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QUATERNARY NEWSLETTER

EDITOR:
Dr Sarah Woodroffe
Department of Geography, Durham University, Lower Mountjoy, South Road, Durham, DH1 3LE
(e-mail: s.a.woodroffe@durham.ac.uk

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 of an ~8 m section, in the Middle Pleistocene Baginton Formation at Waverley Wood quarry, as was exposed in 2011. Quartzose Baginton Gravel at the base of this section is overlain by Baginton Sand, with quartzose Thrussington Till at the top of the section, although the latter is not clearly visible in this view. Westaway (this issue) discusses this site and its regional context.

RESPONSE JAMES CROLL AWARD

It was a huge honour to have been awarded the James Croll Medal in January, just 5 days after the bicentenary of Croll's birth. I wish to thank the people who nominated me, and the QRA for bestowing on me their highest honour. The list of previous recipients is truly impressive and I am really humbled to think that you have now added my name to their number. I should point out that although I have published a number of single-author papers, most of my work has been collaborative, reflecting the diverse multidisciplinary nature of Quaternary science. In accepting this award, I must therefore acknowledge the enormous contribution of my co-workers. In fact, over the years I have collaborated with dozens of people, some of whom I have never even met, and a growing number have sadly now died, including two (Peter Hoare and Richard West), who we have lost during the lockdown. In this response I cannot thank them all individually but they will know who they are.

However, I do need to say some specific thank-yous and to acknowledge a few people who have helped me at certain points during my career.

First, I must thank my wife Barbara, who has been a real support to me over the years. I have participated in a number of overseas expeditions, several of which lasted not 3 or 4 weeks, but 3 or 4 months, and I have even been away for Christmas and New Year. These absences obviously have a domestic cost particularly because we had three young boys and I'm extremely grateful to Barbara for bearing that and for her insistence that I should join these exciting ventures to far-flung places.

Second, I would like to acknowledge the enormous help given to me by Michael Kerney. He kindled my youthful interest in molluscs while I was at school and patiently identified problematic specimens that I sent him, many from my home on the Isle of Wight. He eventually became my PhD supervisor at Imperial College, where he taught me how to identify broken, juvenile and bleached shells from Quaternary sediments, a completely different skill from naming living adult specimens. I spent nearly 7 years at Imperial, where I also held a post-doc. When that ended, I wasn't sure what I was going to do and mentioned this to Phil Gibbard (a previous Croll Medallist), who immediately had a word with Richard West, Professor of Botany and Director of the Subdepartment of Quaternary Research, who invited me to come to Cambridge. As we have all now heard, Richard, a founder member of the QRA, sadly died on New Year's Eve. When I came to Cambridge I didn't have a job, but I did now have a place to work, and what a place it was. As you have seen in the old photo, I was offered space in the Godwin Laboratory then occupied by several luminaries of the Quaternary community including Ann Wintle (another Croll medallist), James Scourse (former QRA president), and Nick Shackleton, who, of course, finally vindicated the Croll-Milankovitch hypothesis. The Godwin Laboratory housed only part of the Subdepartment because the palaeobotanists were based in the Botany School on the Downing site, and there were affiliated members in several other departments. The Subdepartment of Quaternary Research founded by Harry Godwin in 1948 was a truly extraordinary research community (West, 2014) that probably had its heyday during the early 1980s and I'm extremely grateful to Richard and Phil for giving me the wonderful opportunity to join it during this golden period.

The University Museum of Zoology (UMZC) is another extraordinary institution located adjacent to the Godwin Laboratory. This contains thousands of specimens from around the world including many of those collected by Charles Darwin on the voyage of the *Beagle*. Darwin provides another link with Croll because they corresponded (see Darwin Correspondence Project, available online), and Darwin's signature appears at the top of a list of the scientific elite who proposed Croll for Fellowship of the Royal Society. As well as zoological material, the UMZC collection is rich in fossils and, like Portsmouth University, is a major centre for vertebrate palaeontology. Several notable Quaternary vertebrate palaeontologists were based at the UMZC including David Mayhew, Tony Stuart and Adrian Lister. In 1986 the Museum advertised for a Curator of Malacology and when I was appointed to this position my career was set for the next 35 years. I've recently retired but still remain a part of this wonderful Museum, who enabled me to pursue my research, even if it was not always obviously zoological.

Lastly I'd like to say a few words about the QRA. Michael Kerney advised me to join the Association because it was a lively outfit where I was likely to meet other research students with similar interests, which might be very useful. He wasn't wrong – research students and post-docs have long made up a substantial component of the membership and have been responsible for many of its activities. Their involvement in this year's Annual Discussion Meeting is testament to this and a reassuring barometer for the future of our science. I belong to a number of other societies whose membership, without exception, have radically different age-profiles and who are desperate to attract new young members. The second major attraction of the QRA was the importance given to discussing evidence in the field. When I studied Geology during my 1st year at university, we would be taken to geological sections and the professor would provide detailed bed-by-bed accounts of what happened through the sequences. There seemed to be no ambiguity about anything. It was therefore a complete revelation to me when I first attended QRA field trips where at various critical sites different people would offer alternative interpretations of the sections before us. I learnt so much from these discussions and in later years often found myself arguing alternative viewpoints at sites around the coast of East Anglia and elsewhere. I joined the

QRA in 1975, which in retrospect was a great time to have done so because the QRA had just embarked on a national coverage of Quaternary sites. Each year we would visit a different region and a team of local experts would be on hand to describe critical sequences. The coverage achieved was extraordinary, from Jersey, Cornwall and the Scilly Isles, western Ireland to Shetland, and thence to East Anglia and Kent and everywhere in between. A Field Guide was produced for each excursion, which contained the latest views and often much unpublished information. It is very frustrating that copyright issues seem to preclude these being made available online, although there might be some movement on this. In recent years Quaternary science has changed to give greater emphasis to global perspectives, as exemplified by the wonderful talks we heard during this year's conference. These new perspectives are obviously important and it is right that the research community should focus on them but I wonder if there are consequences and whether the QRA would still have the local expertise to embark on such a Doomsday coverage of the British Isles. I once took a party of distinguished climate-modellers to Sidestrand on the North Norfolk coast to show them the, admittedly rather complex, stratigraphy. They were completely flummoxed by what they saw and it was clear that they had little sense of how the climatic oscillations that they had derived from their ocean/ice cores or from their computers, actually translated into field evidence. We should never forget the basic elements of our science.

I am very sorry that we couldn't all be together in Portsmouth from where we could see the Isle of Wight, the place of my birth. But I'll end by repeating the comment made by my fellow islander, Anthony Minghella, when he collected his Oscar, that this is another "Great day for the Isle of Wight"! Thank you all again for awarding me the James Croll Medal.

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Richard Preece
Department of Zoology
University of Cambridge
Downing Street
Cambridge CB2 3EJ
rcp1001@cam.ac.uk

RESPONSE LEWIS PENNY MEDAL

I would like to start by expressing my deepest gratitude to the QRA, as well as my nominator, for the honour of the 2020 Lewis Penny Medal. I am delighted to be listed alongside previous winners of the medal, several of whom will find citations to their work throughout my own. For any that have met me, you will know that I carry a Northern Irish accent, but it hides the fact I was actually born around the corner from the University of Portsmouth. Receiving the medal at the QRA Annual Discussion Meeting in Portsmouth was a poignant moment on home turf, albeit through a laptop screen several hundred miles away! As I go on from this moment, my research has a great many questions still lingering in my head and I am sure they will occupy my career for a while to come. If, by the end of that career, I am able to say that I contributed even half of what Lewis Penny offered I will consider it a career well done.

My career path to this point has been… well... odd. Unbeknownst to many colleagues, I am a keen artist (though, it must be said, not a very good one) and actually started my education studying architecture in Edinburgh. I completed first year before beginning to think about a change, the seeds of which were actually sown at school during one morning registration the year before. My A-level form teacher passed around a leaflet for the British Schools Exploring Society advertising an expedition to Greenland. I had always been interested in the environment and my desire to study architecture was around environmental dangers, in particular earthquake-proof buildings, rather than the contemporary fancy (or bland) glass facades currently popping up in every city. I recall asking to keep the leaflet and my form teacher blasting out "very well AN, but do you know how cold it is there?". I was aware, the picture was literally of a landscape covered in a giant ice cube. I was lucky enough to be offered an expedition place and spent six weeks in East Greenland after I completed first year. As someone who spent years living in an Army barracks and who's holidays only consisted of visiting family in Portsmouth, I had never been outside the UK, I had barely even seen the UK. For Greenland to be my first foray onto foreign soil was a surreal experience. Living out of a backpack, listening to the crunch of ice beneath crampons, and finding polar bear tracks in the snow, were truly life changing experiences. Towards the end of the expedition each Young Explorer experienced a 24-hour period of isolation, alone with just their thoughts and the cutting wind through the fjord. Lying in my pit of isolation that I dug to get away from that wind, I arrived at the epiphany that architecture was not my future. Over the next 18 months, whilst trying to work out what to do, I worked in a nightclub, a sports bar, delivered leaflets about what day was bin day, poked concrete out of second-hand bricks, and even drove a boat in a cave at one stage.

Greenland memories always stuck with me, including one about an enormous crevasse that was about 5 m wide and appeared to be bottomless. It was largely hidden under a snow bridge and we just happened to be walking parallel to it. Upon discovering it, I was suddenly provided with a great sense of fear, but also fascination, at how something so large could have been so nearly missed and how many others we walked over went unnoticed. I eventually settled on studying Geography at Queen's University Belfast in order pursue my environmental interests. The lectures I enjoyed most were on geomorphology – or, as one of my most influential lecturers Prof Brian Whalley put it, "the science of scenery". I then moved to Sheffield to do a MSc in Polar and Alpine Change, where I honed my knowledge further and learned from a large number of leading cryosphere scientists, including my dissertation supervisor Prof Christopher Clark. It also had the added benefit of five weeks in Svalbard – a trip that sealed my desire to pursue a PhD. Brian had also migrated to Sheffield during my time there and between him and Chris, their infectious enthusiasm for the glacial landscapes around us only served to seal the deal further about what career direction I would take.

I arrived at the University of Manchester for a PhD on high latitude marine geology and geophysics. My previous exposure to geophysics was borderline non-existent and provided a steep learning curve – luckily I had two fantastic supervisors in Prof Mads Huuse and Dr. Simon Brocklehurst. They flattened that learning curve and helped me to improve the bread and butter skills required to tell a robust scientific story. My research was primarily focused offshore northwest Europe and sought to unravel Quaternary environmental changes using seismic reflection data. My first paper investigated a number of spiral-shaped iceberg scours that were buried 400 m below the contemporary seafloor of the Norwegian Sea (Newton *et al.* 2016). At first these were just a unique set of cool features, but through many discussions we began to realise they perhaps told a story that was more significant. These features actually captured a record of past geostrophic and tidal currents from the Elsterian glaciation. Their wider palaeo-setting helped to reveal that these iceberg scours were likely formed during the deglaciation of the ice sheet and showed that warm currents swept past the northern British Isles and were likely reduced in magnitude. While reading the literature in preparation of this paper, I realised that many people tended to treat iceberg scours as a nuisance that destroyed the "good" (palaeo-) seafloor geomorphology, rather than a potentially informative feature.

Buoyed by this realization I began to wonder what may have been missed, I led a collaboration with two other PhD students after one mentioned there appeared to be lots of scours buried in their data. Nearly 10,000 mapped scours later, the initial results were presented on a poster at my first QRA meeting in Edinburgh. After some interesting discussions with Prof Brice Rea, we soon realised that we were arriving at similar conclusions from wholly different datasets. Over the next three years we worked together on a major paper, bringing in the additional expertise of Prof Grant Bigg, who taught me at Sheffield. By combining a wide range of methods we revealed that during many glacial stages of the early Quaternary the British and Irish Ice Sheet reached an areal extent in the North Sea that was broadly similar to the late Quaternary (Rea *et al*., 2018). This has interesting implications for not just our wider understanding of glacial history of the British Isles, but also our wider understanding of long-term sea level records and the efficacy of such proxies. This is my most cited piece of work to date and it started with a discussion at a QRA meeting. A follow up piece of work revealed that the results from the ocean modelling matched up very nicely with the geological record (Newton *et al*., 2018), giving further support to our previous paper. I was also fortunate during my PhD to spend time on two research cruises offshore New Jersey collecting 3D seismic data, as well as work on geophysical datasets from other parts of the globe that revealed insights into palaeo-environments in the Barents Sea, offshore the Falkland Islands, and northwest Greenland (e.g. Brown *et al*., 2017; Knutz *et al*., 2019; Newton and Huuse, 2017; Newton *et al*., 2017). This work combined has shown that some of the ice sheets of the early Quaternary appear to have been much larger than previously thought and this was not really reflected in the sea level record – a conundrum I will likely be thinking about for a while to come.

Developing that experience of the glacial signature in the marine record then led me to my current postdoctoral fellowship that I took back to Northern Ireland, returning to Queen's where this journey started. The project is investigating the efficacy of carbon capture and storage (CCS) in the North Sea and in many ways was the natural progression from a teenager worried about sustainability, to a scientist interested in doing something about it. The North Sea has great potential to be a European hub for CCS, but important gaps in our knowledge relate to understanding the role of overburden sediments above CCS targets. In the North Sea this overburden tends to contain a thick succession of Quaternary glacial sediments that, despite the extensive industry interest, we know relatively little about compared to deeper formations. The work for this is ongoing, but I presented some results at the QRA meeting in Portsmouth. This work looked at investigating how these Quaternary sediments in the northern North Sea might play a role in keeping stored fluids in the ground and was serendipitously accepted for publication the day of that presentation (Lloyd *et al*., in press). I have also looked into the geological past beyond the Quaternary and been able to carry out research with a direct relevance to Quaternary studies. This includes the discovery of large reserves of methane hydrates offshore Greenland and the approval of IODP drilling proposal 909, which will hopefully capture a detailed record of northwest Greenland's Quaternary history (Cox et al., 2020). In geoscience we often talk about how the present is the key to the past, but this work also shows how the Quaternary (and older) past is key to our future.

It is not lost on me that the higher education sector faces some major challenges, especially early career academics such as myself. I am lucky to have landed a permanent position and I say, without feigning modesty, that this is not because of my own skills, but because of others that have helped me to develop them. It would take more pages than the QRA can offer if I were to thank all the individuals that have played a role in me receiving this medal, so I will stick to only a few. I would like to thank my Mum, Dad, Sister, and Nan. My Dad passed away just before I finished my PhD, so I would, of course, like to dedicate the medal to his memory. The level of gratitude I have to Mads and Simon for getting me through those final three months of my PhD cannot be expressed through words. I have read many horror stories about student-supervisor relationships, but their ability to get me through in one piece (especially after I set an unreasonable quick submission date – my Dad's birthday), means I will only ever be able to talk about them in the most glowing of terms. I must also acknowledge my thanks to my nominator for showing the faith in me that I was possibly deserving of this recognition. Last, and by no means least, I thank my two dogs. Anybody that has dogs will know that they offer more support than any human could ever dream of giving. This medal is more a reflection of their hard work over the last few years than it is of mine.

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Dr Andrew Newton
School of Natural and Built Environment
Queens University Belfast
A.Newton@qub.ac.uk

ARTICLE

LEET HILL, THE BYTHAM RIVER, AND THE LATE MIDDLE PLEISTOCENE GLACIATION OF CENTRAL ENGLAND REVISITED

Rob Westaway

James Watt School of Engineering, University of Glasgow, James Watt (South) Building, Glasgow G12 8QQ, UK

robert.westaway@gla.ac.uk

QN150 announced the award of the QRA James Croll Medal to Jim Rose (Glasser, 2020). The citation listing Jim's career achievements emphasizes his role in the recognition from the 1980s onward (e.g., Rose, 1989) of the Bytham River, the pre-Anglian west-east drainage linking the West Midlands to the southern North Sea (Fig. 1). To further commemorate this award, QN150 paraphrased the Silva and Phillips (2015) entry on the Leet Hill site (British National Grid reference TM 384 926), in the lower reach of this river (Candy, 2015). However, Candy's (2015) summary cites only three references, by Rose *et al*. (1999) and Lee *et al*. (2004, 2008), the brief texts by Candy (2015) and in QN150 saying nothing about the controversy that has surrounded interpretation of the regional context of this site. It was indeed not an ideal choice to commemorate Jim, since these listed works promote what was first shown many years ago (by Westaway, 2009a; see below) to be a mistaken interpretation of the interaction there between the Bytham River and glacigenic input. However, as Leet Hill is the only Bytham River site recognized by Silva and Phillips (2015), the choice was either it or nothing. QN151 published a 'correction' by Turner *et al*. (2020) of the QN150 piece, with the stated aim of 'correcting' the Candy (2015) summary. Turner *et al*. (2020) touch upon multiple topics, including: the disposition of the pre-Anglian river terrace deposits in the vicinity of Leet Hill; the possibility of interaction between pre-and post-Anglian glaciations and these deposits; and the validity of the Bytham River concept. Their 'correction' indeed summarises views expressed by the same authors in multiple publications over many years. However, their viewpoint omits key information including appropriate citation of important references, thus failing to fully engage with the topics under discussion. Further 'correction' is, therefore, necessary; the topics raised by Turner *et al*. (2020) will be discussed individually.

The disposition of the pre-Anglian river terraces in the vicinity of Leet Hill

The sedimentary record of the pre-Anglian Ingham River in East Anglia, in the form of aggradations of fluvial sand and quartzose gravel, was recognized decades ago (e.g., Hey, 1976, 1980; Clarke and Auton, 1982). Setting aside for the moment

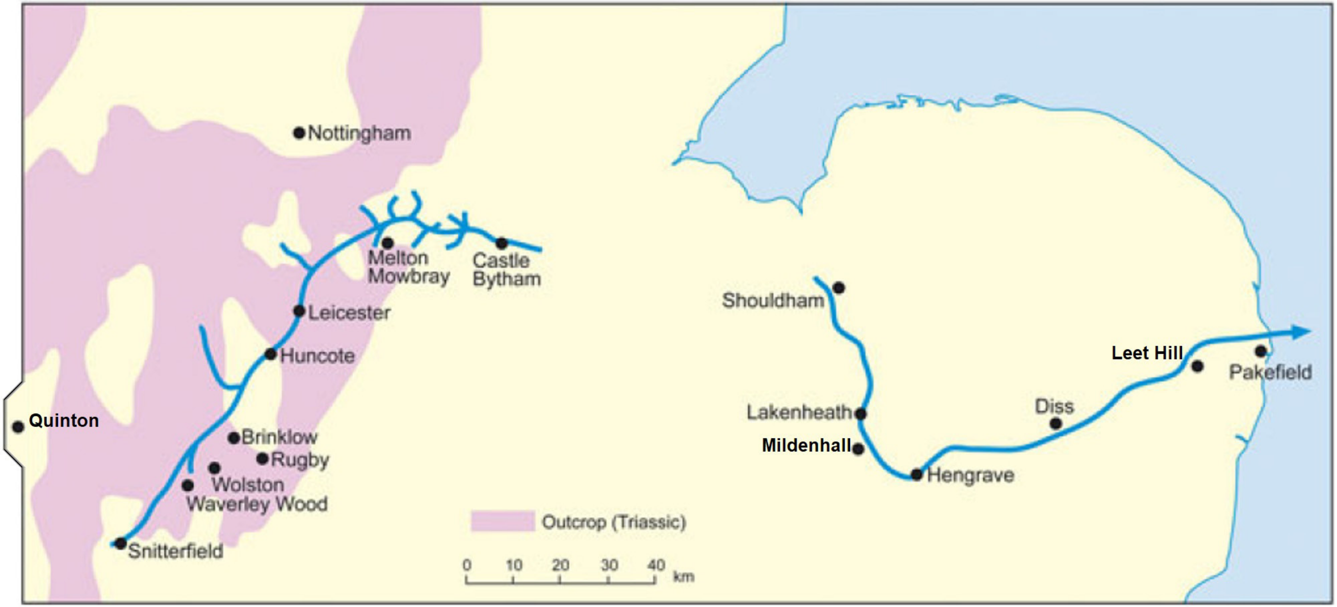

Figure 1. Map of central and eastern England showing the location of expanses of quartzose Pleistocene fluvial sand and gravel in the Midlands and in East Anglia. The Triassic outcrop depicted (which is not accurately geolocated relative to the other detail, but close enough to provide a general impression) includes sources of quartzose pebbles that are found throughout both expanses of fluvial sediment. Modified after Fig. 2(a) of Belshaw et al. (2014).

the question whether these sediments mark the downstream reach of the larger Bytham River (Fig. 1), Turner *et al*. (2020) focused on the numbers of river terrace deposits recognised in previous studies: four by Lewis (1993), six by Lee *et al*. (2004), and 'only' three by Westaway (2009a). They might also have included three by Moorlock *et al*. (2000). Their 'correction' gives the impression that this apparent uncertainty over numbers of terraces, on a relatively local scale, casts doubt on any possible correlation with the upper reaches of the putative Bytham catchment. However, arguably more important than numbers of terrace deposits are the procedures used to subdivide the many exposures and borehole sections into distinct mappable units, and the disposition of these units.

Lee *et al*. (2004) incorporated data from a relatively small number of well-studied field sites (Fig. 2). They recognized evidence of palaeosols at multiple sites, which they used to define the tops of fluvial aggradations, projecting these interpreted 'terrace tops' with subparallel dispositions, but did not define the bases of these deposits. In contrast, the Westaway (2009a) terrace scheme (Fig. 3) was based primarily on data from many boreholes demonstrating quartzose gravel and/or associated sand, drilled for the Mineral Assessment Review (MAR) circa the 1980s. Representative envelopes were thus recognised through tops and bases of terrace deposits, although it was found in the coastal region that these deposits overlap by height, frustrating subdivision. The Lee *et al*. (2004) evidence of palaeosols was not used, first, because most fluvial terrace deposits worldwide lack capping palaeosols, so if sites lacking such evidence were excluded no reliable interpretation would be possible. A second reason is because many British Pleistocene sites provide evidence of temperate stages 'sandwiched' between underlying and overlying cold-climate deposits (e.g., Bridgland, 2006; Bridgland *et al*., 2015). Palaeosol evidence thus provides no basis for defining the top of any mappable fluvial aggradation. Lee *et al*. (2011) nonetheless stated that '… the validity of [the Westaway (2009a)] terrace model is questionable because individual aggradations are largely unconstrained by palaeosol evidence that is necessary to demonstrate that the projected terrace surfaces correspond to recognisable land surfaces …', seemingly overlooking that this was deliberate, to avoid the risk of mistakes, and entirely consistent with standard procedures used in fluvial terrace stratigraphy. The disposition of these fluvial deposits thus varies dramatically between these interpretations: Lee *et al*. (2004) proposed parallel terraces (Fig. 2); whereas in the Westaway (2009a) version the terraces converge downstream towards the North Sea coast (Fig. 3), consistent with the regional context, the transition - via a coastal 'hinge zone' - between onshore uplift and offshore subsidence. Furthermore, some of the fluvial sediment bodies defined by terraces in the Lee *et al*. (2004) scheme project into bedrock (as at Leet Hill) or into early Middle Pleistocene coastal sediments (as at Pakefield), making implausible the disposition proposed in their study. This Westaway (2009a) long profile superseded the Lee *et al*. (2004) version.

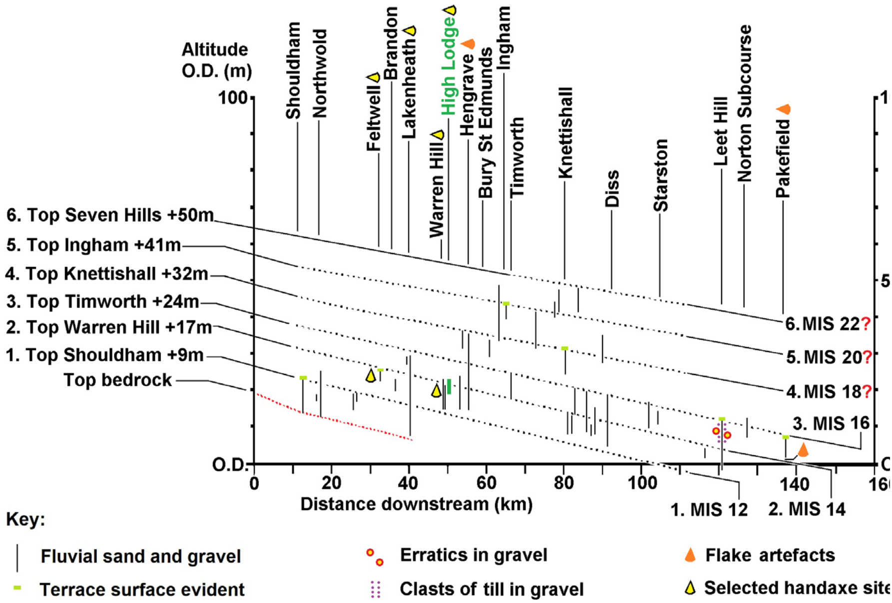

Figure 2. Long profile illustrating the interpretation of terrace deposits of the Bytham River in East Anglia (or Ingham River) by Lee *et al*. (2004), modified from part of their Fig. 7. Note the depiction of the sediments at Leet Hill as forming part of the third youngest Bytham River terrace.

The unpublished Lewis (1993) interpretation, based - like Westaway's (2009a) version - largely on MAR borehole data, likewise indicates downstream terrace convergence. However, aspects of Lewis's (1993) scheme have been published, for example parts of it were recently illustrated in the Lee *et al*. (2020) long profile (Fig. 4), the transverse profile near Ingham in Fig. 5 having been published by Lewis and Bridgland (1991). The main difference between the Lewis (1993) and the Westaway (2009a) scheme is its recognition of four fluvial terrace deposits, not three. This distinction occurs in the Ingham area, where the sediment at Ingham Pit was tentatively regarded by Westaway (2009a) as a basal remnant of the higher and more extensive 'Seven Hills' terrace deposit rather than as a younger fluvial aggradation inset into this older deposit as Lewis (1993) had thought (Fig. 5). In Fig. 3 the Westaway (2009a) long profile has been annotated with the Lee *et al*. (2004) palaeosols. Three of these (at Feltwell, Shouldham, and Leet Hill) are at the top of the youngest fluvial aggradation recognized by Westaway (2009a), one (at Knettishall) being at the top of the second youngest. The final one, at Ingham Pit, is either within the 'Seven Hills' terrace deposit or at the top of the separate Ingham Pit deposit (if this is recognized; Fig. 5). However, if this deposit is indeed recognized as separate, it is much thinner than the others, <5 m compared with >10 m thick. Nonetheless, regardless of whether three or four terrace deposits exist, they converge downstream (Fig. 3).

Subsequently, Lee *et al*. (2017) depicted (as their Fig. 15) a cross-section through the Leet Hill area showing the Bytham River sediments at Leet Hill as forming the lowest terrace of the Bytham River, consistent with Fig. 3 but not with their own previous terrace scheme in Fig. 2. Most recently, Lee *et al*. (2020) have

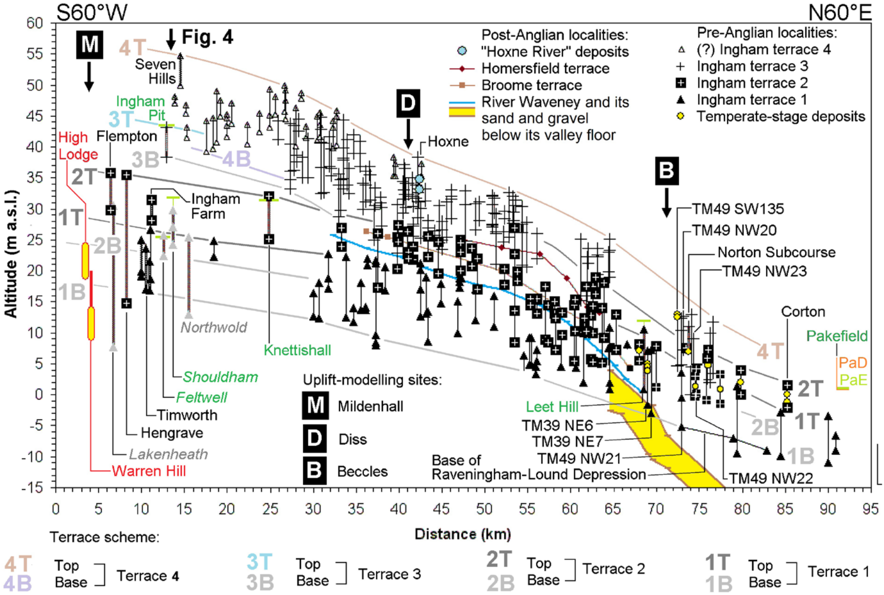

Figure 3. Revised long profile illustrating the interpretation of terrace deposits of the Bytham River in East Anglia (or Ingham River) by Westaway (2009a), modified from his Fig. 6, based mainly on MAR borehole data. The projection is oriented S60°W–N60°E, subparallel to most of the reach of the Ingham River downstream of Bury St Edmunds, distance being measured from TL 750 650, ~10 km south of Mildenhall and ~10 km west of Bury St Edmunds. The height of the Shouldham Thorpe palaeosol has been corrected (cf. Gibbard *et al*., 2012); the Pakefield palaeosol is ornamented differently, it being in sediments inset into older marine sands and gravels (Lee *et al*., 2006). This version has been labelled to resolve four terrace deposits in the vicinity of Ingham (cf. Fig. 5), compared with the three by Westaway (2009a), with suggested ages of MIS 16, 15b, 14 and 12, the sediments at Leet Hill forming part of the youngest terrace. The terraces of the River Waveney (post-MIS 8) and the sand and gravel deposits beneath its modern channel are included to illustrate their disposition relative to the Bytham River terraces; these post-Anglian deposits have a much steeper downstream gradient due the Waveney being a much smaller river. The steeply-graded 'Bungay Terrace', depicted by Lee *et al*. (2020) lower in the landscape than the Leet Hill deposit (Fig. 4), seems to be a misinterpretation of part of the Waveney succession.

published a new terrace scheme with four downstream-convergent terraces (Fig. 4), similar to the unpublished Lewis (1993) and published Westaway (2009a) versions; along with the aforementioned transverse profile through the Leet Hill area, reported by Lee *et al.* (2017), this amounts to a retraction of the Lee *et al.* (2006) scheme with parallel terraces. Overall, it is therefore unhelpful that Turner *et al.* (2020) mistakenly create the impression that the Lee *et al.* (2006) scheme with parallel terraces is still considered valid.

The possibility of pre-Anglian glaciation in the Norfolk-Suffolk border area

Rose *et al.* (1999) and Lee *et al.* (2004, 2008) advocated the so-called 'New Glacial Stratigraphy' (NGS) for Britain, with glacigenic deposits previously considered Anglian (MIS 12) subdivided into products of hypothetical MIS 16, 12, 10 and 6 glaciations. It was promptly recognised that this MIS 16 'Happisburgh' glaciation concept clashed with biostratigraphic ages of MIS 15 and 13 for sediments beneath the glacial deposits (e.g., Preece and Parfitt, 2008; Preece *et al.*, 2009; Rose, 2009). This biostratigraphic dating was supported by amino-acid dating on opercula of the freshwater gastropod *Bithynia* (AABO dating), which was trailed for several years before publication (Westaway, 2009b; Penkman *et al.*, 2011, 2013). Pawley *et al.* (2008) also reported a set of OSL dates supporting reinstatement of MIS 12 age for these four suites of glacigenic deposits in northern East Anglia. It was thus apparent by *c.* 2007-2008 that the MIS 16 element of the NGS was a mistake. Its chronology had been constrained by the recognition at Leet Hill of glacigenic input into what Lee *et al.* (2004) regarded as the third youngest Bytham River terrace deposit (Fig. 2). Assigning each of these terrace deposits to one climate cycle, counting backwards in time from MIS 12, led to the putative MIS 16 age. However, as Westaway (2009a) noted, there are no Bytham River terrace deposits below that at Leet Hill, only bedrock and deposits of the post-Anglian River Waveney (Fig. 3); the glacigenic input is thus into the youngest terrace deposit, therefore dates from MIS 12. Turner *et al.* (2020) now re-state this reasoning, using most of their piece to reach precisely the same conclusion on this aspect as Westaway (2009a) did, something they might have noted themselves.

Lee *et al.* (2017) subsequently reported a new interpretation of the glacial sequence in northern East Anglia, with the four stages from the NGS superseded by a succession of six ice advances, all Anglian (MIS 12). This publication amounts to a retraction of the NGS by its original proponents. Furthermore, Bendixen *et al.* (2018) recognized the SW limit of the MIS 16 Scandinavian Ice Sheet (SIS), ~200 km east of NE Scotland (circa 57°N), ~500 km north of northern East Anglia. The possibility of MIS 16 glaciation of East Anglia is indeed not considered an area of active research; Turner *et al.* (2020) are incorrect to indicate otherwise.

Late Middle Pleistocene glaciation

Many accounts have recently proposed that much of central England, including the Fen Basin, was affected by late Middle Pleistocene glaciation. In the 'TVPP'

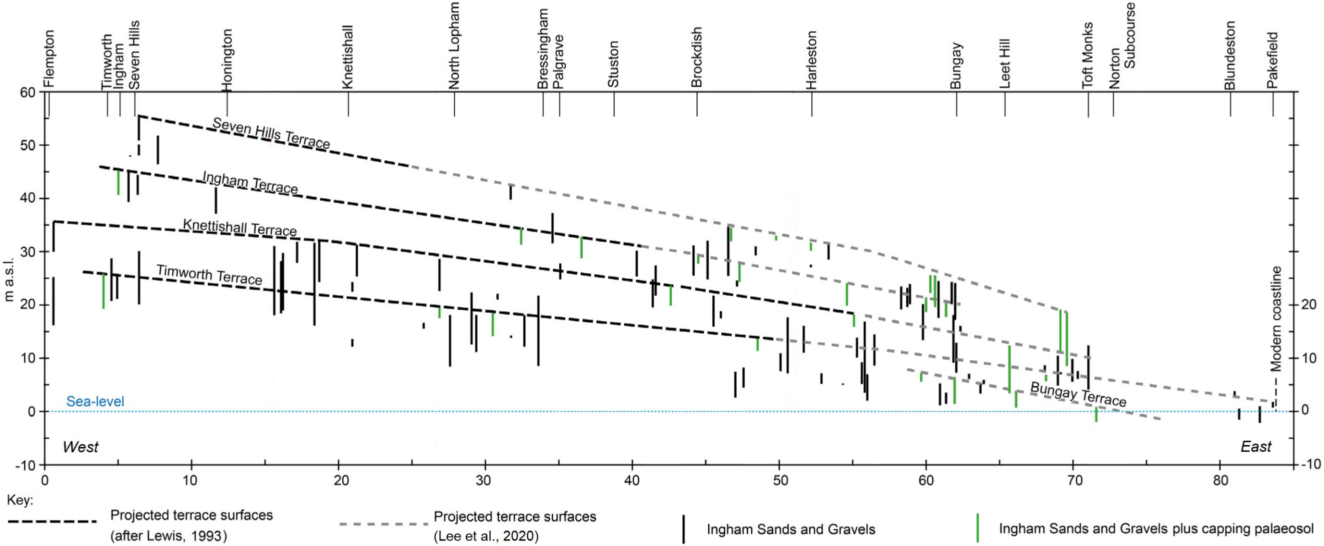

Figure 4. Long-profile terrace reconstruction of the lower reaches of the Bytham River across central East Anglia, after Fig. 13 of Lee *et al*. (2020). This profile is labelled to indicate west-east orientation but the actual west-east distance between the end points Flempton (TL 813 699) and Pakefield (TM 536 886) is ~72 km, not the depicted ~84 km, so the true orientation must be different, creating uncertainty over geo-location (cf. Fig. 3). The reported disposition of fluvial deposits (Ingham Sands and Gravels) is based on data from the British Geological Survey (BGS) borehole database, geological maps, the unpublished Lewis (1993) Ph.D. thesis, and the Lee *et al*. (2004, 2006) publications, the terrace interpretation being in part after Lewis (1993) and in part original. Note the downstream convergence of the terraces, superseding their parallel disposition in Fig. 2, and the use of data both with and without capping palaeosols, which these authors evidently no longer regarded as so significant for terrace reconstruction as Lee *et al*. (2011) did. The steeply graded 'Bungay Terrace', not discussed by Lee *et al*. (2020), appears to be a misinterpretation of part of the post-Anglian Waveney succession (cf. Fig. 3).

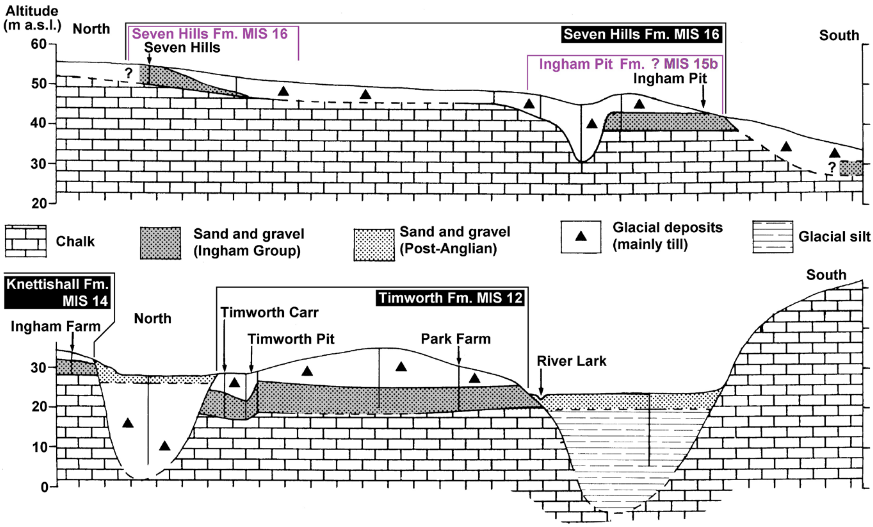

Figure 5. North–south profile through the Ingham/Timworth area (near Hengrave; Fig. 1) indicating the disposition of terrace deposits of the Ingham River in relation to Anglian glacigenic deposits, after Fig. 4 of Westaway (2009a), adapted from Fig. 21 of Lewis and Bridgland (1991). The section was constructed from boreholes, at localities marked, and is roughly aligned north–south (between *c*. TL 863 749 and *c*. TL 846 661), with length ~10 km but not drawn to horizontal scale. The southern end of the upper part of the figure adjoins the northern end of its lower part. Proposed stratigraphic nomenclature indicating the subdivision of the Ingham Group into three formations (in black, after Westaway, 2009a), or four formations (in purple; after the present study), is illustrated.

view, developed during the ALSF-funded Trent Valley Palaeolithic Project, this event – designated the Wragby Glaciation – is assigned to MIS 8 (e.g., White *et al*., 2007, 2010, 2017; Westaway, 2010, 2020; Bridgland *et al*., 2014, 2015, 2019; Howard *et al*., 2014; Westaway *et al*., 2015). Evidence from multiple sites indeed constrains this glaciation as no younger than MIS 8, as temperate-stage deposits that are securely dated to MIS 7 overlie glacial deposits (Fig. 6). The age-control evidence supporting this view includes biostratigraphy (Schreve *et al*., 2014) and AABO dating (Penkman, 2007; Penkman and McGrory, 2007, 2014). Such recognition of MIS 8 glaciation in central England is in accord with the long-standing view of Allan Straw (e.g., Straw, 2000, 2005, 2011, 2015, 2020). Westaway (2020) showed, from its disposition relative to caves with U-series dated speleothem, that the Bakewell Till of the Peak District was also emplaced in MIS 8, thus making it an element of the wider Wragby Glaciation. Most recently, Rose *et al*. (2021) have documented the key site of Clipsham in NE Rutland (~5 km south of Castle Bytham, Fig. 1, circa SK 971 151), where temperate-climate deposits overlie chalk-free till (Bozeat Till), thought to be Anglian, and are overlain by chalky Wragby Till, providing the first direct sedimentary evidence in the East Midlands for two Middle Pleistocene glaciations.

The alternative view, alluded to by Turner *et al*. (2020), holds that the late Middle Pleistocene glaciation occurred in MIS 6 (e.g., Gibbard *et al*., 2009, 2012, 2018; West *et al*., 2014). This age has been based on OSL dates of 160 ka, reported as 'personal communications', from sand at Warren Hill (TL 744 743; near Mildenhall; Fig. 1) and Tottenhill (TF 636 115; near Shouldham; Fig. 1), at the

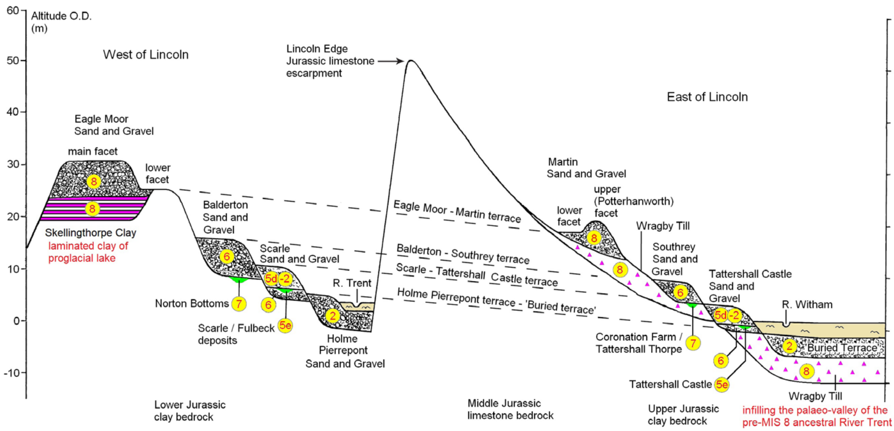

Figure 6. Schematic west-east cross-section linking the reaches of the Lincoln Trent west and east of Lincoln, illustrating the proposed terrace correlation and the stratigraphic relations between fluvial and glacigenic deposits. Modified after Fig. 3 of Westaway *et al*. (2015)

eastern margin of the Fen Basin (Gibbard *et al*., 2009, 2012). However, neither of these OSL dates has been supported by any published technical documentation; this is important, because the OSL technique is liable to provide systematically young dates due to saturation (e.g., Rhodes, 2011). Gibbard *et al*. (2018) added that 'this age correlation is further supported by correlation with The Netherlands and Germany, where the Late Saalian (Drenthe Stadial) glaciation is equated with MIS 6 … . Moreover, as Gibbard *et al*. [(2009, 2012)] and [Gibbard and Clark (2011)] discussed, this equivalence is further reinforced in the southern North Sea Basin. Here, offshore seismic evidence demonstrates the continuity of the … glacial limit north of East Anglia with The Netherlands' Drenthe glaciation maximum … . The seismic analysis clearly differentiates this strongly defined feature from those of the earlier Anglian/Elsterian and later Devensian/Weichselian glaciation.' Fig. 7

presents key evidence relating to this argument. Using seismic survey data, the MIS 6 Drenthe stage limit of the SIS can be traced from the onshore Düsseldorf-Nijmegen-Utrecht-Haarlem moraine complex, westward across the southern North Sea, to a point ~110 km NE of Norfolk. However, seismic survey west and SW of this point (e.g., Dove *et al*., 2017; Roberts *et al*., 2018; Fig. 7), indicates that the Devensian (MIS 2) British-Irish Ice Sheet advanced so far southeast that it overrode this SW limit of identification of the MIS 6 SIS. Thus, rather than demonstrating continuity with any late Middle Pleistocene ice sheet onshore in Britain, as has been claimed, the offshore evidence in this area provides no information regarding any continuation of the SIS in any direction; it might well indeed have been restricted to areas now offshore. Nonetheless, many workers (e.g., Gibbard *et al*., 2009) have depicted this tentative ice-margin extrapolation (G in Fig. 7) as soundly based, thus perpetuating a mistake in the literature that warrants recognition and correction.

Gibbard *et al*. (2018) added that 'suggestions that the glaciation occurred in the Middle Wolstonian (ca MIS 8), based on OSL ages [(Straw, 2000, 2005, 2011, 2015; White *et al*., 2010, 2017)] described as 'inaccurately determined' [(Schwenninger *et al*., 2007a)], are here rejected in the light of the modern multiple age determinations mentioned above [(i.e., the two unpublished 160 ka OSL dates)]. These ages confirm the stratigraphical evidence demonstrating that there is no reliable basis for identifying glaciation intermediate between the Anglian and Late Wolstonian Substage (= MIS 6) Tottenhill advance events in eastern England … .' Gibbard *et al*. (2018) thus dismiss the entire TVPP output on the basis of inaccurate OSL dating by the TVPP in favour of these two unpublished OSL dates. However, although the TVPP generated a large suite of Middle Pleistocene OSL dates (Schwenninger *et al*., 2007a, 2007b; Schwenninger, 2014), these were not used in site interpretations, due to concern regarding possible saturation (see above). Age assignments (summarised in Fig. 6) were thus made using biostratigraphy and AABO dating, as already noted. The backing given by Turner *et al*. (2020) to the dating of early Middle Pleistocene sediments in north Norfolk using biostratigraphy and AABO dating (regarding their dismissal of the MIS 16 glaciation concept) is indeed surprising, given the refusal of the same authors to engage with the same techniques when applied to the late Middle Pleistocene, as in the TVPP. Many of the TVPP OSL analyses indeed indicated ~200-250 ka ages for sediments that were thought (in 2007) to be Anglian. Many of these samples can now be assigned to the MIS 8 Wragby Glaciation, indicating that the OSL dates may well be more-or-less correct, although they remain unused for dating the TVPP sites.

Setting aside the distinction between MIS 8 and MIS 6 age assignments, much of the evidence for late Middle Pleistocene glaciation in the Fen Basin and its surroundings, advocated by both 'camps', is exactly the same. An example is the aforementioned sedimentary sequence at Tottenhill, indicating deposition in a pro-glacial lake (e.g., Gibbard *et al*., 1992, 2009; White *et al*., 2010). A second

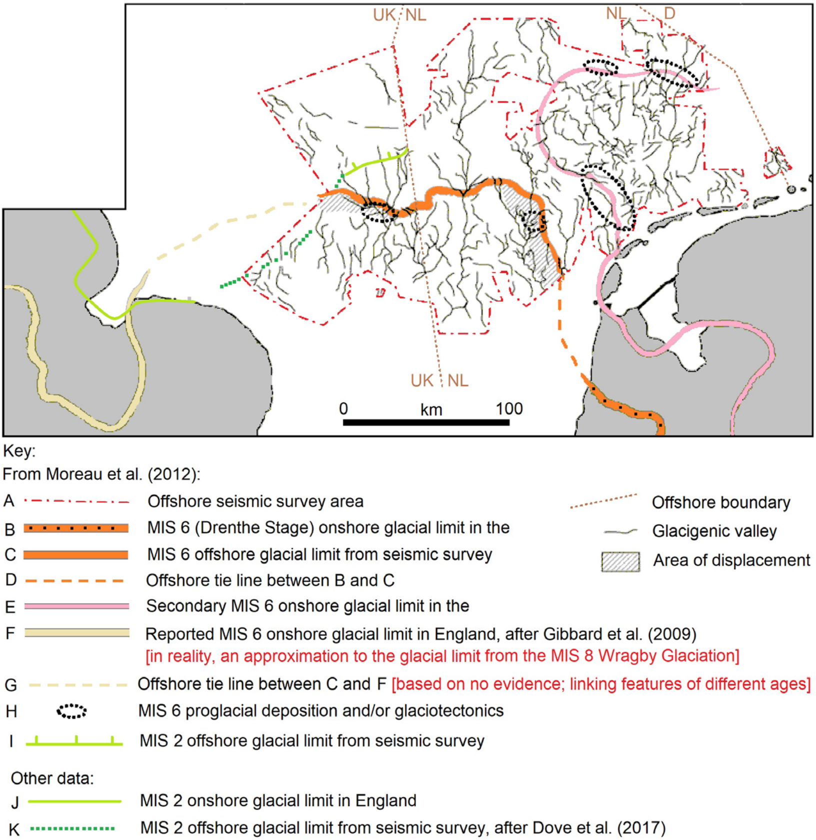

Figure 7. Map of the southern North Sea region showing interpreted late Middle Pleistocene and Late Pleistocene glacial limits. Modified after Fig. 7 of Moreau *et al*. (2012).

aspect is the ice-margin reconstruction indicating that northward drainage was ice-blocked so this Fen Basin pro-glacial lake overflowed eastward from the Little Ouse valley into the Waveney catchment and thence into the southern North Sea (e.g., West, 2009; Westaway, 2010; Westaway *et al*., 2015; Gibbard *et al*., 2018), as illustrated for example in Fig. 9 of Westaway *et al*. (2015). A third aspect is the recognition of southward-directed ice-marginal meltwater channels entrenched into the landscape around the western margin of the Fen Basin ice-lobe. These include the valleys of the rivers Glen and Eden SE of Grantham (north and east of Castle Bytham in Fig. 1; compare Straw, 2020, Fig. 1, with Gibbard *et al*., 2018, Fig. 15). The complex near Stamford (~20 km south of Castle Bytham in Fig. 1) of outwash gravel at Uffington (*c*.TF 064 090), the dry Southorpe palaeovalley in the Welland-Nene interfluve, another interpreted ice-marginal meltwater channel (*c*. TF 083 034), and the deposition in a proglacial lake at Elton (*c*. TF 085 940) in the ice-blocked Nene valley (e.g., Langford, 2004, 2018; Langford and Briant, 2004; Westaway, 2010; White *et al*., 2010; Westaway *et al*., 2012, 2015; Gibbard *et al*., 2018), provides another example.

In contrast, at the southern and eastern margins of the Fen Basin the late Middle Pleistocene ice-margins proposed in TVPP accounts (e.g., White *et al*., 2010; Westaway *et al*., 2015) are conservative compared with the Gibbard *et al*. (2009) version (Fig. 7). Nonetheless, Gibbard *et al*. (2018) propose an even larger glaciated area. Thus, in the south, in the urban area of Cambridge (~30 km WSW of Mildenhall; Fig. 1), their ice-margin (illustrated in their Fig. 15) encompasses localities such as Arbury and Chesterton (reaching *c*. TL 450 603); in the east, it includes the valley of the River Lark upstream (eastward) to circa West Stow (~7 km NW of Bury St Edmunds, near Hengrave in Fig. 1, *c*. TL 812 706), ~10 km east of the Fen Basin. However, ice-margins in these positions would encompass many Pleistocene sites that show no influence of late Middle Pleistocene glaciation. This includes the Histon Road SSSI site in Cambridge (TL 443 611), with sediments from MIS 7 (Boreham *et al*., 2010; Boreham and Leszczynska, 2019); this age precludes local glaciation in MIS 6 but would not exclude MIS 8. In the Lark valley, the Gibbard *et al*. (2018) glacial limit would encompass the Lower Palaeolithic site at Beeches Pit, West Stow (TL 798 719), where Hoxnian (MIS 11) temperate-stage deposits overlie Anglian glacigenic deposits (e.g., Bridgland *et al*., 1995; Preece *et al*., 2007; Westaway, 2009b; Penkman *et al*., 2013) with no evidence of later glaciation.

Farther downstream (westward) in the Lark valley, near Mildenhall, at the eastern margin of the Fen Basin adjoining the western end of the Ingham River palaeo-valley, infilled by glacigenic deposits generally assigned to the Anglian (Figs 1 and 5), are the Palaeolithic sites of High Lodge (TL 739 754) and Warren Hill (TL 744 743), noted by Turner *et al*. (2020). The Anglian age of these glacigenic deposits is supported by AABO dating of overlying sediments at nearby sites (Barnham, Elveden, Beeches Pit) to MIS 11 (Westaway, 2009b; Penkman *et al*., 2011, 2013). At High Lodge and Warren Hill the Palaeolithic archaeology has been associated with fluvial sediments that pre-date this glacigenic material, indicating a pre-Anglian age and suggesting a 'Bytham River' context (e.g., Wymer *et al*., 1991; Ashton *et al*., 1992; Bridgland *et al*., 1995), although these fluvial sediments have not themselves been directly dated. Nonetheless, Bridgland *et al*. (1995) counted 4173 11.2-16.0 mm clasts from Warren Hill, finding zero clasts of Jurassic *Rhaxella* chert. This lithology (derived from outcrop in East Yorkshire), first transported to East Anglia during the Anglian glaciation, pervades Anglian and post-Anglian gravels (e.g., those at Beeches Pit); its absence in such a large sample is thus a strong indication of a pre-Anglian age for the Warren Hill gravel.

In contrast with the above-mentioned interpretations, Gibbard *et al*. (2009) proposed that the Warren Hill gravel was deposited in an MIS 6-age proglacial lake, the only support for this age being the unpublished OSL date. West *et al.* (2014) also proposed new interpretations of the Palaeolithic contexts of the High Lodge and Warren Hill sites, likewise with no factual dating evidence. Thus, in their view, the High Lodge site indicates human occupation during MIS 7, whereas at Warren Hill the artefacts have been reworked from unspecified earlier periods into the putative MIS 6-age proglacial deposits. Notwithstanding the lack of supporting evidence, there is also strong evidence to the contrary, given that the Lower Palaeolithic artefact types from Warren Hill and High Lodge are as expected in Britain for ~500 ka, very different assemblages - indicative of the Middle Palaeolithic - marking MIS 7 (e.g., Bridgland and White, 2014, 2015; White and Bridgland, 2019). Turner *et al.* (2020) also argue that the heights of the High Lodge and Warren Hill deposits should not be used to define any pre-Anglian fluvial terrace scheme, because they are not fluvial deposits, are not pre-Anglian, and (at High Lodge) are not *in situ* due to being glacio-tectonised. Lee *et al.* (2004) recognised that the High Lodge silts are not *in situ*, but illustrated their interpretation of these as forming the upper part of their 'Warren Hill' terrace deposit (Fig. 2), assigning the temperate-stage deposits to MIS 13, emplaced on sand and gravel from MIS 14. Westaway (2009a) did not use data from High Lodge or Warren Hill to define his terrace scheme, but noted from their height that these sediments probably form part of his youngest (Timworth) pre-Anglian terrace deposit, as Fig. 3 illustrates.

Reality of the Bytham River

The pre-Anglian Bytham River (Fig. 8) has been recognised from the sedimentology, quartzose clast lithology, palaeocurrent pattern and elevation range of its sands and gravels across the Midlands and East Anglia (e.g., Rose, 1989). The absence of this sediment within the Fen Basin is explained by the creation of this lowland following Anglian glacial erosion of the Chalk ridge that formerly connected NW Norfolk and east Lincolnshire (e.g., Clayton, 2000; cf. Perrin *et al.*, 1979, Rose *et al.*, 1995), permanently altering the regional drainage. The expanse of quartzose fluvial deposits in the Midlands, extending SW-NE for >60 km from SW Warwickshire (Snitterfield; Fig. 1) to north of Leicester, was recognised by Shotton (1953) and assigned to the 'Proto-Soar River' by Shotton (1983). Midland provenance of the Ingham River gravel was recognised by Hey (1976, 1980), the reach downstream of Leicester, through the Leicestershire-Lincolnshire Wolds, being documented later (e.g., Rose, 1989; Rice, 1991). More recently, the continuity of this catchment has been reinforced by mixing calculations using gravel compositions above and below tributary confluences (Westaway *et al.*, 2015). Thus, for example, the relative proportions of durable Midland lithologies, quartz/quartzite and Carboniferous chert, in the Ingham River gravels in East Anglia, can be explained by mixing of gravels from the main Bytham River and Ancaster River (Fig. 8) in the ratio ~10:1 (Westaway *et al*., 2015). Similar calculations confirm other significant confluences, notably with the 'Hinckley River' SW of Leicester and the 'Derby River' north of Leicester (Westaway *et al*., 2015; Fig. 8), strengthening the overall concept.

In contrast, Turner *et al*. (2020) refer to the Bytham River concept as 'a mistaken imperative to link a fictitious pre-Anglian river in the English Midlands and Fenland with the well-established Ingham River'. They are evidently alluding to the view, proposed by Gibbard *et al*. (2013, 2018) and Belshaw *et al*. (2014), that at no time in the Pleistocene was the Midland drainage connected to the Ingham River.

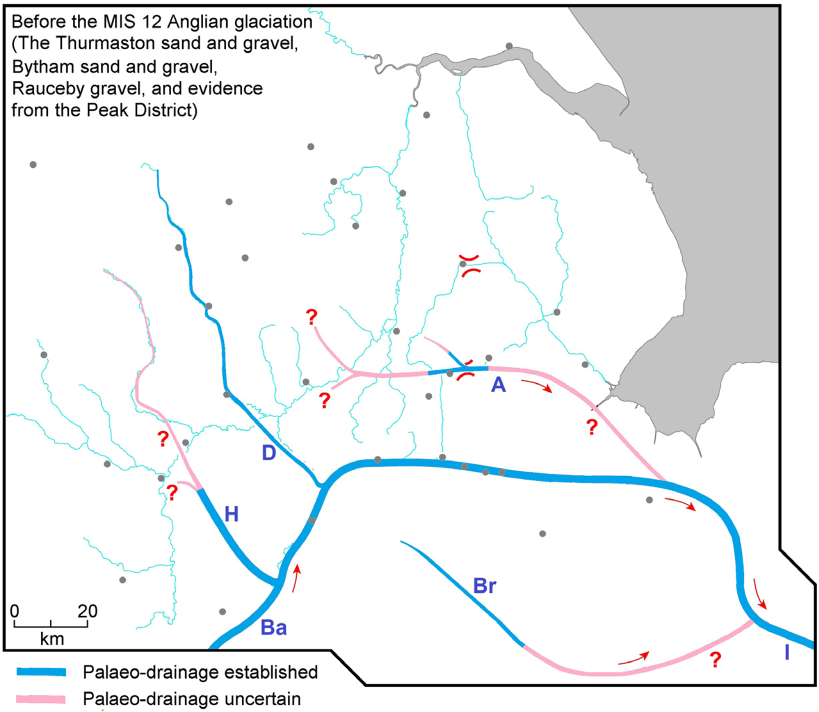

Figure 8. Pre-Anglian drainage reconstruction for central England, including affluents of the Bytham River, after Bridgland *et al*. (2015) and Westaway *et al*. (2015). Principal rivers are denoted thus: A, Ancaster River; Ba, Baginton River; Br, Brigstock River; D, Derby River (ancestral Derwent); H, Hinckley River (ancestral Dove); and I, Ingham River. Modified after Fig. 4(a) of Westaway *et al*. (2015).

Their alternative view (Fig. 9) holds that the principal affluent of the pre-Anglian Ingham River was the Ancaster River, which flowed through the Ancaster Gap in Lincolnshire. However, this is not feasible, given the different compositions of Ancaster River and Ingham River gravels (see above). Furthermore, in their view, between the Anglian and late Middle Pleistocene glaciations, the Midland drainage, represented by the Thurmaston Sand and Gravel (S&G) and counterparts (labelled 'Proto-Soar River' in Fig. 9), led through the Leicestershire-Lincolnshire Wolds at Castle Bytham to the North Sea at The Wash. A hypothetical gradient profile (Fig. 10) predicts that on entry to The Wash this hypothetical river was ~50 m above O.D. (relative to the modern landscape). However, the drainage in this area before the late Middle Pleistocene glaciation was *c*. 10 m O.D. (e.g., Straw, 1958; Westaway *et al*., 2015). This mistake, which invalidates the post-Anglian drainage reconstruction proposed in Figs 9 and 10, was discussed at length by Westaway *et al*. (2015), neither Gibbard *et al*. (2018) nor Turner *et al*. (2020) having engaged with this critique. Both the pre-Anglian and post-Anglian elements of the drainage reconstruction in Fig. 9 can thus be ruled out by straightforward arguments involving plausible long-profile river gradients or clast lithological analysis.

The deposits of the Midland 'Proto-Soar' reach of the Bytham River have received various names, including the aforementioned Thurmaston S&G around Leicester and the Baginton S&G or Baginton Formation near Coventry. Their study has become deeply connected with investigation of local glacigenic sediments, representing what has become known as the Wolstonian Glaciation (e.g., Shotton,

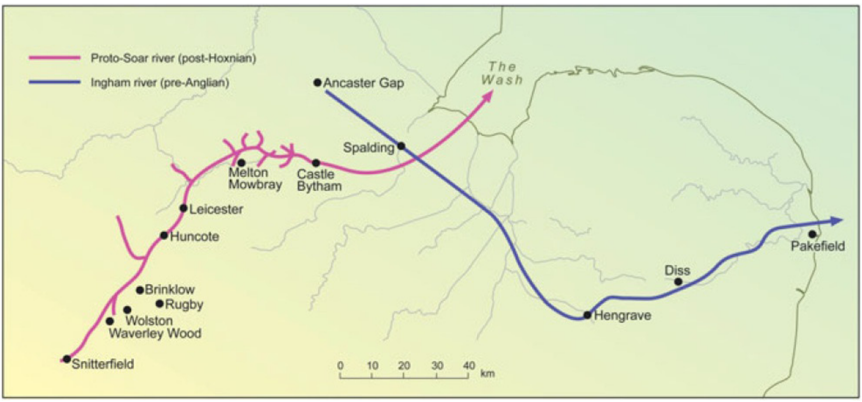

Figure 9. Interpretation of the evidence in Fig. 1 by Gibbard *et al*. (2013, 2018) and Belshaw *et al*. (2014), also alluded to by Turner *et al*. (2020). Modified after Fig. 2(b) of Belshaw *et al*. (2014).

1953, 1968, 1976, 1983), thought to be late Middle Pleistocene, before its reinterpretation as Anglian after Perrin *et al*. (1979) and Rose (1989). The Baginton Fm. underlies Wolstonian glacigenic deposits, indicating that the palaeo-river thus represented was disrupted by the Wolstonian Glaciation (e.g., Rose, 1989). Perrin *et al*. (1979), Rose (1989) and many later workers have equated the Wolstonian with the Anglian, inferring that this Midland palaeo-river was disrupted during MIS 12. However, Gibbard *et al*. (2013) proposed reinstatement of a late Middle Pleistocene age for the Wolstonian Glaciation, correctly noting that Anglian and Wolstonian tills in this region might be indistinguishable because similarly-oriented ice-advances over the same bedrock would create tills with equivalent compositions. Two till facies, whether Anglian or younger, are widespread in the Midlands: the quartzose Thrussington Till, derived from ice-advances from the NW across Triassic outcrop; and the Oadby Till, emplaced as a result of ice-movement from the NE across outcrop of Chalk and Jurassic mudstone. Concurrent TVPP-based studies independently assigned much of the Midland glacial record to the MIS 8 Wragby Glaciation (e.g., Bridgland *et al*., 2014, 2015; Westaway *et al*., 2015). These analyses did not consider the possibility that any part of the Baginton Fm. might be late Middle Pleistocene, although Westaway *et al*. (2015) deduced that the Earth's crust in the Leicester-Coventry area is highly stable, with very slow uplift, implying that the altitudinally-undifferentiated 'Proto-Soar' deposits (Fig. 10) might well represent a substantial age span. The crustal stability of this area is reflected in the gradual downstream divergence, over distances of many tens of kilometres, of Middle Pleistocene river terraces as modern rivers flow away from the stable region: the Soar to the NE (Rice, 1968; Westaway *et al*., 2015); and the Warwickshire Avon to the SW (e.g., Tomlinson, 1925, 1935). Other rivers that are not flowing out of stable crustal regions have parallel terraces much closer to their headwaters, a notable example being the Evenlode in the upper Thames catchment (e.g., Bridgland and Schreve, 2009). The observed downstream divergence of the Soar and Avon terraces is therefore not a consequence of limited erosional power in headwater reaches, as might be tentatively proposed as an alternative explanation.

At Waverley Wood (SP 326 713; Fig. 1), temperate-stage deposits that are unequivocally pre-Anglian from biostratigraphy and AABO dating (e.g., Candy *et al*., 2015) underlie the Baginton Fm. Gibbard *et al*. (2013) pointed out, again correctly, that there is no evidence to preclude a late Middle Pleistocene age for these overlying sands and gravels. Gibbard *et al*. (2013) also noted the record from Froghall quarry (Fig. 11; SP 416 736; near Wolston in Fig. 1). Here, temperate-stage deposits from MIS 11 or 9 (likewise constrained by biostratigraphy and AABO dating; e.g., Keen *et al*., 1997; Westaway, 2009b) overlie the Froghall Lower Gravel that must be post-Anglian from its substantial flint and minor *Rhaxella* chert contents (Keen *et al*., 1997). Nearby, higher in the landscape, representing outwash from the Oadby Till glaciation, are spreads of the Dunsmore Gravel, the

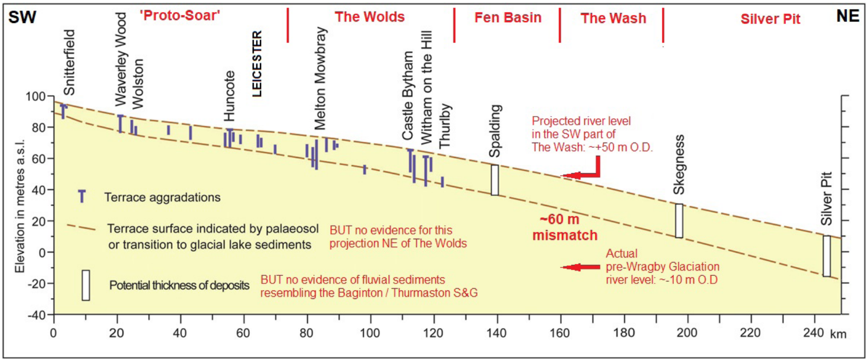

Figure 10. Long profile of the hypothetical drainage connection (from Fig. 9) between the Soar valley and the Wash, after Fig. 7 of Gibbard *et al*. (2013).

uppermost part of Shotton's 'Wolstonian' succession, which includes the Wolston Clay that overlies the Baginton Fm. However, contradictory interpretations have been published for stratigraphy of this site. Sumbler (1989) regarded the Froghall Lower and Upper gravels and the intervening temperate-stage sediments as correlative to the Fourth Terrace deposit of the River Leam, and thus to the Fourth or Ailstone terrace deposit of the Warwickshire Avon. This latter terrace deposit dates from latest MIS 8 to MIS 6 (e.g., Bridgland *et al*., 2004; Penkman *et al*., 2013). However, this interpretation was rejected by Keen *et al*. (1997). In contrast, Gibbard *et al*. (2013) regarded the Froghall Upper Gravel as part of the Dunsmore Gravel, making the 'Wolstonian' succession late Middle Pleistocene, although this is not how Keen et al. (1997) or BGS DigiMap interpret the site. Conversely, Keen *et al*. (1997) regarded the Froghall Upper Gravel as inset into the Dunsmore Gravel but the Froghall temperate-stage deposits as much older, separated by an erosional unconformity. This interpretation is preferred here (Fig. 11), it being also inferred that the Dunsmore Gravel post-dates the Froghall temperate-stage deposits, making the 'Wolstonian' succession an element of the MIS 8 Wragby Glaciation.

Further evidence, not considered by Gibbard *et al*. (2013), concerns the mammalian biostratigraphy. At Pratt's Pit (SP 328 675) and Manor Pit (SP 332 671), Lillington (in Leamington Spa, between Waverley Wood and Snitterfield; Fig. 1), the Baginton Fm. has yielded remains of late Middle Pleistocene mammals, notably woolly mammoth *Mammuthus primigenius* and woolly rhinoceros *Coelodonta antiquitatis* (e.g., Shotton, 1983; Lister, 1989). *C. antiquitatis* is known from sites in western Europe that immediately pre-date the Elsterian ice-advance (notably, Bad Frankenhausen in Germany) (e.g., Kahlke and Lacombat, 2008) but is more in keeping with a late Middle Pleistocene context (e.g., Kahlke, 1999). However, *M. primigenius* is thought to have not entered western Europe until ~200 ka (e.g., Lister *et al*., 2005). Its presence in MIS 8-age sediment would thus indicate an early occurrence, whereas age MIS 12 would appear implausible. This biostratigraphic evidence thus favours a late Middle Pleistocene age over a pre-Anglian age for this deposit. Furthermore, at Quinton (SO 992 847; Fig. 1) in SW Birmingham sediments that are biostratigraphically dated to the Hoxnian (MIS 11) interglacial are interbedded between tills of the Nurseries Fm., considered Anglian, and of the late Middle Pleistocene Ridgeacre Fm. (e.g., Horton, 1989; Thomas, 2001). Maddy *et al*. (1995) proposed a MIS 6 age for the Ridgeacre Fm. using cosmogenic dating, but their numerical results have large uncertainties, making a MIS 8 age tenable (White *et al*., 2010). Elsewhere in the region, Shotton (1929) recognised a widespread clayey deposit, thought to be till, beneath the Baginton Fm., which became known as the 'Bubbenhall Clay'. Shotton (1953) depicted the 'Bubbenhall Clay' as much less extensive, but whether it existed anywhere was disputed by Sumbler (1983). Although Shotton (1983) maintained its reality as an indicator of pre-Wolstonian (? Anglian) glaciation, no-one else who has described it has accepted it as a till; for example, Sumbler (1983) thought it might possibly indicate Triassic mudstone bedrock or mixing by cryoturbation of Triassic mudstone bedrock and the Baginton Fm. The difficulty distinguishing till formed of Jurassic mudstone from *in situ* Jurassic mudstone bedrock has indeed been noted elsewhere in the region (Westaway *et al*., 2015).

A further issue is the presence or absence of glacially-transported material in the Baginton Fm. If this deposit is pre-Anglian one would expect such material to be absent, whereas if any part of it were emplaced between the Anglian and Wragby glaciations one would expect material in it that had been glacially transported to the Midlands before being fluvially reworked. It has been stated (e.g., by Rice, 1981) that lithologies from outside the 'Proto-Soar' catchment, such as flint, are absent from the Baginton Fm. in the Leicester area. However, an earlier description of the same area, by Rice (1968), noted nineteenth-century reports of the presence of rare flint at sites that no longer existed so such evidence could no longer be verified. In the Coventry area, Shotton (1953) reported rare flint at multiple sites and a single clast of Lake District andesite at one site, Baginton (*c*. SP 344 748). Shotton (1953) inferred from this evidence that this area was affected by an earlier (i.e., pre-'Wolstonian') glaciation, which he associated with the emplacement of the 'Bubbenhall Clay'.

On balance, given the above data, it is suggested that much, if not all, the Baginton Fm. in the 'Proto-Soar' area is late Middle Pleistocene, it having hitherto been impossible to differentiate subdivisions of it from different climate cycles given the crustal stability and consequent very slow uplift of the area (Westaway *et al*., 2015). It is further suggested that the Wolstonian Glaciation of the Midlands is equivalent to the Wragby Glaciation (or 'Ridgeacre' glaciation) and dates from MIS 8, the northeastward 'Proto-Soar' drainage having persisted until then. However, downstream of Leicester, rather than heading eastward through the

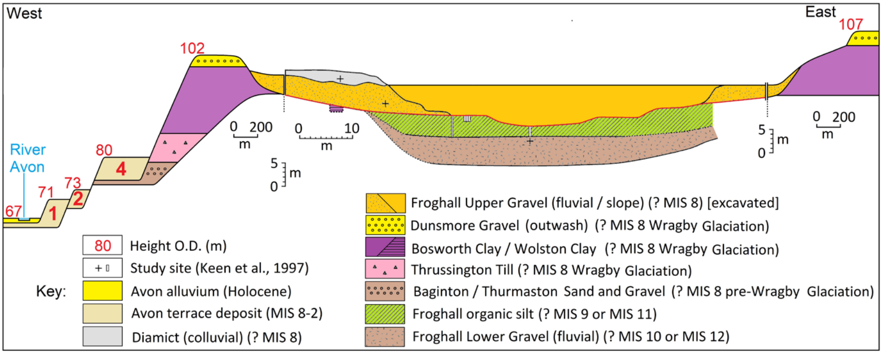

Figure 11. Transverse profile through the Middle Pleistocene deposits at Froghall. Modified after Fig. 3 of Keen *et al.* (1997), with additional information from BGS DigiMap and Ordnance Survey topographic maps and with the erosional 'cut' late in MIS 8 highlighted.

Wolds as in Fig. 9, it is proposed (after Bridgland *et al.*, 2015, and Westaway *et al.*, 2015) that this drainage led northward to Nottingham, then NE through the Lincoln Gap, then SE to The Wash, as depicted in Fig. 12.

It follows that the Wragby Glaciation palaeo-environment was essentially as envisaged decades ago (e.g., Shotton, 1953, 1983; Bishop, 1958) during the late Middle Pleistocene 'Riss' or 'Catuvellaunian' Glaciation, providing a remarkable instance of scientific ideas turning full circle. Thus, once the 'Proto-Soar' outlet through Nottingham became ice-blocked, the extensive proglacial Lake Harrison became impounded (Fig. 13), resulting in deposition of the Wolston/Bosworth Clay. This lake arguably overflowed, first, through a 'gap' near Daventry into the River Nene, then (when this 'gap' became ice-blocked as the Oadby Till ice-lobe advanced) through the Fenny Compton gap into the Cherwell, then (when this, likewise, became ice-blocked as the ice advanced farther) through the Moreton-in-Marsh gap into the Evenlode, then (after ice-retreat, re-opening the Fenny Compton gap) again into the Cherwell (e.g., Bishop, 1958; Shotton, 1983). Such overflow into the Evenlode would correspond to emplacement of the Wolvercote terrace deposit, now securely dated to MIS 8 (e.g., Bridgland and Schreve, 2009; Westaway, 2011); in the Cherwell a correlative deposit is recognised (Bishop, 1958). The tentative MIS 8 glacial limit, indicated in Fig. 13, is based on the southern margins of extensive outcrops of till north and east of Stratford-on-Avon (*c.* SP 190 584 and SP 310 513, after DigiMap), it being inferred that the small outcrops of till farther south and west are Anglian. Removal of the Welsh ice-blockage to the west (Fig. 13) created the Warwickshire Avon catchment from the upper reach of the 'Proto-Soar', the modern Soar - Avon (Sowe) divide

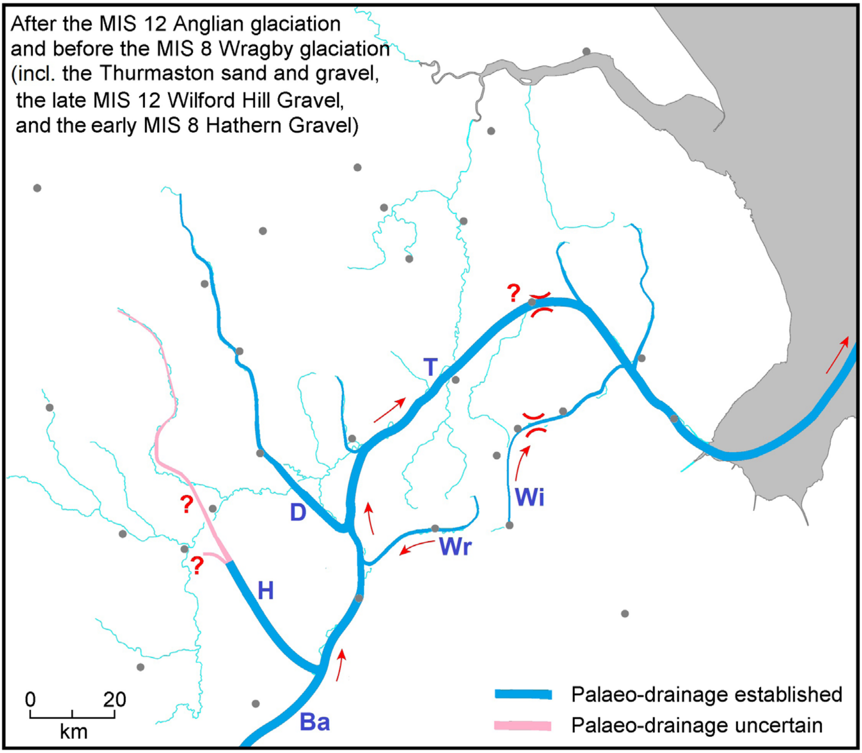

Figure 12. Proposed drainage reconstructions for central England for the late Middle Pleistocene, between the Anglian and Wragby glaciations, including the ancestral River Trent. Display format is the same as Fig. 8, except: T, ancestral River Trent; Wi, ancestral River Witham; and Wr, River Wreake. Modified after Fig. 4(b) of Westaway *et al*. (2015).

being near Brandon, ~7 km NE of Brinklow and ~4 km NE of Withybrook (*c*. SP 470 850; Figs 1 and 13), indicating that roughly three-quarters of the maximum extent of Lake Harrison developed into the Avon catchment. The Avon terrace staircase indeed dates back only to MIS 8 (e.g., Bridgland *et al*., 2004), consistent with this hypothesis.

Concluding remarks

The emphasis given by Turner *et al*. (2020) to dismissing the NGS argument for MIS 16 glaciation using the stratigraphic position of sediments at Leet Hill is misplaced; this point was demonstrated by Westaway (2009a) and the field moved

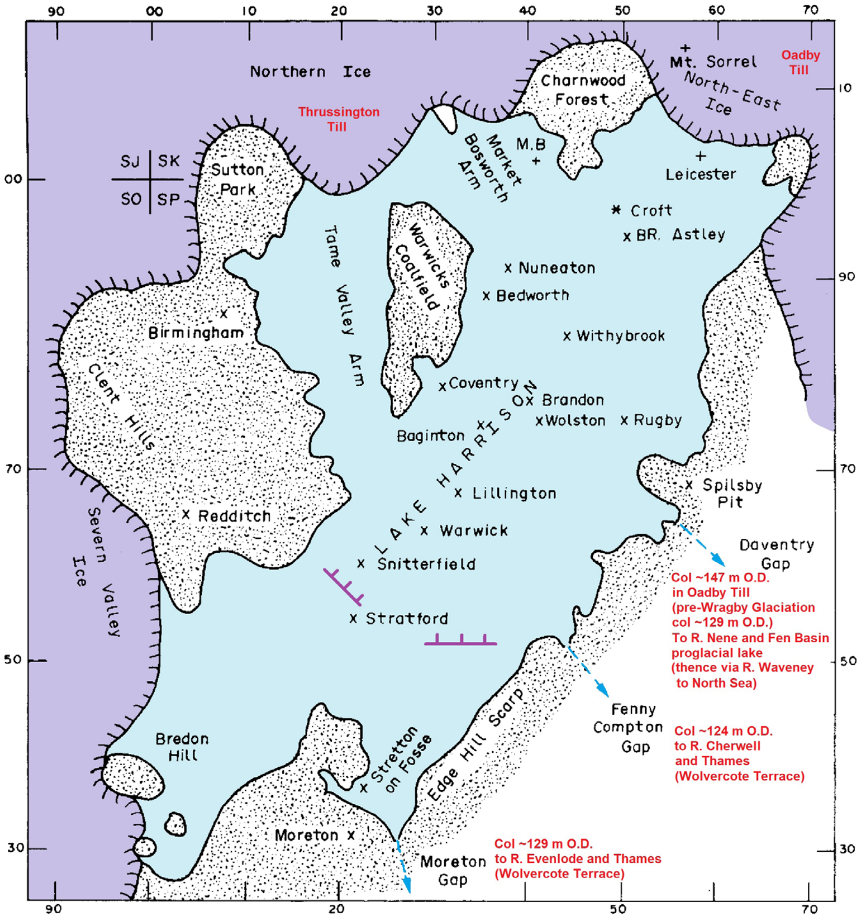

Figure 13. Maximum extent of Lake Harrison as estimated by Shotton (1983) during the ice advance at the start of the Wolstonian (Wragby; MIS 8) glaciation, also showing potential drainage outlets and (from this study) the estimated glacial limit. Col heights are relative to the present-day landscape, uncorrected for contemporaneous ice loading or subsequent uplift. Modified after Fig. 1 of Shotton (1983).

on. Turner *et al*. (2020) are also highly critical of the past attempts at subdividing the sediments of the pre-Anglian Ingham River into terrace deposits (Ingham Fm. 'members' / Ingham Group 'formations', whatever) but offer no insights into how they would undertake this difficult task themselves. Nonetheless, these deposits converge downstream across East Anglia, as Westaway (2009a) also showed

(Fig. 3) and as Lee *et al*. (2020) have recently confirmed (Fig. 4). Turner *et al*. (2020) also allude to age-assignments for key sites based on unpublished OSL dating; however, unpublished dating evidence such as this should be considered void (i.e., should carry no weight), and should not continue to be cited. Other dating techniques, such as biostratigraphy, should be used objectively, not only when they support one's preferred interpretations (and be overlooked when they do not). Turner *et al*. (2020) indeed overlook telling arguments, based on aspects such as clast lithology and Palaeolithic artefact morphology, which support pre-Anglian ages for key sites. They also dismiss the pre-Anglian Bytham River concept, which is likewise established primarily using clast lithology, in favour of untenable drainage patterns with significant contradictory evidence, as in Figs 9 and 10. However, given the available evidence, this concept is secure; Jim Rose indeed deserves recognition for its discovery (cf. Glasser, 2020). Nonetheless, extensive evidence exists for late Middle Pleistocene glaciation in central/eastern England; an MIS 6 age for this is untenable but MIS 8 is feasible, the 'Proto-Soar' reach of the Bytham River arguably persisting until this MIS 8 Wragby/ Wolstonian Glaciation (Fig. 12).

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2020 QRA ANNUAL DISCUSSION MEETING, QUATERNARY EARTH SYSTEM PROCESSES AND FEEDBACKS: CHALLENGES FOR SOCIETY

University of Leeds 8th-10th January 2020

The 2020 Quaternary Research Association Annual Discussion Meeting was hosted by Leeds Quaternary at the University of Leeds from 8th – 10th January. Leeds Quaternary formed in 2016 and is a joint School of Earth and Environment and School of Geography research group consisting of over 50 academic staff and researchers. This was the first time in the 54 years of the QRA that the University of Leeds hosted the ADM, and it was a pleasure to be able to do so. The theme of the meeting was 'Quaternary Earth System processes and feedbacks: challenges for society' organised around six plenary sessions to explore the role Quaternary science can contribute to better understand the Earth system and societal interactions.

Following an evening ice breaker session, the meeting kicked off on Wednesday 8th January with a session on 'ice, oceans and sea level', with keynote speaker **Natalya Gomez** (McGill, Canada), giving an overview of state-of-the-art ice sheet and glacial isostatic adjustment modelling. **Edward Gasson** (Bristol), **Sarah Bradley** (Sheffield) and **Kenji Izumi** (Bristol) all then presented results from modelling recent glacials periods, including outputs from CESM2.1/CISM2.1 and PMIP4. **Jeremy Ely** (Sheffield) provided a transition from modelling to data, highlighting persistent mismatch between the two in a study of the last British-Irish ice sheet. Focus then moved to geophysical and core data from the North Sea, with evidence for the Saalian glaciation presented by **Víctor Cartelle** (Leeds), and submerged Holocene landscapes of the Brown Bank by **Rachel Harding** (Bradford). **Martina Conti** (York) presented her work developing molecular fossils as proxy for Quaternary sea-level change. **Sophie Norris** (Alberta, Canada) showed evidence for rapid retreat of the Laurentide ice sheet, driven by the Bølling-Allerød warming and **Jenna Sutherland** (Leeds) illustrated the importance of proglacial lakes on past outlet glacier dynamics during the Last Glacial Maximum in New Zealand.

The remainder of the day focused on the 'recent advanced in Quaternary geochronology' with an excellent keynote summary by **Kirsty Penkman** (York) into the developments, advances and results of amino acid dating. Two further talks from the University of York by **Marc Dickinson** and **Lucy Wheeler** focused on developing chronologies using intra-crystalline protein in mammalian enamel, and in foraminifera applied to Quaternary sea-level records, respectively. The final talk of the day was by **Diana Sahy** (BGS) on the age of methane-derived authigenic carbonates at seafloor cold seeps on the U.S. Atlantic Margin. The first day of the meeting closed with the QRA Annual General Meeting, during which Yorkshireman **Jim Rose** was awarded the James Croll Medal (in Yorkshire!) for his outstanding contribution to the field of Quaternary Science; and **Natasha Barlow**, 2020 ADM co-organiser and Leeds Quaternary co-leader was awarded the Lewis Penny Medal.

Day 2 started with keynote speaker **James Rae** (St Andrews) starting the 'Quaternary carbon cycling' session with his talk on high latitude controls on glacial CO_2 and climate. **Charles Maxson** (Nottingham) highlighted his work on a Holocene carbon isotope record from Queensland, Australia and **Craig Smeaton** (St Andrews) presented a summary of the spatial heterogeneity of sedimentary carbon in mid-latitude fjords. The session was concluded by an excellent presentation by **Ben Fisher** (Leeds), on his Masters research into the implications of carboxylic acids for the preservation of iron associated organic carbon in the seafloor. It is great to be able to provide a platform to researchers right at the start of their careers to present their work.

The coffee and lunch breaks in the iconic Parkinson Building provided a fantastic opportunity to mingle with colleagues and explore the wide range of posters on topics including using Bayesian methods to learn about past ice sheet shapes (**Fiona Turner**, Sheffield), oceanography records from the Uruguayan margin (**Andrew Mair**, Leeds), the application of testate amoebae in Colombian peatlands (**Bing Liu**, Lehigh USA), southern hemisphere storminess during the last deglaciation (**William Roberts**, Northumbria) and HadCM3 modelling of North African precipitation (**Katie Cupples**, Birmingham). On display was coring, water and field equipment by meeting sponsors Van Walt, and the QRA sponsored VR Glaciers and Glaciated Landscapes by **Des McDougall** (Worcester). Little did any of us know this would likely be the last in-person meeting any of us would attend for some time, certainly the last finger buffet we would be allowed to share and how much we would need to make use of Des' virtual field trips!

Following coffee, the fourth session 'Ecosystems' was kicked off by keynote speaker **Angela Gallego-Sala** (Exeter) who summarised the challenges and opportunities that global peatland carbon present. **Paul Morris** (Leeds) presented the spatiotemporal dynamics of Holocene fen-bog transitions in northern peatlands and **Mariusz Gałka** (Lodz, Poland) a summary of sphagnum succession in mountain peatland ecosystems across central and western Europe. Another excellent presentation of Masters research into the drivers of palsa distribution in North America was given by **Richard Fewster** (Leeds). Following lunch, **Dylan Young** (Leeds) pointed out the potential to misinterpret carbon accumulation rates in records from near-surface peat. **Graeme Swindles** (Leeds) presented his work into Leeds' local peatland at Ilkely Moor, with a multiproxy palaeoecological record from a contemporary refugium. This was joint piece of work led by Leeds Quaternary and the University of York, and we wish to remember the contribution of the late **Richard Payne** (York) to this research. The session closed with **Rosie Everett** (Warwick) on the challenges of contextualising multi-proxy taphonomic processes in understanding past ecosystem dynamics.

The final session of the day, 'Quaternary science for the Earth's future' was introduced by **Matt Jones** (Nottingham) who presented work on palaeobenchmarking resilient agricultural systems. **Paul Valdes** (Bristol) gave a provocative and though-provoking keynote asking 'Does Quaternary Science help predict the future?', which lead to some interesting discussions during the evening social events. **Peter Hopcroft** (Birmingham) highlighted the application of climate model parametrisation to the termination of the African Humid Period. The QRA is fortunate to have regular contributors from outside of academia and **Paul Fish** and **Tom Berry**, both from Jacobs, highlighted the use of Quaternary science in applied settings, both in the management of nuclear waste on the Cumbria coast, and engineering guidance for hazard mitigation in relict periglacial landscapes.

The Leeds City Museum holds the remains of the Leeds hippopotamus, which is the logo for the Leeds Quaternary research group. The bones were unearthed in 1851 in a brick field in south west Leeds and have been dated to the Last Interglacial. We are grateful to the City Museum for hosting several private visits to the Leeds hippo for many of the delegates. It was then only right that a QRA ADM held in West Yorkshire hosted the conference dinner at a curry house, and many attendee's enjoyed a wonderful meal at the Michelin-recommended Tharavadu, where we also said goodbye to Graeme Swindles as he departed the University of Leeds for Belfast.

The final day of the conference focused on 'state shifts and abrupt changes'. The first session saw the presentation of several new palaeo datasets including state shifts in permafrost since the Middle Pleistocene in Siberia by **Julian Murton** (Sussex). Focus then moved to lakes with **Adrian Palmer** (Royal Holloway) presenting his work on developing British distal glacial lacustrine varve records as high resolutions achieve of abrupt climate change, **Jonathan Dean** (Hull) on rapid shifts in Turkish lakes during the late glacial-Holocene climatic transition, and **Alastair Curry** (Hertfordshire) exposed the secrets of the Lady of the Lake with a 11,000 history of talus erosion in the Brecon Beacons. The pre-coffee session finished with a Northern Hemisphere terrestrial climate dataset for the past 60,000 years by **Edd Armstrong** (Bristol). Wiley-sponsored keynote speaker, **Camille Li** (Bergen, Norway), gave a wonderful summary from the crossroads of atmosphere-ice-ocean mechanisms for abrupt climate change. The session was closed with talks by **Louise Sime** (BAS) on the impact of abrupt sea ice loss on Greenland water isotopes during the Last Glacial Period and **Lauren Gregoire** (Leeds) on the role of ice sheet dynamics during the 8.2 kyr event. Finally, **Mark**

Bateman (Sheffield) bought us back to Yorkshire with his evidence for abrupt shifts in ice advance during MIS 3.

We thank the QRA for the opportunity to host the ADM at the University of Leeds. We apologise for the delay in this meeting report due to the COVID pandemic that not long after swept the world, and we look back fondly to in-person meetings and a drink shared with friends and colleagues, which we hope some day to be able to safely return to.

Natasha Barlow

On behalf of Leeds Quaternary and the organising committee of Ruza Ivanovic, Christian März, Paul Morris, Graeme Swindles (now Belfast), Karen Bacon (now NUI Galway), Luis Rees-Hughes, Andy Emery (now GDG), Niall Gandy, Thomas Sim and Jenna Sutherland (now Leeds Beckett).

2021 QRA ANNUAL DISCUSSION MEETING, LANDSCAPES OF CHANGE: PAST, PRESENT, AND FUTURE PERSPECTIVES

University of Portsmouth, 6th-8th January 2021

The 2021 Quaternary Research Association Annual Discussion Meeting (ADM) was hosted by the School of the Environment, Geography and Geosciences, University of Portsmouth, organised and convened by **Clare Boston**, **Sabine Wulf**, **Mark Hardiman**, **Harold Lovell,** and **Tim Barrows**. This was the first QRA ADM to be held virtually. The meeting totalled 275 registrations, almost 50% of attendees and speakers were women, ~25% of registrations were PhD students, and ~13% were early career researchers. There were 42 talks and 12 posters presented by participants from institutions across the UK, and from Europe, India, China, Morocco, Iraq, the Canary Islands, Brazil, and the USA, making this one of the most international ADMs to date. Moreover, the combination of an online conference format and waivered registration fees increased wider accessibility and participation, attracting a number of attendees not affiliated with the QRA. Despite the challenges of organising an online meeting, the 2021 ADM proved to be an outstanding success.

The ADM focused on Landscapes of Change: Past, Present, and Future Perspectives. Landscape evolution and environmental response to climate change present new societal and ecological challenges. Disentangling the processes leading to, and mechanisms behind, landscape evolution during the Quaternary are key steps towards understanding future environmental change. As such, the aim of this year's ADM was *to explore the role of landscape change within a wide range of Quaternary-related sub-disciplines*. To address this, the meeting was split into five themes:

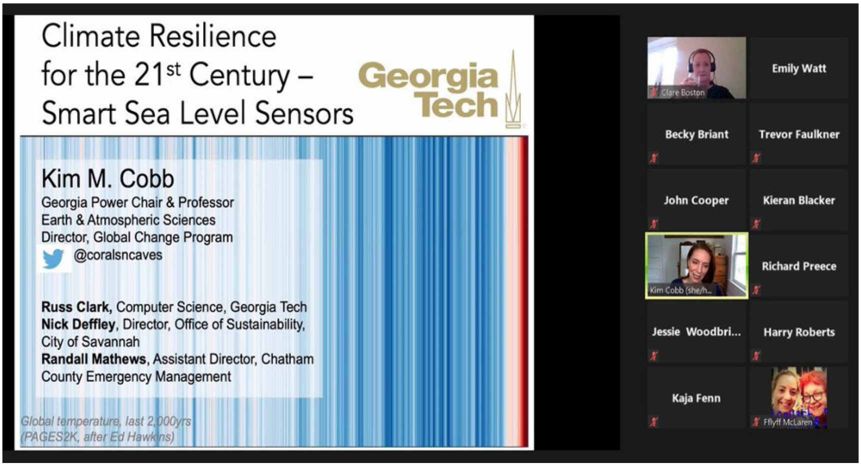
- Changing Coastal and Marine Environments
- Towards the Future
- Abrupt Environmental Change and Extreme Events
- Human-Landscape Interactions
- Evolving Landscapes

Day one of the conference opened with the ***Changing Coastal and Marine Environments*** session, chaired by **Mark Hardiman** (University of Portsmouth). It began with a keynote address by **Natasha Barlow** (University of Leeds), who demonstrated that by integrating sediment records with offshore geophysical surveys, there are now numerous opportunities to provide significant progress towards wider understanding of North Sea environmental and sea-level change. This sparked discussion of the recent availability of open-access offshore datasets, how we can encourage companies to engage and release this data, and the potential for its broader use by the Quaternary community. Next up, **Michael Grant** (University of Southampton) discussed reconstructions of past landscapes of the Bulgarian Shelf. This work identified that chemostratigraphy, palaeomagnetics, and tephra may improve dating of Black Sea records, alleviating issues with complex radiocarbon reservoir conditions. Furthermore, the researchers extended the distal ranges of Mediterranean cryptotephra into the western Black Sea area. **Tim Atkinson** (University College London) ended the first half of the session with discussion of exposure-age dating of marine gravels located on a chalk escarpment at Little Heath, the Chilterns. The deposit was found to be likely Pliocene in age, correlating Little Heath with the Red Crag in Essex. As these deposits were formed close to sea level, new ages allowed average uplift rates to be calculated.

Following the coffee break, an invited talk by **David Thornalle**y (University College London) kicked off the second half of the session with discussion of the North Atlantic, a key area for understanding global climate change and ocean circulation. Findings included: a strong early-Holocene Atlantic Meridional Overturning Circulation (AMOC), despite increased meltwater influx at this time, a weak industrial era AMOC, and a unique Holocene contraction in the subpolar gyre, with implications for our broader understanding of AMOC, climate change, and management of fisheries and fishing stocks. In particular, this highlighted the need to engage with policymakers, and disseminate community research findings to the wider public. Following this, **Oliver Pollard** (University of Leeds) took us back to the North Sea, incorporating earth rheology, geometry, and ice mass into a sea level model to examine relative sea level change in the North Sea basin. The model showed greatest sensitivity to changes in upper mantle viscosity. **Víctor Cartelle** (University of Leeds) compiled lithostratigraphic information from offshore boreholes and vibrocores to study the distribution and character of last Interglacial deposits in the southern North Sea. This provided a more comprehensive picture of regional last Interglacial landscape evolution. **Andy Emery** (University of Leeds) then discussed research that incorporated seismic reflection surveys, geotechnical logs, and sediments to reconstruct landscape evolution at Dogger Bank. This revealed the role of sea level versus existing topography in marine inundation of the site, illuminating a series of events beginning with terrestrial exposure, marine transgression, and eventual complete marine inundation by the mid-Holocene. **Patrick Robson** (Aberystwyth University) ended the first session with research presented as part of the CHERISH (Climate, Heritage and Environments of Reefs, Islands and Headlands) Project, aiming to tackle past, present, and future challenges of climate change and extreme weather events on the Welsh and Irish coasts.

Following the morning sessions, we took a break to enjoy lunch and engage with some breakout group networking. This functioned well, facilitating small group discussions, and would work nicely for any future online meetings. Following the lunchbreak, the second session of the day was ***Towards the Future***, chaired by **Clare Boston** (University of Portsmouth). The session was opened with the **Wiley Lecture** given by **Kim Cobb** (Georgia Institute of Technology, USA) who discussed the application of a low-cost network of Smart Sea Level Sensors for flood forecasting along the Georgia coastline. A transdisciplinary project that focused on climate resilience, and community and stakeholder-driven science. Over 50 sensors were installed enabling the assessment of coastal flood risk, and the development of more direct flood planning and mitigation strategies. This project really highlighted the need for community engagement, and interdisciplinary research to communicate goals and deliver measurable impact. Following on, we had an invited talk by **Andrew Newton** (Queen's University Belfast) who discussed the efficiency of carbon capture and storage in the North Sea. By mapping the Quaternary deposits of the North Sea, an assessment of site suitability was completed. This identified underlying Quaternary deposits that may facilitate fluid flow from carbon reservoirs and risk leakage. **Harry Roberts** (University of Lincoln) then presented preliminary results from ongoing work at Crowle Moor, North Lincolnshire, which aims to understand: 1) fire history and its influence on peatland, 2) climate history, and its effect on fire patterns, and 3) changes in carbon sequestration through time. Before the break, the final speaker was **Jessie Woodbridge** (University of Plymouth) who discussed two ongoing projects. Firstly, a project addressing interactions between climate and land-use in Anatolia, which investigated the relationship between humans and vegetation change. The second, a project addressing the use of past environmental change on informing water usage, conservation, and drought in southern Turkey. The second will develop palaeoenvironmental records, and use stakeholder interviews and education to understand water resource use and barriers to management.

Following a short interlude, the second half of the session aimed to highlight the wide range of virtual resources available to the Quaternary community, a dominant topic in light of the ongoing barriers to practical teaching. The first talk was presented by Liz Hurrell (University of Central Lancashire), Simon Hutchinson (University of Salford) and Jane Bunting (University of Hull) who discussed virtual laboratory and fieldtrip resources (ViPs) for palaeoenvironmental teaching, an initiative developed in response to the pandemic. The aim of ViPs was to collate existing resources, provide support, upskilling and expertise, and to provide a central location for sharing assets. An example of a virtual fieldtrip to the Peak District, which utilised Google Earth and GoPro footage, displayed one of the multiple ways this could be implemented. Steve Juggins (Newcastle University) and Jane Bunting (University of Hull) then discussed the eSlide Project, a virtual microscope used for teaching microfossil identification, a product originally designed in 2009 to prepare students for microscopy practicals. The software has been updated and can now change focus, count slides, and run on multiple platforms. Next up was Derek McDougall (University of Worcester) who discussed VR Glaciers and Glaciated Landscapes. The site provides a ground-level, virtual fieldwork experience, and includes 13 freely available field trips that can be used to support in-class teaching of glaciers and glaciation. The session was closed by Becky Briant (Birkbeck, University of London) and Annie Ockelford (University of Brighton) who advocated use of Google Jamboard for aiding online teaching. The tool is a collaborative online whiteboard that allows multiple groups to work consecutively, and students to stay anonymous, alleviating the pressure of targeted questions and promoting student engagement. In particular, these talks highlighted just some of the many tools becoming available through the hard work of theary community, and the new and innovative ways we can engage and support students in higher education.



Kim Cobb discussing the deployment of a network of Smart Sea Level Sensors in Georgia

The second day of the conference began with the ***Abrupt Environmental Change and Extreme Events*** session, chaired by **Sabine Wulf** (University of Portsmouth). The day started with the **QRA Lecture**, given by **Achim Brauer** (Potsdam University, Germany) who provided an overview of varved sediments as high-resolution archives of climate and environmental change, highlighting that abrupt events and extreme floods are often well preserved in these records. Next up, **Chris Satow** (Oxford Brookes University) investigated the role of sea-level on the eruptive history of the Santorini Volcano, an ideal site due to its complete and well-dated stratigraphy. Geophysical modelling implied that the timing of eruptions at Santorini are strongly influenced by sea-level, and eruption

Enjoying a virtual trip to Col du Sanetsch via VR Glaciers and Glaciated Landscapes

frequency intensifies with lower absolute sea level. **Kristen Beck** (University of Lincoln) then discussed a Pleistocene diatom record from a lake at Darwin Crater, Tasmania. Transitions in the diatom record were found to be driven by one species, and diatom cell size fluctuated between glacial and interglacial periods. **Amy McGuire** (University of Cambridge) then finished off the first half of the session with a vegetation record from Ioannina, Greece. A site with well-preserved tephra and pollen. The pollen record expressed fewer expansions and contractions than there are interstadials and stadials in the Greenland record. It is possible that this trend is due to the site's unique ecology, topography, and microclimates.

Following the break, we began with an invited talk by **Celia Martin Puertas** (Royal Holloway University of London) who presented evidence for increased windiness at ~2.8 ka from two lake sites: Meerfelder Maar, Germany, and Diss Mere, UK. Evidence provided by the varve thickness record (Meerfelder Maar) and diatom record (Diss Mere) suggested the onset of windiness occurred both in continental Europe and the East Atlantic region during the Grand Homeric minimum. **Patricia Piacsek** (Universidade Federal Fluminense, Brazil) then presented a reconstruction of low-latitude ocean-atmosphere dynamics over the last 130,000 years based on Alnus pollen. They suggest that periods of strengthened northeast trade winds restrained the North Brazilian Current, with Alnus pollen presence reflecting these transitions. **Emma Hocking** (Northumbria University) then discussed the occurrence of an unreported Chilean tsunami accompanying an earthquake in 1737. The tsunami was caused by an offshore rupture and evidenced in tidal marsh sediments by sand deposits of a marine source. The session was brought to a close with an invited talk by **David Sear** (University of Southampton) who discussed the relationship between climate forcing and human migration into the Tropical Pacific, investigated through island lake cores. Data may suggest a pause between island discovery and colonisation, and that a regional dry phase may have reduced resource availability and instigated human migration from Samoa and Tonga to eastern Polynesia.

Following the lunchbreak, the Annual General Meeting and awards ceremonies were chaired by **Helen Roe** (Queen's University Belfast) and **Simon Lewis** (Queen Mary University of London). The **Undergraduate Dissertation Prize** was awarded to **Ellie Day** (University of Durham) for her dissertation titled: *A sedimentological reconstruction of the glacial history of Happisburgh, Norfolk, through Marine Isotope Stage 12*. This year's runner up was **David Warnes** (Newcastle University) for his dissertation titled: *A chironomid record of Late-Glacial and Holocene palaeotemperature from Lake Kascadnoe-1 in the Sayan Mountains, Southeast Siberia*. The **Quaternary Research Award** went to **Cathy Delaney** (Manchester Metropolitan University) for a project investigating Irish Ice Sheet ice dynamics during onshore retreat, Last Glacial Termination. The **Lewis Penny Medal** went to **Andrew Newton** (Queen's University Belfast), and the **James Croll Medal** went to **Richard Preece** (University of Cambridge). A thoroughly deserving set of recipients, and congratulations to all!

Following the Annual General Meeting and prize giving, the day was brought to a close with two hours of poster sessions across the five themes. Small group sessions facilitated targeted and engaging discussions for presenters, and showcased the wide variety of research within the Quaternary community. In the ***Changing Coastal and Marine Environments*** session, **David Jarman** (Mountain Landform Research) presented on rock slope failure clusters around the coast of Scotland, with likely links to glacial erosion and tectonics. **Zuzanna Swirad** (Scripps Institution of Oceanography, USA) modelled 7000 years of coastal cliff retreat in North Yorkshire using ^{10}Be concentrations to determine the rate and pattern of erosion. **Zelna Weich** (University of Cambridge) discussed a sea surface temperature reconstruction and planktic foraminifera assemblage from the Agulhas Bank, near southern Africa. In the ***Towards the Future and Human-Landscape Interactions*** session**, Adam Jeffery** (Keele University) presented a virtual platform in which to undertake microscopy work via Thinglink. **Katie Gunning** (University of Lincoln) discussed the ecosystem impact of de-silting agents by examining relationships between trophic statuses, food webs, and macrophyte communities, and **Nick Schafstall** (Czech University of Life Sciences, Czechia) presented a 1400-year pollen, geochemical, Coleoptera and charcoal record from Tatra National Park, Slovakia, to investigate natural disturbances and establish environmental baselines.

The ***Abrupt Environmental Change and Extreme Events*** session featured presentations from: **Daniel Howlett** (University of Portsmouth) who discussed a reconstruction of abrupt environmental changes from, Munsley Bog, Isle of Wight, covering the Late Glacial and early-Holocene. **Dale Tromans** (University of Chester) who presented multiple oscillations in organic and carbonate content and diatoms from a lake sediment core in the Dinaric Alps, and **Amy Walsh** (Royal Holloway University of London) who presented a Holocene tephrostratigraphy linked to a varve chronology from Diss Mere, extending the known distributions for multiple cryptotephras. In the ***Evolving Landscapes*** poster session, **Henk Cornelissen** (University of Manchester) presented results from a study that will address the Holocene formation history of a montane wetland system on the Yagour Plateau, Atlas Mountains. **Emma-Louise Cooper** (Royal Holloway University of London) described glacial geomorphological mapping and glacier dynamics from three valleys in north-central Patagonia. Last but not least, **Benjamin Pennington** (University of Southampton) discussed the gradual aridification of the Egyptian Sahara between 5000-4000 cal yr BP from XRF data on Nile Delta sediments, drawing day two of the conference to a close.

The third and final day of the conference began with the ***Human-Landscape Interactions*** session chaired by **Mark Hardiman** (University of Portsmouth). The day started with a keynote address by **Ralph Fyfe** (University of Plymouth) who presented results of a project to synthesise biodiversity change within the British Isles using existing pollen datasets. Results reflected significant relationships between human population and vegetation diversity, vegetation diversity and climate, and highlighted that population may be less prevalent in driving diversity change than the types of land use being employed. **Julia Unkelback** (University of Göttingen, Germany) then discussed results of a multi-proxy investigation of two sites in the Mongolian Altai, investigating the drivers of environmental change and influence of human populations. Natural climate variations and human activities both drove environmental changes, with human activity playing a key role in this turnover. **Benjamin Pennington** (University of Southampton) then took us back to ancient Egypt to investigate the landscape evolution of the Nile Delta, and its wider implications on ancient Egyptian society. 1500 borehole records allowed for the reconstruction of Nile Delta evolution between 8000-4500 BC. It was found that changes in human settlement patterns and the development of the ancient Egyptian state was strongly linked to evolution of the Nile Delta, which became agriculturally and economically viable, and a key point of power for the regional elite. **Farha Zaman** (Dibrugarh University, India) then discussed the significance of historical ponds in the Brahmaputra Valley, India, during the Ahom Era. The ponds were constructed in marshy lands that tap into underlying aquifers, and provided a water resource that has never dried up. **Abi Stone** (University of Manchester) then finished off the first half of the session with a discussion of tufa formation at a near-coastal site on the Arabian Peninsula. The age of deposits was found to be broadly interglacial, and revealed a wetter environment than present at the time of formation. This may have provided favourable conditions for the dispersal of *Homo sapiens*.

Althea Davies addressing the questions: are we making a difference?

Following the coffee break, **Jaafar Jotheri** (Al-Qadisiyah University, Iraq) began the second half of the session with a talk investigating the palaeoshorelines and deposits in the Najaf Sea, western Iraq. Sedimentological results from eight test pits at three sites were presented. **Michela Mariani** (University of Nottingham) then discussed pollen modelling and charcoal datasets to assess relationships between land cover and fire activity in southeast Australia. Data analyses suggested that the disruption of indigenous wildfires had promoted unprecedented activity in recent years due to a change in vegetation and forest fuel availability. **Alvaro Castilla-Beltrán** (Universidad de la Laguna, Canary Islands) then discussed geochemical, pollen, and spore data from southern Macaronesia to assess local response to climate and human disturbance. Initial results suggest that palaeofires occurred pre-human occupation with no lasting affects on vegetation structure, and that erosive events were associated with the African Humid Period, as well as the arrival of human occupants. **Francis Rowney** (University of Plymouth) then discussed the Reclaiming Exmoor Project, which combines palaeoecology, environmental archaeology, and historical documents to assess ecological processes and their relationship with human activities on Exmoor. The project will use palaeoecology to inform ongoing restoration activities. To round off the session, **Althea Davies** (University of St Andrews) presented an invited talk that examined palaeoecology and whether this is making a difference to wider policy and practice. In particular, the talk highlighted the need for researchers to better understand the priorities, constraints, and working practices of their audience, in order to provide stronger contributions outside of academia.

After lunch, we moved on to the fifth and final session of the conference, the ***Evolving Landscapes*** session, chaired by **Harold Lovell** (University of Portsmouth). The first talk of the session was a keynote address by **Alice Doughty** (University of Maine, USA) who discussed evidence to suggest that MIS 4 glacial advances may have been more extensive than those of MIS 2, based on moraine ages from numerous sites across the globe. Local, catchment-related, or topographic controls cannot explain this global synchronicity in ice extent. Likely explanations are that either 1) temperature was colder in MIS 4 than MIS 2, or 2) temperature in MIS 4 was as cold as MIS 2, but climate was wetter. **Matt Tomkins** (University of Manchester) then analysed the effect of moraine boulder position on exposure-ages, demonstrating that suitable boulders were distributed randomly across the landform, with no clear increase in sample suitability associated with moraine crest sampling over slope sampling. Instead, he argued that landform stability is of greater importance than boulder characteristics. **Benjamin Boyes** (University of Brighton) presented an impressive, high-resolution, glacial geomorphological map of the Kola Peninsula and Russian Lapland, northwest Arctic Russia. Mapping comprised 245,584 glacial landforms, including 66,000 subglacial bedforms, multiple new ice limits, and evidence for ice-dammed lakes. This provides a strong basis for subsequent modelling and regional reconstructions. The last talk before coffee was given by **Della Murton** (University of Cambridge) who discussed variations in sediment colour and the processes and pathways that may explain colour differences, with a focus on the origin and distribution of reddish-brown sediments in the Vale of York. In the deeper areas of the basin, origin may be colluvial transport of periglacially weathered bedrock. In shallower parts of the basin, sediments may indicate incursions from the proto-Trent.

Following the break, **Bethan Davies** (Royal Holloway University of London) kicked off the second half of the session by discussing Little Ice Age to present-day glacier extent, morphology, and dynamics of the Juneau Icefield, Alaska. These glaciers are particularly susceptible to rapid equilibrium line altitude changes brought about by rising temperatures, which have caused increasing detachment of glaciers from their tongue since 2005. Data shows that detachment encourages downwasting and stagnation of the detached glacier tongues, which has not been accounted for in modelling of global ice volume evolution. **Daniel Le Heron** (University of Vienna, Austria) discussed monitoring of the Gepatsch Glacier, Austria. Annual and daily monitoring of the glacier forefield revealed that the glacier forms annual moraines, and had formed flutings in the last three years. In the short-term, structures are cannibalised by the glacier or reworked by younger geomorphological processes. Monitoring provided new insights into the timing and rates of erosion and sediment cannibalisation at the glacier forefield. **Rebecca Schlegel** (Swansea University) followed on by discussing use of a radar system to characterise bed properties below the Rutford Ice Stream, West Antarctica. Water was found overlaying soft sediments, on the crest of subglacial landforms. The water may be linked to the formation process of these landforms

Alice Doughty discussing the evidence and causes of a global maximum **ice extend during MIS 4,**

or may be trapped due to spatial variability in sediment permeability. Lastly, the final speaker of the session, and the conference, was **Hellen Hallang** (Swansea University) who finished off with an environmental reconstruction of the slopes of Galdhøpiggen, Norway, since ~4,300 cal yr B.P, showing a transition in the tree line and lower permafrost limit occurred over the course of ~4000 years.

Clare Boston (University of Portsmouth) closed the conference, rounding up a fantastic three days of presentations. Amidst what has been a difficult year, all participants, speakers, and organisers had a fully enjoyable and enriching experience. A big thank you goes out to the organisers of the 2021 QRA ADM **Clare Boston, Sabine Wulf, Mark Hardiman, Harold Lovell, and Tim Barrows** for pulling together a thoroughly engaging ADM for all involved. We hope to see you all in person at the **2022 QRA ADM: Quaternary Glaciations: Processes, environments, and reconstructions** at the **University of Sheffield!**

Emma Cooper
Centre for Quaternary Research
Royal Holloway University of London
Egham, Surrey, TW20 0EX
emma.cooper.2013@live.rhul.ac.uk

IS THERE ANY STRATIGRAPHIC EVIDENCE OF THE STOREGGA TSUNAMI REACHING BUDLE BAY, NORTHUMBERLAND?

Background/ Rationale

Regarded as one of the world's largest submarine landslides, the Storegga slide occurred on the continental slope, west of Norway between 8200 and 7900 cal. yr BP. The slide produced a tsunami which reached onshore elevations of 10-12m in western Norway, 20m on the Shetland islands and 3-6m in northeast Scotland (Bondevik *et al*., 2005). Deposits from the Storegga tsunami have been found in the coastal areas of Norway, eastern Scotland, Shetland and Faeroe Islands, and North East England (Dawson *et al*., 2011; Dawson *et al*., 1988; Leynaud *et al*., 2009). Despite previous studies being undertaken within North East England, inconclusive evidence remains for whether the Storegga Slide is recorded on the Northumberland coast. Establishing the age of any coarse-grained material interpreted as being deposited by the tsunami associated with the Storegga Slide is essential in order to confirm correlation with this event and rule out deposition of another high-energy event.

Results and Discussion

Upon being granted the 14 Chrono Centre Radiocarbon Dating Award by the Quaternary Research Association (QRA), three samples were submitted to the Belfast CHRONO centre; one marine shell and two wood fragments (see results in Table 1). Depths of extracted samples in relation to recovered cores are shown in Figure 1.

UBA No	Core and Depth (bgl)	Material Type	^{14}C Age (yr. BP)	Calibrated yr. BP (95.4%)
UBA-39041	BU18/2 (74cm)	Shell	7239± 27	5653- 5913
UBA-39042	BU18/2 (244cm)	Wood	7570± 49	8214- 8454
UBA-39043	BU18/7 (272cm)	Wood	7344± 40	8025- 8302

Table 1: AMS Radiocarbon Dating Results. The shell sample was recalibrated using a local marine calibration curve (MARINE13) (Russell *et al*, 2015) and both wood samples were calibrated using the terrestrial calibration curve (IntCal13).

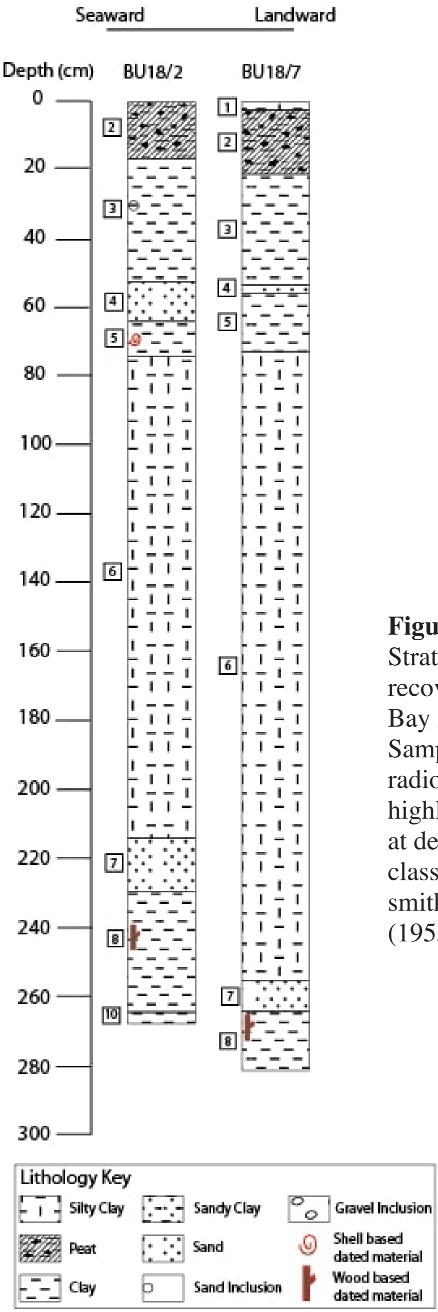


Figure 1: Recorded Stratigraphy of two cores recovered from Budle Bay in Northumberland. Samples submitted for radiocarbon dating are highlighted by type and at depth. Lithology was classified using Troels-smith Classification (1955).

Results of radiocarbon samples UBA-39042 and UBA-39043, which were sampled below the suspected Storegga tsunami layer (Unit 7 in Figure 1), have produced calibrated age ranges within that of the Storegga Slide's occurrence. UBA-39041, which was sampled below another identified sand layer (Unit 4 in Figure 1), produced a calibrated age range younger than that of the Storegga tsunami.

Particle size analysis conducted on Core BU18/2 shows a high energy event associated with Unit 7 (see Figure 2) due to high percentages of sand particles. Diatom analysis also supports Unit 7 being attributed to a high energy event as identified diatoms are predominantly fragmented and marine in origin (see Figure 3) (Dawson *et al*., 1996; Dawson and Shi, 2000). Both analyses produced results that are characteristic to identified Storegga tsunami deposits within the United Kingdom (Smith *et al.,* 2004).

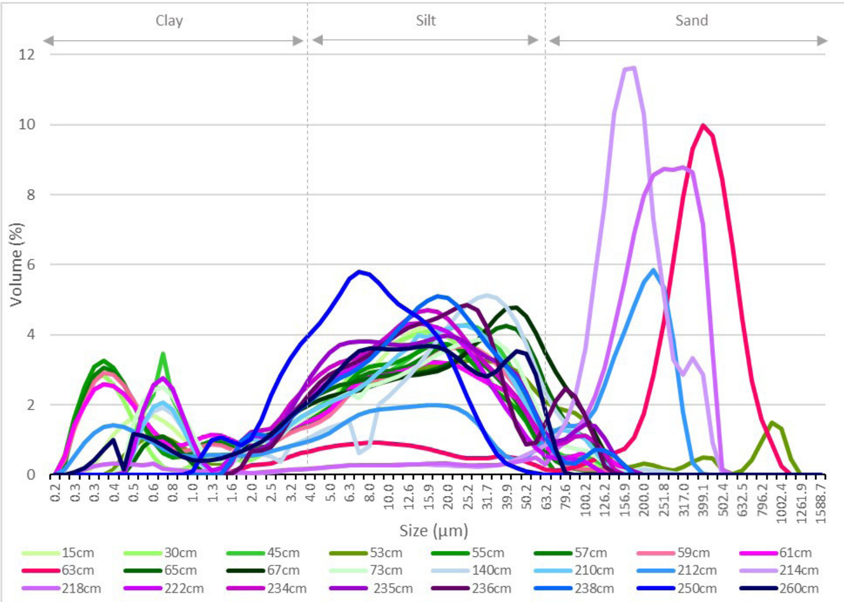


Figure 2: Particle Size analysis from one core (BU18/2) taken at Budle Bay. Colouration related to different stratigraphy and depositional environment; Unit 2 (Green), Unit 3 (Green), Unit 4 (Pink), Unit 5 (Green), Unit 6 (Blue), Unit 7 (Purple), Unit 8 (Blue). Green represents a freshwater environment, pink a high energy environment, purple represents the Storegga tsunami and blue a marine *environment*.

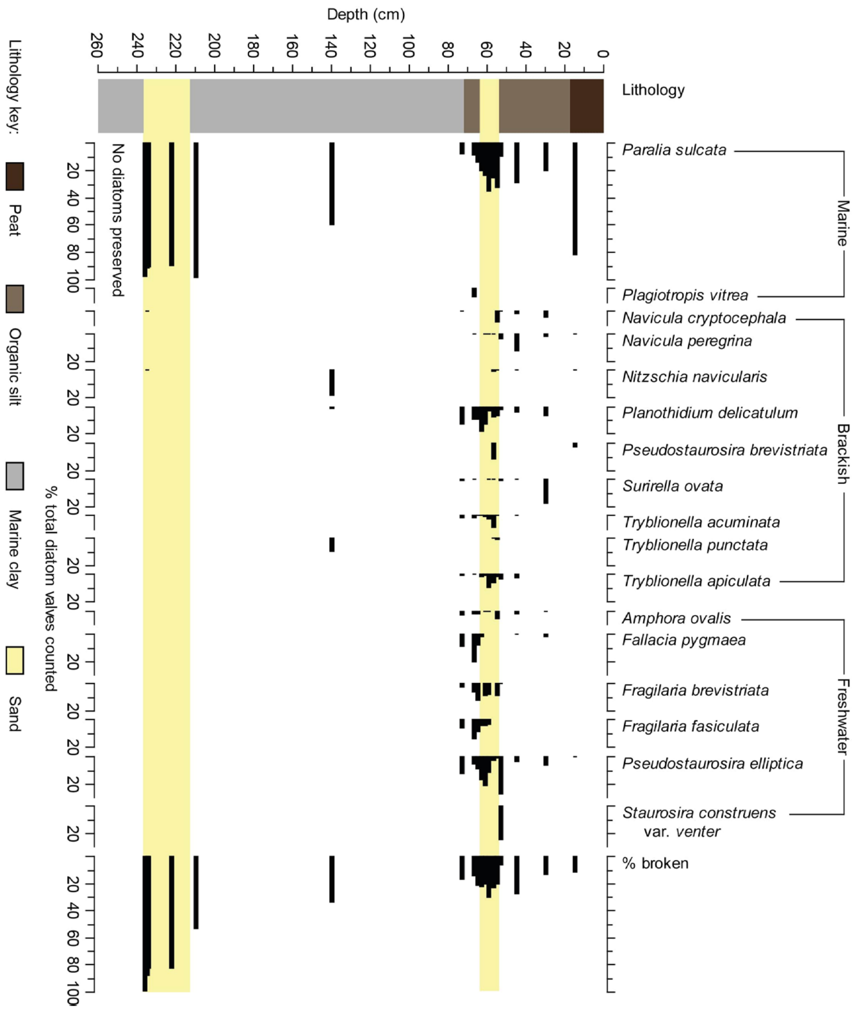


Figure 3: Diatom Analysis of Core BU18/2. All species presented were present above 5% in each sample.

Significance

As a result of the QRA grant, dating the two sand layers within Core BU18/2 was possible. Using these dates alongside multiproxy analyses have provided strong evidence suggesting that the Storegga tsunami reached Budle Bay in Northumberland.

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Leeza Pickering
Department of Geography and Environmental Sciences
Northumbria University, Ellison Place, Newcastle upon Tyne, NE1 8ST
pickering.leeza@gmail.com

Dr. Emma Hocking
Department of Geography and Environmental Sciences
Northumbria University, Ellison Place, Newcastle upon Tyne, NE1 8ST
emma.hocking@northumbria.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:

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

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