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'Iceberg Alley', the main route by which Antarctic icebergs leave the continent, passes through the Scotia Sea depositing crucial evidence of Antarctic Ice Sheet evolution. The poor preservation of carbonate in the Scotia Sea hinders radiocarbon dating of this record, limiting our understanding of Antarctic ice-ocean dynamics. Tephrochronology is therefore particularly important for constraining the age of the Scotia Sea sedimentary record, but the current tephrochronology of this area is limited, extending to maximum of 35.4 ka (Moreton and Smellie, 1998). Reported here are five novel tephra layers identified in cores collected from the Scotia Sea during IODP expedition 382. Three of these tephra layers exhibit a similar but unusual bimodal distribution of trachytic and basalttrachyandesitic shards, and their physical and chemical characteristics suggest a volcanic source of Deception Island in the South Shetland Isles. The other two tephra layers are rhyolitic; their geochemical signatures also resemble Deception Island tephra the most closely, though discriminant function analysis reveals a significant difference between the two groups. The currently existing chronology allows only two of the bimodal layers to be dated, placing them at around 80.6 and 81 ka. Based on a complete characterisation of physical and chemical properties compared with assimilated tephra and whole rock data, all five tephra layers are interpreted as hitherto undocumented eruptions from Deception Island.

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BUILDING A CHRONOLOGY FOR QUATERNARY EUROPE

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The Quaternary Period is characterised by cyclic periods of climate change, involving dramatic shifts between long glacial periods (where giant ice sheets and glaciers extended to low latitude and lowland areas) and warm interglacials. It is also in this period that hominins first appeared in the archaeological record and migrated out of Africa. There is a rich record of these events throughout continental Europe, but the discontinuous and sporadic nature of non-marine deposits can make it challenging to correlate archaeological and geological sites with each other, or with the global climate record. Furthermore, often material required to perform radiometric dating (such as argon-argon or uraniumseries dating) is not present, making it challenging to determine the age of deposits. Amino acid geochronology is a relative dating method that is reliant on the spontaneous degradation of proteins within biominerals. Methods based on the intra-crystalline proteins found within the calcitic opercula of freshwater gastropods (fossils prevalent throughout European deposits) can be used to build a chronology for sites across the continent, taking account of regional temperature differences. Once a chronology is established, it can be used to test the validity of age determination by other stratigraphic methods such as lithology, biostratigraphy, or pollen sequences within a stratigraphic sequence. In addition, it can provide correlation to the marine oxygen isotope stages.

KEEPING ABOVE THE WAVES? THE RESPONSE OF COASTAL FRESHWATER PEATLANDS TO SEA-LEVEL RISE

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Global mean sea-level rise is occurring at an increasing rate, and is projected to continue in all emissions scenarios. With high emissions, we cannot rule out a rise of 15 m at 2300 (IPCC AR6, 2021). Understanding coastal response to sea-level rise is a priority for policymakers and land managers. What can be understood as part of 'the coast' is shifting inland. Much previous work has addressed the impacts of sea-level rise on saltwater wetland systems such as saltmarshes and mangroves, however less attention has been given to currently freshwater systems such as peatlands. Peatlands are significant ecosystem service providers: they store at least twice as much carbon as forests, attenuate floods, improve water quality, and enhance biodiversity (Loisel *et al*., 2020). Will rising seas threaten the survival of these systems? Or will they adapt or keep pace with this environmental change? My PhD takes a past-present-future approach, with a particular focus on peatland palaeoecology. Using a palaeoecological lens, we can reconstruct Holocene environments and investigate what past sea-level rise has meant for peatland function. I study two key sites in the UK: Cors Fochno, a raised bog on the Welsh coast, and Wheatfen, a floodplain fen in Norfolk. Here I will present my results thus far, including work on testate amoebae, loss on ignition (LOI), local sea-level rise projections, and ecohydrological monitoring data.

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CLIMATE AND ENVIRONMENTAL CHANGE IN SOUTHEAST ICELAND

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Understanding climate dynamics in the North Atlantic Ocean gives an important insight into the role of thermohaline circulation in terrestrial climate change. Iceland's location provides a unique opportunity for identifying and understanding North Atlantic climate variability, ocean circulation and rapid climate change. Icelandic lake sediments have demonstrated their ability to produce high resolution, quantitative palaeoclimatic reconstructions throughout the Holocene, exhibiting climatic variability across the region. However, little is known of the climate in southeast Iceland prior to the Little Ice Age and further evidence is needed to refine our understanding and produce new reconciled quantitative palaeoclimatic records extending beyond modern archives. This project will focus on multi-proxy analysis of lake sediment cores from high altitude lake Káravatn, in order to provide the first chironomid-based palaeoclimatic reconstruction in southeast Iceland. Sedimentological and geochemical analysis will include C:N ratios, magnetic susceptibility, particle size analysis, loss on ignition and X-ray fluorescence, as well as radiocarbon dating and tephrochronology. Cosmogenic radionuclide dating of glacial landforms from key Vatnajokull ice cap outlet glacier Skálafellsjökull will be useful for understanding glacier chronology and investigating the important interaction between glaciers and terrestrial climate change. This study will produce a high-resolution chronology and record of Holocene environmental and climatic change in southeast Iceland and provide further detail of the interactions between climate change, glacier response, and terrestrial response to changes in ocean and atmospheric circulation in this key region.

QRA CIRCULAR HIGHLIGHTS OCTOBER 2022

1. QRA Annual Discussion Meeting

Applications of Quaternary Geoscience to Engineering: process, properties and behaviour.

The 2023 Annual Discussion Meeting (ADM) will take place between **Thursday 5th and Saturday 7th January 2023,** and will be hosted at the Geological Society of London, Burlington House, London as an in-person event. This is a joint meeting with the Engineering Group of the Geological Society and invites participants from both academia and industry. The conference themes are:

- Quaternary geoscience supporting the low carbon economy
- Engineering in glacial and periglacial sequences
- Significance of river terraces and uplift to engineering and geoarchaeology
- Climate change, sea-level and coastal processes

Attendance from academia, industry and government bodies is encouraged. The conference will identify knowledge gaps and research needs, and will act as a trigger for collaboration to assist the community with engineering and academic endeavours.

Organisers:
P. Fish, J. Davis, R. Briant, S. Price, J. Murton, C. Mellett (Paul.Fish@Jacobs.com)

Abstracts and Registration:
Abstracts are invited on the themes listed above and to be submitted before 1st November 2022. Further information can be accessed at https://qra2023.wordpress.com

Registration Fees
Full Conference registration fee (members): £175
Postgraduate/unwaged registration fee: £95

Members:	(Thurs 5th/Fri 6th)	Day fee: £70
	Sat 7th	Day Fee: £40
Students/ Unwaged:	(Thurs 5th / Fri 6th)	Day Fee: £40
	Sat 7th	Day Fee: £25

The in-person registration fee does not include the conference dinner.

Deadline for Registration: 1st December 2022

2. QRA Annual General Meeting 2023

The Annual General Meeting will take place during the afternoon of **Friday 6th January 2023**. Further details of the time, format and joining instructions will be made available via the website and email news briefings.

3. QRA Executive Committee Nominations

As noted in the June Circular, three positions on the QRA Executive Committee will become vacant in January 2023. The following nominations have been received for the vacant posts; these officers will begin their appointments in January 2023:

President: Jane Hart (University of Southampton
Publicity Officer: Jenni Sherriff (King's College London)
Ordinary Member: Katy Roucoux (University of St Andrews)

4. QRA Awards *qra.org.uk/grants-awards-prizes/*

The next deadline for Awards applications is **15 January 2023**. In this round we welcome applications for the following awards: ***New Research Workers' Award; Quaternary Conference Fund; Quaternary Research Fund; The Bill Bishop Award; Radiocarbon Dating Short Course Bursaries; ^{14}C-CHRONO Centre Radiocarbon Dating Award***. Please consult the QRA website for eligibility criteria and application procedures or contact the Awards Officer (*awards@qra.org.uk*). Information on the INQUA Congress Travel Fund can be found on the website (https://www.qra.org.uk/inqua-2023/) with a deadline for applications of the **15th December 2022.**

5. QRA Outreach Fund: *qra.org.uk/outreach*

The QRA encourages its members and others to promote and foster engagement between Quaternary Science and a wide and diverse audience. To support this, we operate an Outreach Fund with awards of normally up to £1000, although larger requests are also considered. Please contact the Outreach Officer, James Lea for more details (*outreach@qra.org.uk*). The next application deadline is **1 March 2023**.

6. Calendar of QRA Meetings: *qra.org.uk/meetings*

Further details of forthcoming meetings are available from the QRA website.

Oct. 2022 GLWG and QRA Engineering Group field training course in sedimentology, engineering geology and geohazard significance of glacial and periglacial sediments

Location: The Conway Centre, Anglesey, Wales.
Leaders: D. Evans, P. Fish, J. Murton, S. Price (Paul.Fish@Jacobs.com)
Details: 27th to 30th October 2022

This training course is now fully subscribed but if you are interested in further information or events please contact Paul Fish.

Field meeting:

May 2023 QRA Field Meeting; The Quaternary of Wester Ross: glacier dynamics and post-LGM evolution of glaciated mountainous terrain

Location: Kinlochlewe.
Leaders: Colin Ballantyne and Doug Benn
Details: 25th to 28th May 2023
Contact: Colin Ballantyne (ckb@st-andrews.ac.uk)

If you have any suggestions for meetings, workshops, or other activities - particularly events that can be hosted online, or in compliance with social distancing regulations - please contact the Meetings Officer, Emrys Phillips (meetings@qra.org.uk) or the Secretary, Adrian Palmer (secretary@qra.ac.uk).

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 *c.* 1,200) is open to all interested in the objectives of the Association. The annual subscription is £20 with reduced rates (£10) for students and unwaged members and an Institutional rate of £35.

The main meetings of the Association are the Field Meetings, usually lasting 3–4 days, in April, May and/or September, a 2-3 day Discussion Meeting 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 Annual Discussion Meeting in January. Current officers of the Association are:

President: ***Professor Simon Lewis***, School of Geography, Queen Mary University of London, London E1 4NS (email: president@qra.org.uk)

Vice-President: ***Professor David Roberts,*** Department of Geography, Durham University, Lower Mountjoy, South Road, Durham DH1 3LE.
(email: vice_president@qra.org.uk)

Secretary: ***Dr Adrian Palmer,*** Department of Geography, Royal Holloway of London, Egham Hill, Egham TW20 0EX
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Dr Cathy Delaney, Department of Natural Science, Manchester Metropolitan University, All Saints Building, Manchester M15 6BH
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Treasurer: ***Dr Rupert Housley,*** Department of Geography, Royal Holloway of London, Egham Hill, Egham TW20 0EX
(e-mail: treasurer@qra.org.uk)

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Editor, Journal of Quaternary Science:
Professor Neil Roberts, University of Plymouth, Portland Square, Drake Circus, Plymouth, Devon PL4 8AA (e-mail:editor@qra.org.uk)

Publicity Officer: ***Dr Christopher Darvill,*** Geography, School of Environment, Education and Development, The University of Manchester, OxfordRoad, Manchester M13 9PL
(e-mail: publicity@qra.org.uk)

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**.

The QRA home age on the world wide web can be found at: http://www.qra.org.uk

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