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QUATERNARY NEWSLETTER

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Instructions to authors

Quaternary Newsletter is issued in February, June and October. Articles, reviews, notices of forthcoming meetings, news of personal and joint research projects etc. are invited and should be sent to the Editor. Closing dates for submission of copy (news, notices, reports etc.) for the relevant numbers 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

Vista of the north Pennines (photo David Evans) (see report of the QRA fieldtrip in this issue)..

SPOTLIGHT ON A SITE

QRA50: TOP 50(80) QUATERNARY SITES – SPOTLIGHT ON A SITE: SEWERBY RASIED BEACH, YORKSHIRE, ENGLAND.

This autumn, as we celebrate the life of Mary Penny and in doing so remember Lewis Penny, in whose memory the QRA Lewis Penny medal was established, the site from the QRA50 (Silva and Phillips, 2015) that we highlight is the Last Interglacial Raised Beach at Sewerby in East Yorkshire.

Photo 1 Sewerby raised beach site with relict beach at the bottom against chalk paleocliff (behind spade), with till and sewerby sands and gravels at the top (Photo: M. Bateman).

Here is a summary of the entry for Church Moor from Silva and Phillip (2015, p87-88):

This top site has year round public access and encompasses many aspects of Quaternary science, representing a complete interglacial-glacial cycle.

At the base of the sequence is interpreted as a raised beach banked against a palaeocliff-line from higher sea-levels during MIS 5e.

Above this is a unit of what were coastal dunes, formed during a regression of sea-level, dated to 120 ± 12 ka using luminescence dating (Bateman and Catt, 1996). This unit contains a diverse mammalian fauna assemblage, including elephant, hippopotamus and rhinocerous.

Overlying this are periglacial colluvium and then the Skipsea till, representing the extension of the Last British Icesheet at the Last Glacial Maximum (Bateman *et al*., 2011).

At the top of the sequence are the Sewerby sand and gravels, containing periglacial ice-wedge features, and topped with a Holcoene soil.

References (and key sources for the site)

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OBITUARY

JOHN TREVOR HOLLIN (1930 – 2016)

With the death of John Hollin on 3 October, 2016, Quaternary Science has lost one its global pioneers and mega thinkers. George Denton has recorded that even in the 1960s John was 'one with great insight into how the ice-age world worked'. The areas of his main research may be summarised as: (a) glacier profiles and their reconstructions, (b) Last Interglacial sea-levels and implications for Antarctica and global climate, and (c) Palaeozoic cyclic sedimentation and coal deposits.

John was a very engaging character, modest in the extreme, charming, witty, well informed and someone who one instantly one took a liking to. Apparently in his middle school years he was known as 'Cherub' due to his angelic face. Although extremely talented he lacked a definite career plan and became a professional 'Research Associate' living primarily on 'soft money' related to research contracts etc. He even described himself as a 'gypsy scholar'. Sadly, he never married.

John was born on 25th October, 1930, the only son of Archie and Edith Hollin. He spent his early years in Derby before moving to Halifax and then to York where he attended Nunthorpe Grammar School. As was the norm in those days he did his compulsory two-year stint of National Service. He was assigned to the RAF which sent him to Austria where he learnt German and became of proficient skier. After discharge, he read geography at Oxford (St Edmund Hall) 1950-1953 followed by a one-year teaching diploma. Educationally, it seems that he did not value his Oxford degree experience, judging it a waste of time and expense, he even considered suing the University for taking money under false pretences. After Oxford, he was appointed as an instructor at the Outward Bound School Eskdale in the UK Lake District until 1957 by which time he had become Chief Instructor.

Being trained in the Scouts, having an outdoor disposition and excelling as a climber, he joined a Brian Harland led Cambridge expedition to Nordaustlandet Spitsbergen in 1951. Four years later he returned but on this occasion, he was the leader of a multidisciplinary group team of geoscientists which included Richard West and Joakim Donner. Richard recalls him being 'an excellent leader, always helpful and relaxed'. In 1957 his growing reputation as a glaciologist and logistical

expert led to an unexpected invitation to be chief glaciologist at the American Wilkes Station in East Antarctica during the International Geophysical Year (he replaced Olav Loken). Upon his return in 1959 he became a United States resident for virtually the rest of his life.

First, he worked at the Institute of Polar Studies at the Ohio State University in Columbus until 1961. Following the award of the Gibbs Fellowship, he spent 1963-64 at Yale before moving to Princeton where from 1964-70 he had both teaching and research assistant posts. During that time, he worked on his PhD dissertation '*Ice-sheet surges and interglacial sea levels*'. His doctorate was awarded in 1971. In the same year, he became an Associate Professor of Geological Sciences in Institute for Quaternary Studies, University of Maine at Orono. For 1974-75 he switched to work on the CLIMAP programme. He then moved to Boulder, Colorado where he was based until his passing. After spending two years at the National Oceanographic and Atmospheric Administration he moved to the Institute of Arctic and Alpine Research (INSTAAR) in the University of Colorado for the remainder of his career.

John was dealt with a major blow when, shortly after moving to Boulder, he was diagnosed as having Multiple Sclerosis. Fortunately, his form of the disease progressed relatively slowly such that he could maintain an independent life until his last few years. Nevertheless, strenuous field activities were curtailed although he never complained and maintained an amazingly cheerful positive disposition.

The writer (Peter Worsley) first met John at a meeting of the British Glaciological Society in Cambridge *c*. 1968. He was 'marketing himself' by offering to give lectures as he was searching for a permanent position in the UK. Consequently, I arranged for him to lecture in the Geography Department, University of Reading. He gave a superb talk on Carboniferous cyclothems and their possible linkage to repeated Gondwanaland ice sheet collapses. But alas, most in the audience knew little about Carboniferous stratigraphy and the geologists next door showed no interest so his visit must have been disappointing to him. We talked of the sequences in the Thames estuary as he was searching for stratigraphic evidence of a hypothesised Antarctic glacier surge related rapid rise in sea level towards the end of the Last (Eemian) Interglacial.

An abiding memory was his habit of constantly taking notes during conversation. He was extremely thoughtful and had an excellent memory. For example, I had talked of how railways rivalled Quaternary geomorphology during my time in Boulder in 1975. Many years later, out of the blue, he sent me a magazine featuring Colorado narrow-gauge railways.

I recall that in the early spring of 1974 Jean-Claude Dionne had organised a conference on 'Le glacial' (geological action of drift ice) in Quebec City. By coincidence we met at the General Wolfe statue, and being resident in Ottawa I was accompanied by my family. John was having a problem with the zip of his

trade-mark black anorak. The remedy was for my daughter Lucy (then just over a year old) to donate him one of her nappy pins, an event which was recalled often over the following years.

In the mid-1980s, I had moved to Nottingham and had invited John to give a seminar as he was on one his periodic trips back to the UK to see his mother then resident in York. At my home he met Lucy again, but unsurprisingly they could now talk. They got on like a house on fire and the conversation drifted into the topic of Arthur Ramsome, the author of the Swallows and Amazons books which are mainly set in the English Lake District. It turned out that they were both avid fans and John revealed that in his youth he had drawn his own map of the fictional north country lake setting using clues in the texts. Ransome had invented a fictional geography but it was inspired by Windermere and Coniston Water. John's intimate knowledge of the Lake District and his geographical skills were to the fore in his cartographic reconstruction. He had even corresponded with Ransome about his map. Later he kindly donated the map to Lucy along with Ransoms' letter of reply which she still retains.

Jim Rose also has had an analogous experience, with John giving seminars in the Department of Geography at Birkbeck College, University of London. Further, he recalls how, when his Quaternary class was in Mallorca examining raised beach deposits, John suddenly appeared out of the blue and asked if he could join the group, which of course he did. Over the next few days he charmed the students and greatly enhanced the excitement of searching for Last Interglacial raised beach deposits.

Over the years we had periodic exchanges of news, latterly by email. Two years ago, whilst on a visit to Colorado primarily to experience the narrow-gauge railways again, I factored in time to see John. Due to his MS, by now his mobility was restricted but his mind was 100%. He was anxious to learn first-hand what was happening in the British Quaternary scene and we talked for several hours over a range of Quaternary related issues particularly the vexed topic of intra Anglian – LGM glaciations. Clearly his heart still longed for the UK Quaternary and the Quaternary Research Association in particular. He regarded his essay review of 1996 in Arctic and Alpine Research of three new books on the British Pleistocene as his personal contribution to the multi-authored Lower Thames QRA Guide. I think he was disappointed that he had not had any direct feedback although this is possibly explained by his choice of publication. He also updated me on his background encouragement of global research into Last Interglacial shorelines. He was clearly frustrated that time was running out for him. He sought advice on the disposal of his extensive library; sadly the logistics of getting a lot of material relating to the UK back to where it would be highly valued proved intractable. He was concerned that the unpublished research results from the Oxford Spitsbergen expeditions might be lost. Finally, he discussed his enjoyment Lucy's history programmes on television, Arthur Ramsome and of course the

nappy pin. We mourn the passing of a wonderful human being.

I thank John Andrews, Jen Hall-Bowman, Jim Rose and Richard West for sharing their memories of John.

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MARY PENNY (1923 - 2017)

We mark the sad loss of Mary Penny, as a major benefactor to the Quaternary Research Association, through the Lewis Penny Medal (photo 1), set up in memory of her husband, following Lewis' passing in 2000. We refer readers to issue 93 of *QN* to read Lewis' obituary. He was a founding member of the Quaternary Field Studies Group (which later became the QRA in 1968). Lewis was the first Treasurer and Secretary of the QRA (then a joint post) from 1964-68 and the second President (1971-1973). The Lewis Penny Medal is presented to a young (normally less than 35 years old) or new research worker who has made a significant contribution to the Quaternary Stratigraphy of the British Isles and its maritime environment. The QRA are extremely grateful to Mary for her generous support of the QRA and of all the medal winners, who have made great contributions to the understanding of the Quaternary Science of the British Isles. Danielle Schreve (Royal Holloway, University of London) reminiscences here on the setting up of the medal and of her meetings and correspondences with Mary.

Following Lewis' passing in 2000, a medal fund in memory of Lewis had been set up under the guidance of John Catt and had raised £2542. It was agreed to round this figure up to £5000 at the September 2002 meeting of the QRA Executive. A meeting then was held between Danielle Schreve (QRA Awards Officer), Peter Allen (QRA Treasurer) and John Catt at the Geological Society in London on 5th December 2002 to discuss the design and criteria for the award of the medal. A visit was also paid to Sarah Stafford (Administrator of the Geologists' Association) to examine the GA's range medals and discuss manufacturing options. By January 2003, the terms of the prize had been agreed and it was decided to make the award to a young or new researcher who had made a significant contribution to the Quaternary Stratigraphy of the British Isles and its maritime environment, including adjacent areas of continental Europe that have relevance to the British Isles.

Danielle recalls "I first visited Mary in early 2003 at her home in the village of Kirk Ella, on the western outskirts of Hull, in order to discuss the process for commissioning a medal. I had asked her for some photographs of Lewis and together, over several cups of tea, we selected a black-and-white image to send to the Medal Department of the Royal Mint in Pontyclun in south Wales, who were to draft the outline design. The photo was a good choice as it showed Lewis' distinctive spectacles clearly, which made for a striking relief image on the final medal. It was an enjoyable afternoon as Mary had clearly played an active role in Lewis' academic life – she knew a number of colleagues in the QRA and we discussed at length Lewis' work in Holderness. The Royal Mint struck the medal in time for the April 2004 Annual Field Meeting in the Isle of Man, with the inaugural recipient being Jonathan Lee from the British Geological Survey. We were delighted that Mary was able to attend the AGM at the Imperial Hotel in Douglas and, together with the President, Professor David Keen, to present the award in person (Photo 2). She was always interested to hear from successive recipients of the medal and indeed maintained a written correspondence with some of them and with past QRA awards officers until her death".

Mary at AGM in Douglas

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ARTICLE

TRACE ELEMENT ANALYSIS OF LATE HOLOCENE TEPHRAS FROM GREENLAND ICE CORES

Gill Plunkett, Nick J.G. Pearce, Joseph R. McConnell, Jonathan R. Pilcher, Michael Sigl, Hongli Zhao

Abstract

Locating and geochemically characterising cryptotephra in polar ice cores is critical for identifying the sources of volcanic markers that the ice cores contain. Trace element analysis of tephras is an important compliment to major element analysis as trace element composition can help differentiate volcanic sources and provide insights into the processes that generated the tephra. Here, we examine the trace element composition of selected tephras from Greenland ice cores using laser ablation inductively coupled plasma-mass spectrometry (LA-ICP-MS) in an attempt to verify their sources. Our results support the attribution of the ~1641 BCE acid layer in Greenland ice to Aniakchak, but we demonstrate that an eruption from an unidentified source was coeval with the Millennium Eruption of Changbaishan in 946 CE. We find that small shard size and the presence of multiple tephra populations pose particular challenges to the successful analysis of sparse tephra layers in the ice.

Introduction

Polar ice cores provide important records of palaeovolcanism that are critical for evaluating the role of volcanic forcing of climate. Sulphur dioxide and other aerosols from volcanic eruptions are potential contributors to past climate change and form acid layers within the ice which can be used in climate models to account for volcanically-induced changes in the Earth's radiative balance (e.g. Gao *et al*., 2008). Acid layers cannot reveal their source, however, nor can they reliably differentiate between high-, mid- or low-latitude eruptions, and the potential to examine the likely palaeoenvironmental impacts of the eruptions is therefore limited. The identification and characterisation of tephra in the ice cores can significantly improve the understanding of the source, impact and timing of volcanic activity, and tephra studies can thus contribute enormously to the evaluation of volcano-climate processes.

Over the last two decades, efforts to identify tephras in the Greenland ice cores have intensified (see review in Abbott and Davies, 2012). Much of the attention has been focused on Last Glacial ice, where a large number of tephras have been found, most of which have major element compositions that compare mainly with sources in Iceland (Abbott *et al*., 2012; Bourne *et al*., 2015), although some sources around the North Pacific Rim have also been reported (Bourne *et al*., 2016). In contrast, mid- to Late Holocene tephras appear to derive *mainly* from non-Icelandic sources, including Alaska and China (Coulter *et al*., 2012; Jensen *et al*., 2014; Sun *et al*., 2014; Sigl *et al*., 2015). While these apparent discrepancies may be due to differences in sampling strategies employed to each of the intervals (continuous sampling of Last Glacial ice *versus* focused sampling on events of interest in the Holocene), it is notable that non-Icelandic sources are comparatively rare in the continuous Last Glacial records, whereas sampling of some centuries-long Late Holocene sections (e.g. ~845–953 CE in NGRIP; Coulter *et al*., 2012) did not detect *any* of the many tephras erupted in Iceland during this time, despite targeting specific Icelandic events. An alternative explanation for the greater frequency of non-Icelandic tephras in the later period may that the predominantly easterly flow of air masses in the northern high-latitudes emerged in the Holocene. The precise origins of many tephras remain unidentified, however, mainly due to a dearth of published comparative glass data from potential volcanic regions (proximal sources). This apparently greater potential source area for mid- to Late Holocene tephras in Greenland ice cores raises the possibility that major element data alone may be insufficient to discriminate tephras from different volcanic regions that share similar major element compositions.

Here we attempt to verify the source of selected Greenland tephras by analysing their trace element compositions using laser ablation inductively coupled plasma-mass spectrometry (LA-ICP-MS). We highlight the difficulties of obtaining successful datasets on sparse, fine tephra shards, and demonstrate the need to match major and trace element data from discrete shards to ensure a more complete characterisation of the sample and the reliable distinction of heterogeneous populations, particularly for small and analytically-challenging shards.

Sample selection and methods

We selected three ice core tephra samples whose major element geochemistries have previously been analysed by electron probe micro-analysis (EPMA) and for which either reference sample material or published trace element data were available for their suggested correlatives (Table 1). QUB-1819 is a bimodal tephra from the NEEM-2011-S1 ice core, both of whose major element populations correlate with the mid-9th century CE "Millennium Eruption" of Tianchi, Changbaishan, on the North Korea-China border (Sun *et al*., 2014). A

Table 1. Ice core and comparative samples selected for LA-ICP-MS analysis. *Age based on NS1-2011 timescale (Sigl *et al*., 2015) ** Age based on GICC05 chronology (Vinther *et al*., 2006)

	Age	Sample origin	Suspected source / correlation
ICE CORE SAMPLES			
QUB-1819	AD 946-7*	NEEM-2011-S1, Greenland	Millennium Eruption (Tianchi)
QUB-1528	AD853±1*	NGRIP, Greenland	AD860B/WRAe (Mount Churchill)
QUB-1198	1641 BC**	NGRIP, Greenland	Aniakchak caldera eruption 3.6 ka
COMPARATIVES			
K02017		Tianchi crater	Millennium Eruption (Tianchi)
K02065		Tianchi crater	Millennium Eruption (Tianchi)
QUB-109		Sluggan Bog, N. Ireland	AD860B/WRAe (Mount Churchill)

similar tephra has been identified in NGRIP (Coulter *et al*., 2012). QUB-1819 contains a mixture of fine (~30 μm) and very fine (~10 μm) shards, and the presence of a third population (QUB-1819c) was suggested by one dissimilar major element analysis that is not characteristic of Changbaishan tephra (Sun *et al*., 2014). For comparison, reference samples (rhyolitic component, K02017; dacitic component, K02065) whose major element compositions were previously established by Zhao (2010), (Sun *et al*., 2014) and (Zhao *et al*., 2017) were analysed.

QUB-1528 has been matched on major element composition to the AD860B tephra found widely in Europe (Pilcher *et al*., 1996; Hall and Pilcher, 2002; Lawson *et al*., 2012) and recently correlated with the White River Ash Eastern Lobe (WRAe) from Mount Churchill, Alaska (Jensen *et al*., 2014). An extensive major, minor and trace element dataset for this tephra has been published by Preece *et al*. (2014). For comparison, we analysed QUB-109 from Sluggan Bog, the first sample in which the AD860B tephra was found in Europe, though it is mixed with a second population, AD860A, of presumed Icelandic origin.

A major acid spike in the Greenland ice cores at 1641 BCE (GICC05 chronology) has been attributed to Thera (Hammer *et al*., 2003), but the correlation of its associated tephra in the GRIP core (A1340-7) has been questioned on the basis of its major and trace element composition (Pearce *et al*., 2004; Denton and Pearce, 2008). Coulter *et al*., (2012) identified a tephra (QUB-1198) in the

NGRIP ice core whose major element geochemistry more closely resembles the rhyolitic component of the Aniakchak caldera eruption of 3.6 ka. A single dacitic shard was recorded within this sample that is distinct from Aniakchak rhyolitic and andesitic end-members. Here we examine the trace element composition of QUB-1198 to compare with the composition of the A1340-7 tephra determined by Hammer *et al*. (2003) using ion microprobe analysis, and of Aniakchak (Kaufman *et al*., 2012) and Thera ash (Pearce *et al*., 2002) determined by LA-ICP-MS data.

All samples had been mounted on glass slides in Buehler epoxy resin, ground, polished and carbon-coated prior to EPMA. The same mounts were used for trace element analyses, but slide co-ordinates for the analysed shards were not available to allow the same shards to be analysed for their trace composition. LA-ICP-MS analysis on single shards was performed using a Coherent GeoLas 193-nm Excimer laser with a Thermo Finnigan Element 2 high-resolution sector field mass spectrometer at the Department of Geography and Earth Sciences, Aberystwyth University. Data were collected using a 10 μm ablation crater, employing ^{29}Si as an internal standard and NIST SRM 612 silicate glass as a calibration standard (Pearce *et al*., 1997; 2007; Pearce, 2014). Instrument operating conditions and corrections for fractionation effects followed Pearce *et al*. (2011).

Results

QUB-1819 (Millennium Eruption trget)

The two components (K02017, K02065) of the Millennium Eruption reference material show a strong relationship with each other and indicate a highly differentiated product depleted in Ba and Sr and enriched in Y, Zr and rare earth elements (Figure 1). The comparable Ba:Y ratio between the two components suggests a fractionation trend between them. Both populations correlate with proximal tephra from Changbaishan recently published by Chen *et al*. (2016). Analysis of QUB-1819 was complicated by the small size of the shards both in terms of locating and distinguishing tephra from non-tephra, and of obtaining a large enough target for analysis (Figure 2). Twenty points were analysed, of which only eleven produced results consistent with volcanic glass. With an ablation crater size of 10 μm, however, several of the elements lie close to or below the lower limit of detection. Determining the correct ^{29}Si value to employ as an internal standard was not possible given the presence of three populations whose SiO_2 content ranged from 67.63 wt % to 76.53 wt %, and therefore the mean SiO_2 content of the total dataset (71.03 wt %) was used. This will have only a modest impact on the results, underestimating some analyses by about 5 %, overestimating others by a similar amount. The results indicate particles that are clearly less

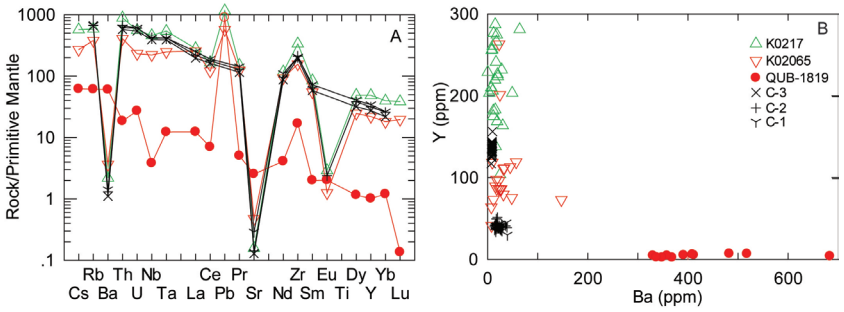

Figure 1. Glass trace element characteristics of the Millennium Eruption tephra (K02017, K02065) and one component of QUB-1819, compared with published proximal Changbaishan (C-1, C-2, C-3) tephra (Chen *et al*., 2016). A) Primitive mantle normalised elements (based on averaged data) showing a clear difference between QUB-1819 and the Millennium Eruption/Changbaishan data (primitive mantle values from Sun and McDonough 1989). B) Biplot illustrating Ba depletion and Y enrichment of the Millennium Eruption/Changbaishan samples in contrast to the less evolved shards in QUB-1819.

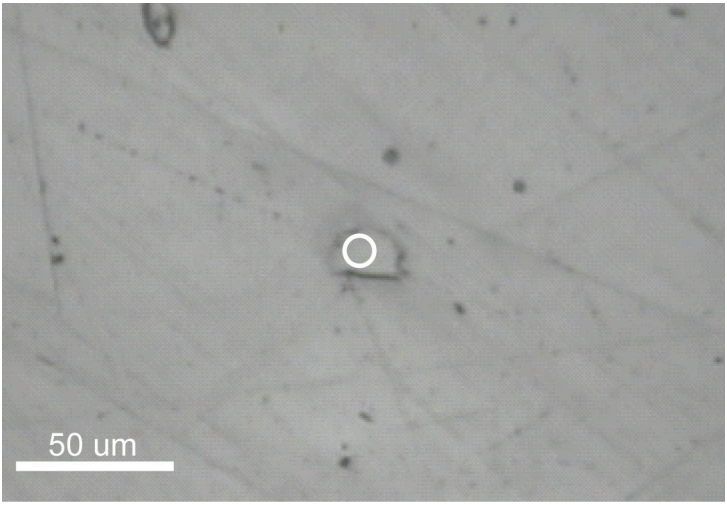

Figure 2. Example of an exposed surface of a QUB-1819 shard (beneath red circle, which is 10 μm in diameter). The very small size of the shard renders it difficult to obtain a complete and accurate analysis. Scale bar: 50 μm.

evolved than the Millennium Eruption reference samples, and the analysed material is evidently not from this source. The trace element composition is transitional with adakite-like characteristics (Castillo, 2012), suggesting an origin at a subduction zone. Comparable trace element compositions have been reported for Japanese tephras (Marayama *et al*., 2016), some of whom have major element geochemistries similar to QUB-1819c (SiO_2 >76 wt %, FeO and CaO < 1 wt %). In view of these data, we tentatively suggest that a second eruption coeval with the Millennium eruption and possibly in the Japan arc or neighbouring region, may have simultaneously dispersed tephra towards Greenland in 946 CE.

QUB-1528 (AD860B/WRAe target)

Of the 25 points that were analysed from QUB-1528, and 28 from QUB-109, no reliable datapoints that were clearly consistent with volcanic glass were obtained. Low signals were returned from a large proportion of targets, possibly due to the small size and vesicular nature of these shards, and other analyses were influenced by the presence of zircon, feldspar and quartz inclusions. We cannot therefore evaluate the correlation between these two tephras and WRAe.

QUB-1198 (Aniakchak target)

Tephra shards were easily recognisable in the QUB-1198 sample, and in some instances an impression from the rastered beam used during major element analysis was evident (Figure 3). In total, 21 targets were analysed from QUB-1528, of which only three yielded results that were considered acceptable. Notwithstanding the small size of the population, the results are consistent with data from the mid-Holocene Aniakchak eruption (Kaufman *et al*., 2012; Figure 4) and support the attribution of this tephra to Aniakchak (Coulter *et al*., 2012). They also reveal a strong similarity to the A1340-7 tephra from GRIP.

Discussion

In this investigation, an attempt to characterise the trace element composition of selected Late Holocene ice core tephra samples has met with limited success. A major limiting factor has been the small shard size that prevents sufficient counts from being acquired before shards are entirely ablated. As a result, it was not possible to obtain reliable data for QUB-1528 or QUB-109, both of which feature mainly small, vesicular shards. Furthermore, because slide co-ordinates were not available for those shards whose major element compositions had previously been determined, analysis was complicated by difficulties in locating glass shards of known geochemical composition

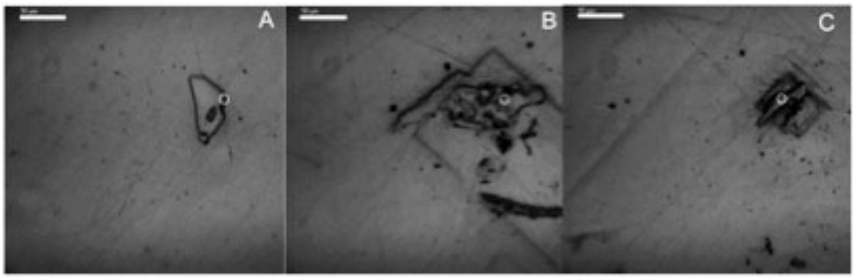

Figure 3. Exposed surfaces of shards from QUB-1198. Oblique rectangular outline of rastered beam (demagnified) following major element analysis is visible in B and C. Scale bars = 50 μm; circle diameters = 10 μm.

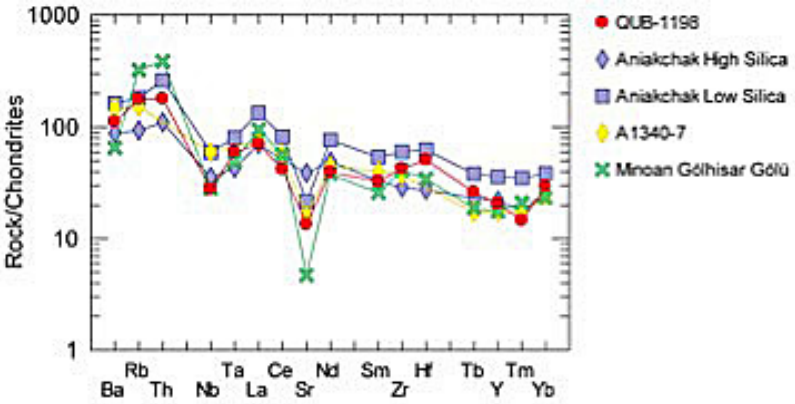

Figure 4. Chondrite normalised spider plot (based on averaged data) showing similarities between QUB-1198, the Aniakchak caldera eruption (Kaufman *et al*., 2012) and A1340-7 in the GRIP ice core (Hammer *et al*., 2003). The Minoan (Thera) tephra from Gölhisar Gölü (Pearce *et al*., 2002) is distinguishable by its notably lower Sr and higher Rb and Th composition. Chondrite normalisation is based on Thompson (1982).

and in determining the correct internal standard (^{29}Si content) to apply to the trace element data where multiple populations are present. We strongly recommend, therefore, that the recording of coordinates for shards analysed by EPMA should be standard practice in order to facilitate trace element characterisation of those same shards.

Our trace element results do not provide support for the correlation of QUB-1819 with the Millennium Eruption of Tianchi. We do not, however, reject this potential correlation because the major element data provide compelling evidence for a strong match with both the rhyolitic and dacitic end-members of this event. Furthermore, recent independent dating of the eruption (Oppenheimer *et al*., 2017) is consistent with the NS1-2011 ice core age for the QUB-1819 tephra. One possible explanation for the disparity in our results may be that we have inadvertently analysed glass from a third population. QUB-1819 is known to contain a population whose source has not yet been determined, and it is possible that the trace element data relate to this component. Subsequent examination of the specimen indicates that many of the shards analysed by LA-ICP-MS were obliterated, and we are therefore unable to determine if this component is morphologically distinct in any way that would have made it more prominent during LA-ICP-MS analysis. Furthermore, many of those shards from which we had obtained major element data remain intact, demonstrating that we have not obtained trace element data from them; further research may therefore be possible to verify their correlation with the Millennium Eruption.

Although only three datapoints were obtained from QUB-1198, the results are consistent with tephra from Aniakchak, as well as the GRIP tephra A1340-7 previously attributed to Thera (Hammer *et al*., 2003). Our trace element data from QUB-1198 support, therefore, the contention that the tephras in the ice cores at this time instead correlate with Aniakchak (Pearce *et al*., 2004).

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QUATERNARY RESEARCH FUND

COSMOGENIC NUCLIDE BURIAL DATING OF EARLY PLEISTOCENE SEDIMENTS IN WESTBURY CAVE, SOMERSET, ENGLAND

Background and rationale

Knowledge of the Early Pleistocene in Britain is principally derived from the sediments of the Crag Basin in East Anglia and river terraces across central and southeast England (Jones and Keen, 1993) but little is currently known about the palaeoenvironmental conditions that prevailed outside this area over a million years ago, when early human ancestors made their first forays into northern Europe (see Chauhan *et al*., 2017 for a review). A small number of cave sites have been discovered and excavated that have yielded purportedly Early Pleistocene sediments in other areas, such as Derbyshire (Spencer and Melville, 1974), Dorset (Fisher, 1905) and Somerset (Andrews *et al*., 1999), but these have only tentatively been dated by poorly constrained mammalian biostratigraphy. As such, these sites are limited in their capacity to provide data that can be linked to the wider scale climatic and environmental changes known from other terrestrial archives across Europe (e.g., Kahlke *et al*., 2011).

Recent re-investigations of the supposedly Early Pleistocene sediments at Westbury Cave in the Mendip Hills of Somerset have revealed an unprecedented mammalian faunal assemblage, with records of taxa new to the British Early Pleistocene (Adams, 2015, 2017). Given the newly recognised importance of the sediments at Westbury Cave, a series of absolute dating techniques is being applied at the site to provide independent tests of the biostratigraphical age estimates.

Relatively few absolute dating techniques can date non-volcanic, siliciclastic sediments back as far as the Early Pleistocene. One that has shown considerable success in similar depositional environments is cosmogenic nuclide burial dating (Granger and Muzikar, 2001), which dates sediments that have been exposed to cosmic rays prior to burial using the decay rates of cosmogenic nuclides (^{26}Al and ^{10}Be) over timescales of up to five million years. Funding from the QRA was used to cover analytical costs for cosmogenic nuclide burial dating of several sediment samples from Westbury Cave at the Centre Européen de Recherche et d'Enseignement des Géosciences de l'Environnement (CEREGE) in Aix-en-Provence, France.

Results

The results of the cosmogenic nuclide dating analyses (Figure 1) suggest burial of the Early Pleistocene sediments in Westbury Cave occurred during the early-mid Early Pleistocene (ca. 1.6-2.2 Ma). Multiple samples were taken from the same lithological units to test whether similar burial ages would be proposed by the dating analysis. In total nine samples were taken from five units, and all the samples from the same units were within error of each other, increasing the confidence that can be put behind the age estimates.

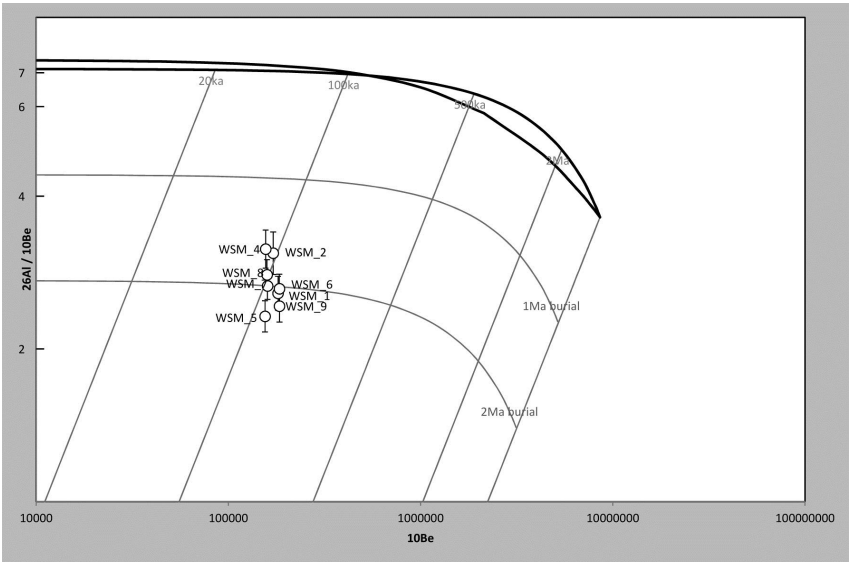

Figure 1. Results of the cosmogenic nuclide burial dating analysis of nine samples from Westbury Cave, with estimated burial ages of between 1.6 and 2.2 million years ago (Ma).

Significance

This work importantly represents the first time that any absolute dating technique has been successfully attempted at an Early Pleistocene site in Britain. The new absolute ages for the Early Pleistocene succession at Westbury Cave are in broad agreement with the older end of biostratigraphical age estimates made by Adams (2015) from the newly recovered mammalian faunal assemblage and with suggestions from palaeomagnetic dating of an age within the Matuyama reversed chron (0.78-2.58 Ma). Tests of these absolute ages will be provided in the

near future since independent techniques using coupled electron spin resonance (ESR)/ U-series dating and extended-range luminescence dating are also being attempted at the site.

Acknowledgements

Access to land for sampling in Westbury Quarry was kindly granted by Alford Technologies Ltd. and Natural England. I thank Régis Braucher (Laboratoire National des Nucléides Cosmogéniques (LN2C), CEREGE, Aix-en-Provence, France) for conducting the laboratory and dating analyses; Danielle Schreve, Jean-Jacques Bahain, and Pierre Voinchet for assistance with sample collection in the field; and the QRA for supporting this research.

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DEGLACIATION OF THE FORTH AND TAY PALAEO-ICE STREAM CORRIDORS, SOUTHERN SCOTLAND

Background and rationale

Ice streams are critical components of the ice sheet system that drain a disproportionate volume of the ice and sediment and exert an important influence on its geometry, mass balance and stability. The central sector of the last British Irish-Ice Sheet (BIIS) was characterised by complex, multi-phase ice-stream behaviour and repeated marginal fluctuations (e.g. Golledge and Stoker, 2006; Livingstone *et al*., 2012). However, despite the wealth of geomorphological and sedimentological evidence contextualising the pattern of ice flow (e.g. Hughes *et al*., 2014), the timing and rate of retreat is poorly constrained. Here we present results from part of an ongoing systematic and directed campaign to collect and date the Tyne, Stainmore-Eden, Tweed and Forth-Tay palaeo-ice stream corridors in the central sector of the last BIIS in order to constrain the timing and rate of retreat, and explore mechanisms controlling ice stream behaviour and changing BIIS dynamics during deglaciation (e.g. Livingstone *et al*., 2015).

Results

The Forth-Tay Palaeo-Ice Stream (FTIS) catchment (Figure 1) drained eastward and NE through the Firth of Forth, Firth of Tay and Strathmore into the North Sea (e.g. Golledge and Stoker, 2006) and was a major tributary of the North Sea Lobe, which flowed southwards down the east coast of England (Davies *et al*., 2011). Initial glacial geomorphology mapping was carried out to identify ice-flow phasing relationships and a recce in April 2015 identified samples sites, including exposed bedrock surfaces suitable for cosmogenic radionuclide dating (^{36}Cl and ^{10}Be), natural lake and bog sites for coring and radiocarbon dating, and exposed sandur/delta sediments for optically stimulated luminescence dating (Figure 1).

Quaternary Research Association funds supported our 2016 fieldwork campaign to collect ten samples at five different sites for ^{36}Cl cosmogenic radionuclide dating. Samples were taken from a variety of crag-and-tails exhibiting evidence of glacial erosion. They included outcrops formed in volcanic bedrock, including basalt, microgabbro and andesite. These typically comprised upstanding plucked and abraded bedrock blocks or small roches moutonées (Figure 2). Samples were collected from the centre of blocks away from joints or edges using a rock saw. This allowed the removal of intact surface blocks of roughly 10 x 10 x 4 cm (~3 kg). All samples had their position, altitude, topographic shielding, surface dip/direction, dimensions and surface characteristics recorded.

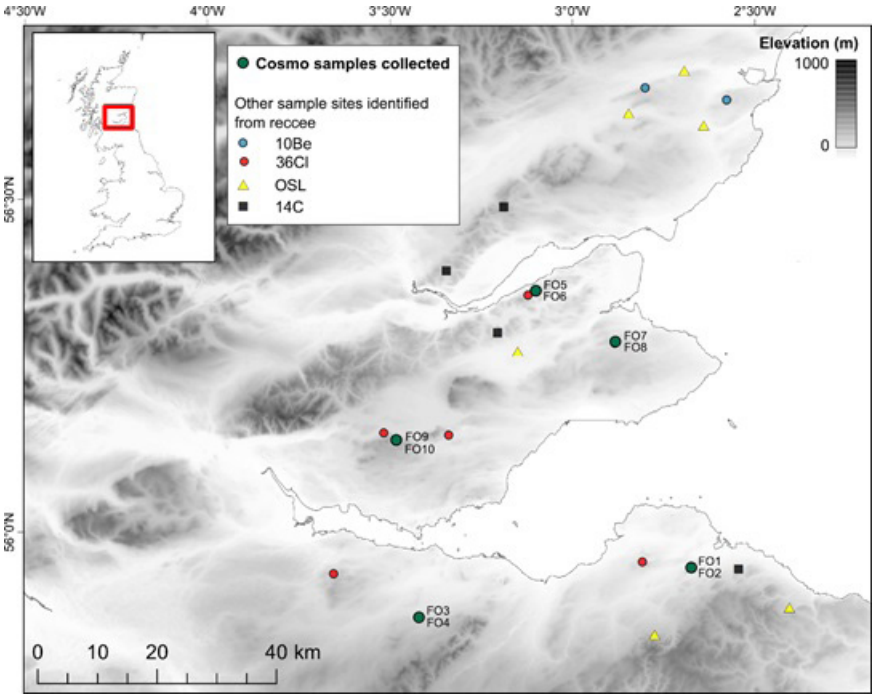

Figure 1. Sample locations along the Forth-Tay Paleo-Ice Stream Corridor.

The ^{36}Cl deglacial ages provide improved constraints on the timing of retreat of FTIS. Ages ranged from 8.4 to 19.4 ka BP and paired samples were within error to 1σ with the exception of FO3 and FO4 (Figure 1). The range of ages suggest that some of the samples may either contain an inherited signal, resulting in an older than expected age, or experienced burial (by sediment, vegetation or snow) or post-glacial exhumation, resulting in a younger than expected age.

Acknowledgments

The cosmogenic nuclide dating was funded by a NERC Cosmogenic Isotope Analysis Facility grant (9149/1014). We thank the various landowners and farmers who gave us permission to work on their land.

Figure 2. Photographs of sample site FO7 - Duncarrow Hill. Small roches moutonées on top of a craggy ridge (226 m asl) north of the Forth. The sample was taken from the upper mid to stoss side of the roches moutonées. Once sampled, the bedrock was roughened up to remove the scar observed in the lower right panel.

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INVESTIGATING THE SEDIMENTARY ARCHITECTURE OF THE BRAMPTON KAME BELT USING GROUND-PENETRATING RADAR (GPR)

Introduction

The Brampton kame belt is a large (>40 km^2) glacio-depositional complex located at the centre of one of the most dynamic sectors of the former British-Irish Ice Sheet (Livingstone *et al*., 2015). It is composed of an array of ridges (both continuous and fragmentary), flat-topped hills, channels and depressions, and has been associated with the development of a complex glacier karst formed by ice stagnation in the lee of the Pennines (Livingstone *et al*., 2010). Previous work in this area has focused on geomorphological mapping from high-resolution digital elevation models (DEMs) and detailed sedimentological logging from a handful of boreholes and exposures within aggregate quarries (e.g. Huddart, 1970, 1981; Livingstone *et al*., 2010). In this fieldwork we used Ground-Penetrating Radar (GPR) to undertake a systematic, large-scale study of the subsurface sedimentary architecture of the kame belt in order to (i) test the application of GPR in investigating complex glaciofluvial landform-sediment assemblages; and (ii) better understand the formation of the kame belt within the wider context of the deglaciation of the last British-Irish Ice Sheet.

Methods

In total, over 20 km of survey lines were collected using the University of Portsmouth's Mala GPR system 100 Mhz and 50 MHz rough terrain antennas (Figure 1). The survey targeted the full range of geomorphic features present within the kame belt, including ridges, flat-topped hills, channels and depressions, and, where possible, survey lines were collected both along and across features in order to provide an insight into their 3D architecture. At two locations we were able to collect survey lines above man-made sediment exposures, which were logged in order to tie the radar data to the sedimentary facies.

Results

Figure 2 shows a 60 m survey line collected transverse to the crestline of a ridge, starting at the ridge crest and descending along its flank. The radargram shows a largely consistent pattern of reflectors, which we identify as a single radar facies with horizontal to sub-horizontal bedding to a depth of approximately 6 m. This suggests an aggradational depositional environment that has built-up over time. The depth of penetration and the uniformity of this facies possibly indicates a sand-dominated environment. Occasional high-angled, thin reflectors away from the central core of the ridge may represent faulting within the unit. This is consistent with fluvial sedimentation within a subglacial environment (e.g. Brennand, 1994), followed by post-depositional collapse after removal of supporting ice.

Figure 1. Collection of a survey line across a flat-topped hill using the GPR 100 MHz antenna.

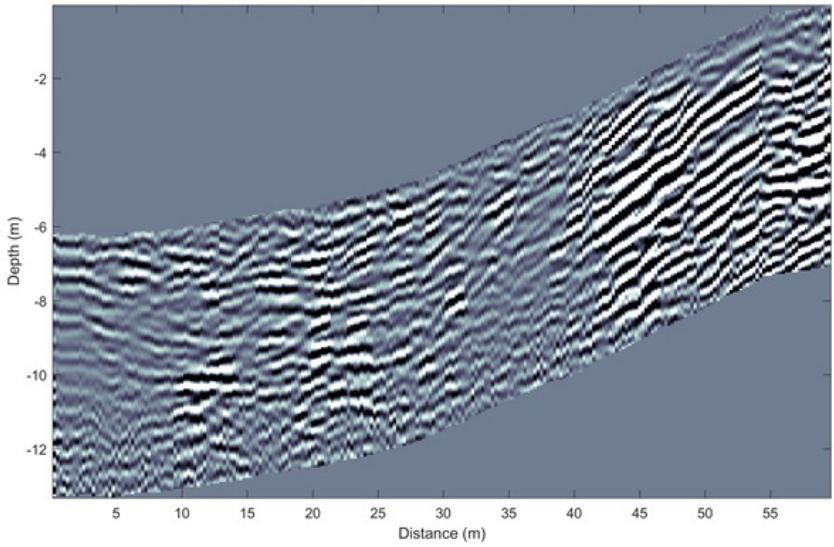

Figure 2. Radargram of a survey line collected across a ridge within the Brampton kame belt. The line was collected transverse to the crestline of the ridge, starting at the ridge crest and descending along the NW flank.

Summary

Initial analysis of GPR data collected from a variety of sites across the Brampton kame belt demonstrates it is possible to identify large-scale sedimentary architecture, including bedding, changes in sediment type, and deformation structures (e.g. faulting and folding). It is also possible to tie radar facies to sediment facies exposed in section. Further analysis of the data derived from this approach will help to improve existing models of kame formation through better understanding of individual landform-sediment assemblages, transitions between them and spatial variations in the pattern, style and volume of kame sediments in the region.

Acknowledgements

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REPORTS

THE QUATERNARY PERIGLACIATION OF KENT: JOINT QRA AND ENGINEERING GROUP OF THE GEOLOGICAL SOCIETY (EGGS) FIELD MEETING

10th – 12th June 2016

The joint QRA and Engineering Group of the Geological Society publication '*Engineering geology and geomorphology of glaciated and periglaciated terrains*' was launched with a one-day seminar on the 1st June 2016. This field trip later in June provided a fantastic opportunity to continue the momentum and enthusiasm for linking knowledge of the Quaternary and its implications for ground engineering. This was something well understood by previous members of the Quaternary and engineering communities including Mike Paul, Geoffrey Boulton, John Hutchinson, Peter Fookes, Alec Skempton, Denys Brunsden and Fred Bell. This common industrial and academic interest is exemplified as early as 1981 in the QRA's own publication 'Soil mechanics in Quaternary Science' (Paul, 1981).

With this in mind, participants from the Quaternary and ground engineering communities embarked on a journey to investigate the evidence for, and nature of, periglaciation in lowland Britain. The base for the investigation was the unique Walpole Bay Hotel and museum in Cliftonvile, just to the east of Margate in Kent. Famous hotel guests included Tracey Emin, Chas 'n' Dave and TV's own Jim Bowen. And now the QRA and EGGS.

We were welcomed by the leaders, **Professor Julian Murton** (University of Sussex) and **Dr David Giles** (University of Portsmouth) and the Walpole Bay Hotel's Jane Bishop. After an introduction to the geology and geomorphology of the Weald and Downs landscapes of Kent, we were fortunate to be shown photographs of the Sevenoaks solifluction lobes from the personal collection of Alan Weeks. This complimented the introduction to periglacial processes and stratigraphy and its implications for ground engineering. After a satisfying bar meal, most people retired at a reasonable hour ready for the first day in the field.

Saturday 11th June

Day one took us to Hubbard's Hill, near Sevenoaks and a series of morphological features associated with solifluction lobes (Figure 1). This locality and the surrounding area was investigated by engineering geologist and geotechnical engineer, **Alec Skempton** and colleagues after initial road construction for the A21 caused landsliding. His investigations revealed the presence of

solifluction lobes and relict shear surfaces formed on the footslope of the Hythe Formation scarp. Here we could observe landforms associated with solifluction of debris derived from the Hythe Formation which has moved downslope over the Weald Clay Formation. At least two generations of solifluction debris comprising clay-rich head deposits up to 2 m thick are present. A palaeosol is developed where a lower and upper solifluction sheet are developed and a radiocarbon age of 12 250 ± 28 ^{14}C yrs BP, placing soil development during the Late Devensian Interstadial.

Figure 1. Solifluction lobes/active layer detachment lobes at Hubbard's Hill, Sevenoaks (Photo credit: Dave Evans).

The importance of the growth and degradation of different types of ground ice, consolidation theory and mobilisation of residual strength in facilitating soil movements on slope angles as low as 1.3° was discussed in depth. The use of the word diamicton prompted a lively discussion about geological and engineering material descriptors with some agreement that genetic nomenclature should be avoided. In fact, it was pointed out that the process involved in the emplacement of the younger lobes probably related to active layer detachment and sliding rather than solifluction lobes. The locality offered the opportunity to appreciate the value of combining knowledge of past periglacial processes alongside geotechnical behaviour to produce an effective design strategy for the subsequent construction of the A21. Localities exhibiting a transition to familiar landslide styles including rotation of Hythe Formation bedrock, surface water ponding and tree displacement were viewed before travelling for lunch Morris Men entertainment in the High Weald village of Groombridge.

After a beer garden lunch, the group travelled via the impressive Groombridge Station of the historic Spa Valley Railway to Birchden Vale Woods and Harrison's Rocks. A distinctive cliff line of Early Cretaceous fine-grained sandstone of the Ardingly Sandstone Member is exposed above a tributary of the Grom river valley and provides excellent opportunities for bouldering for keen climbers. It also exposes vertical and subvertical joints which were investigated and their mode of origin discussed. Given the topographic location above the valley and the presence of underlying clays, the vertical fissures were interpreted as gulls. Valley bulges were considered likely but not seen on the trip. The group investigated the casehardening crust on the sandstone surface in addition to polygonal weathering cracks, up to 25 cm diameter. The day ended with a wet return journey for an excellent formal meal and further conversation back at the Walpole Bay Hotel.

Figure 2. Participants examining loess of the Pegwell Formation (upper light to dark reddish brown unit) overlying Paleocene Reculver Member of the Thanet Formation. Pegwell Bay.

Sunday 12th June

The final day dawned warm and humid as everyone made their way by bus to Pegwell Bay to continue the search for evidence of former ground ice and periglaciation. The group examined an excellent exposure of silt interpreted as loess, nearly 4 m thick overlying Paleocene bedrock of the Reculver Member (Figure 2). Two units were identified; a lower silt unit with calcareous rhizoliths and an upper darker, non-calcareous unit. Prismatic jointing was well-exposed. Black, well-rounded flint gravel was identified at the base of the lower loess unit with

some clasts vertically aligned. The mode of formation of the sediment, including vertical clast alignment, was discussed with heave resulting from the formation of segregated ice (frost-jacking) considered a likely candidate process. The upper unit has been interpreted as a decalcified equivalent to the underlying silt. **Dave Entwisle** of the British Geological Survey gave an overview of the results of a recent mineralogical and luminescence study that resulted in the reinterpretation of the upper unit as a solifluction deposit. This interpretation was challenged in part on the basis of the absence of other characteristic structures including platy soil fabrics observed in many solifluction deposits. The geotechnical significance of loess was widely discussed including its open, metastable structure making it susceptible to collapse under applied load.

Figure 3. Type 1 brecciated chalk overlain by involutions of brown silt in turn overlain by possible solifluction debris of gravelly clay and silt. Grenham Bay.

A walk eastwards along the beach breakwater provided an opportunity for a group photograph (Figure 3) and impressive exposures of the Cretaceous-Paleocene contact and further still, that of an infilled dry valley. The infill comprises brown, gravelly silt (diamicton) and silt of probable loessic and solifluction origin. Importantly for ground engineering, the nature and style of weathering of underlying chalk bedrock was observed to change in relation to the location of the dry valley. Brecciated chalk with rounded gravel to cobble clasts in a matrix

of clayey chalk has been classified as Type 2 chalk and underlies and borders the dry valleys. Brecciated chalk with vertical and horizontal, fracture-bounded tabular blocks is classified as Type 1 chalk and occurs on interfluves between the dry valleys.

Type 1 brecciated chalk was well-exposed in the cliffs in the final locality of the day after Sunday lunch and a vote of thanks, at Grenham Bay (Figure 4). Here, ice-wedge pseudomorphs in the form of sub-vertical infilled veins were observed and interpreted as indicative of the former presence of ground ice the form of ice veins. The growth and degradation of segregated ice-rich, near-surface bedrock and its contribution to bedrock brecciation was discussed at length. The formation of involutions drew a lot of interest including the implications for interpreting the depth of the palaeo-active layer and implications for lithological variability and permeability during ground investigation.

Figure 4. Group photograph, Pegwell Bay.

This field trip was very timely. It provided an exciting opportunity to demonstrate the tangible benefits of collaboration between Quaternary scientists and ground engineers. Understanding subsurface variability is a key uncertainty in ground investigation and geotechnical design and the events of the Quaternary have played a key role in this. The field trip highlighted an exciting future for Quaternary engineering geology and the comments of Peter Fookes in 1997 still provide an impetus for future collaboration:

"It is the geological events of the Quaternary that have had the overwhelming influence on the near-surface characterisation of rocks and soils (for engineering)" Fookes (1997). Indeed.

Acknowledgements

Thanks are due to the QRA and EGGS, Julian, Dave and the colleagues who helped organise an excellent and enjoyable trip. We all learned a lot. Not least that the Walpole Bay Hotel must be the only one in the word with a mini geological museum in its reception desk.

The field guide, Murton, J. B. and Giles, D. P. (2016). *The Quaternary periglaciation of Kent* is available now. See the QRA Field Guide page on the QRA website for an extract and to make an order.

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QRA FIELD MEETING: THE QUATERNARY OF THE NORTHERN PENNINES

11th-14th May 2017

Introduction

In May, QRA members met in the small town of Middleton-in-Teesdale situated on the Pennine Way in the Durham Dales, for a three-day field meeting. The focus was on the area of Teesdale, a location not previously explored by the QRA, and one of which it would appear little is known about its glaciation. This meeting aimed to bring light upon the rich glaciological, palaeoecological and archaeological history of Teesdale by compiling, challenging and building upon existing research and concepts. The trip, led by **Dave Evans** (Durham University) with contributions for numerous others, set up lively discussion amongst the 30 or so attendees that comprised a mix of long-term QRA members, early career researchers, amateur enthusiasts and first time field meeting participants.

Figure 1. North Pennines field meeting participants at Cotherstone Moor (photo: Dave Evans).

Thursday 11th May

On the evening of Thursday 11th May, members gathered for a hearty welcome dinner at the Teesdale Hotel, a historic 18th Century coaching inn. With stomachs satisfyingly filled, the group moved to the local church hall. **Dave Evans** provided an introduction to set up the two and a half days that would follow, outlining the broad-scale long-term landscape evolution of Teesdale and adjacent areas, the main geomorphological features, and previous work on ice sheet and drainage reconstructions. The group retired for an early night ahead of what would prove to be a packed field meeting.

Site 1: The upper Teesdale, Cow Green and Harwood Beck

A 20-minute drive north west out of Middleton to the first stop gave the group stunning panoramic views over the upper and mid Teesdale catchment and Cow Green Reservoir. **Dave Evans** described the cross cutting of streamlined drift features found to the north west of Cow Green which reflect a changing direction of ice flow associated with the migration of the ice divide over the Tees-Wear interfluve, Cross Fell and Dufton Fell (Mitchell, 2007). In the few locations where sections of flow structures are exposed, flow directions can also be picked out in clast fabrics. A large geomorphological map brought into the field provided the group with context for these features, although keeping it held on display was a constant battle in some windy conditions!

Site 2: Tarn Rigg

The next site gave the group an opportunity to stretch their legs with a 30-minute walk from the car park at Forest-in-Teesdale, crossing the Tees in the process, to reach Tarn Rigg. This slightly arcuate, 1.3km long ridge lies close to the base of talus slopes of Cronkley Scar, but is interestingly separated from the slopes by a depression. **Peter Wilson** set out the problem of its method of formation; as a lateral moraine formed near the end of the last glaciations (Dweeryhouse, 1902) or based upon its composition of local lithologies and arcuate sections curving towards the slopes, the terminal moraine of a smaller glacier, which developed below Cronkley Scar in the Loch Lomond Stadial (Wilson and Clarke, 1995). The group discussed both options, with suggestions that the hypothesised LLS glacier could be modelled to give an indication of whether such a glacier could be sustainable at this time.

Site 3: Coldberry Gutter

The third site of the day brought in a fascinating debate between human and natural methods of landscape change. Coldberry Gutter is a 1km long, 40m wide and 10m deep channel like feature, crossing between the Bow Lee and Hudeshope valleys on the north side of Teesdale. **Brian Young** explained that the Gutter is traditionally considered to be 'hush' (Dunham, 1990), a product of a once thriving lead mining industry. However, Brian argued that this should

Figure 2. Peter Wilson discusses the formation of Tarn Rigg (photo: Dave Evans).

be called into question. A lack of waste material from what would have been an excavation of significant volume, unmineralised debris in the gutter, and weak, mineral poor shale and siltstone wall rocks, makes a solely mining related method of formation difficult to justify. Instead, Brian speculated that the gutter was a meltwater drainage channel, only later exploited for lead mining on a small scale. A timely lunch gave attendees further chance to chat and ponder the questions raised from the day so far.

Site 4: Bollihope Common archaeology

After lunch, the topic turned from glacial processes to archaeology, with a visit to Bollihope Common in the upper section of the Bollihope Burn valley. The Common, excavated between 1998 and 2011 has revealed structures ranging from Iron Age to post-medieval. Whilst moving across the site, **Rob Young** invited the group to envisage past dry stone enclosures and hut circles, the stone outlines of which are still visible underfoot. Rob explained how much of the stone from these features had been robbed to form the 4 acre, late 18th to early 19th century 'Peg's House' enclosure which remains on the site today as a sheep fold. The site also provides evidence for Medieval lead and iron smelting with small bowl furnaces and significance amounts of lead slag. The group discussed a possible source for the iron, with **Brian Young** suggesting the surrounding shale, as opposed to local bogs.

Site 5: Glacial landforms of the Holwick and Middleton-in-Teesdale area

On the return drive to Middleton-in-Teesdale, the group stopped just upstream of the town to inspect the streamlined mounds which extend down the Teesdale valley floor. **Dave Evans** explained how these features are anonymously more rounded than the drumlins further up valley at Holwick and beyond, and in fact could be remoulded eskers. The group retired for dinner at the Teesdale Hotel, followed by drinks in the hotel bar.

Figure 3. Rob Young presents archaeological sites at Bollihope Common (photo: Dave Evans).

Saturday 13th May

Site 1: Stack Holme multiple till sequence

As the group gathered outside the Teesdale Hotel on the morning of the second day, the sky was ominously dark overhead and the air was notably nippier than the day before. The first site of the day gave the group their first opportunity of the meeting to get up close to a section. The 8m high exposure through a valley floor drumlin near Stack Holme shows accreted layers of deformed material, emplaced sub-glacially. **Dave Evans** explained how modern glaciers only have basal till layers up to 2m in thickness, and stacked till layers less than 1m (Evans *et al*., 2016). Thicker sections such as at Stack Holme record multiple accretionary events. This was visible for the group to see, as a sequence of three diamictons were separated by narrow bands of clay and silt.

Site 2: Lundale meltwater channels and Lonton moraine

A short drive into Lundale lead the group to a densely spaced selection of lateral meltwater channels, cutting sub-parallel down the steep slopes of the Moor Rigg northern interfluve between Teesdale and Lunedale. These channels formed at the margins of cold-based glacier snouts.

Down valley of the interfluve, at the point where former Lunedale and Teesdale ice met, anonymously large mounds are located on the valley floor. Previously mapped as glacio-fluvial in origin, **Dave Evans** described one hypothesis that these Lonton moraine mounds formed subglacially as 'interlobate moraines' where the two ice streams met. The main mound's streamlined form also suggests that this feature could represent a moraine overridden by glacier ice.

Site 3: Hayberries and the Romaldkirk esker complex

The next stop was the Hayberries nature reserve, where **Rob Westaway** gave a comprehensive summary of the geological history of Teesdale. The Hayberries quarry exposes a section at the western end of the Romaldkirk esker, consisting of fine sand, silt and clay rhythmites, overlain unconformably by courser gravels and sands, all of which are capped by diamictons and are deformed by a series of folds and faults. Dave Evans explained the complex multiphase formation of this puzzling landform and the history it reveals; from a glacial lacustrine to a glaciofluvial esker setting during the Hayberries stage readvance, followed by subglacial till deposition and glaciotectonic deformation.

Site 4: Eggleston Burn valley

Following lunch in nearby Middleton, the group then drove to the Eggleston Burn valley, located topographically high up on the landscape. Here the group were given the opportunity to consider evidence for an ice dammed lake in the upper Eggleston Burn valley, as proposed by Mills and Hull (1976). Incised channels provide evidence for glacial lake spillways, with the few available outcrops in the valley exposing laminated fine grained sediments. **Dave Evans** explained how notable shallow rotational landsides on the valley side could be composed of bedrock shale or lake clays, and provide a possible site for further investigation. There is still lots of work to be done! The group discussed whether shorelines would be visible, but their absence could be accounted for by the lake's short lived nature. The point was also made that the volume of Teesdale ice which would have been required to have backfilled the valley was significant.

Site 5: Parrick House kettle hole

The final site of the day took the group to Parrick House bog to the north of Barnard Castle for some obligatory coring! This kettle hole site provides the opportunity to add data to others at Seamer Carrs (Jones, 1976), Kildale Hill (Jones, 1977) and the nearby Romaldkirk depression (Bellamy *et al*., 1966), to constrain the timing of deglaciation in Upper Teesdale and help reconstruct the area's vegetation history. **Jim Innes** explained how basal organics at this site date to the start of the Lateglacial Interstadial, providing a minimum age for deglaciation, although ice retreat likely occurred well before this date. **Dave Evans** and **Dave Roberts,** assisted by some first time corers, brought up a core to reveal a late glacial tripartite sequence. A fitting ending to a very successful second day.

Sunday 14th May

Site 1: Goldsborough Crags and Cotherstone Moor

On the final day, the group enjoyed a short walk up onto Goldsborough summit on the Pennine Way, a sandstone mesa, horned crag-and-tail feature, once at the centre of the Stainmore Gap ice stream. **Stephen Livingstone** explained how

^{10}Be cosmogenic nuclide surface exposure dating has been used to constrain the deglaciation of the Stainmore ice stream. Samples from this site in combination with a site at Low Crags ca. 5km to the SE, provide an age of deglaciation of 16.6 ka BP. The group discussed how these dates tied in with those from the Vale of Eden and Tyne gap, undergoing deglaciation at a similar time. The group also discussed the theory behind surface exposure dating, in particular how nuclide inheritance through insufficient erosion of boulders during glacial transport can lead to outlying dates. **Dave Evans** explained a working hypothesis of how the diamicton topped mounds at Burners Hills and Knotts Hills to the west are scatters of plucked bedrock, deposited in a form of 'bedrock moraine'.

Site 2: Startforth – river terraces of the Tees

A brief stop near Barnard Castle allowed **Rob Westaway** to demonstrate to the group the former incision of the River Tees, as evidenced by some prominent benches. Entrenchment by up to 300 m is evident in this area.

Site 3: Humbleton Mound Belt

In the area around Humbleton, east of Barnard Castle, **Dave Evans** introduced the group to a conspicuous arc of discrete mounds and hummocks that have been only faintly streamlined in contrast to the very prominent drumlinization of the terrain to the west, centred over the Tees Valley. He proposed that this hummocky terrain is likely the product of large scale glacitectonic disturbance, with each large mound representing a bedrock mega-raft. Clearly an hypothesis for further testing in the future, provided some exposures are made available at some time.

Site 4: Woodland Fell and Langleydale area

The final few stops were amongst the well-developed morainic topography and meltwater channels relating to the initial stages of ice stream decoupling at the end of the last glaciation. **Dave Evans** explained how the Langleydale palaeo-valley was partially plugged with drift and then re-excavated by meltwater, speculating also that the palaeo-valley could not have served as the proto-Tees due to its initiation at deeply entrenched bedrock gorges high on the Tees/Langleydale watershed. The group finished off at a small and unremarkable looking section at the Woolly Hills to see an excellent exposure through bedrock glacitectonite.

Acknowledgements

Special thanks are due to Dave Evans for organising this field meeting and for his unique insight and clear and engaging explanation throughout. Thanks are also due to the numerous contributors, whose knowledge and expertise helped make this another diverse and enjoyable meeting. Finally, thanks are due to the Teesdale Hotel for their hospitality and those who drove cars and minibuses between sites.

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FROM CAVES TO CLIMATE: CREATING THE SISAL GLOBAL SPELEOTHEM DATABASE

21st – 23rd June 2017

This first SISAL meeting was held in Dublin, Ireland. Speleothem based paleoclimate records have risen in prominence over the last few years as long-term, precisely dated, continental archives of past changes in the hydrological cycle. Yet these valuable records have yet to make significant contributions to recent big data syntheses. For example, only 7 records are included in the standard Palaeoclimate Modelling Intercomparison Project (PMIP) benchmark dataset (Harrison *et al*., 2014). A synthesis of existing speleothems records has great potential for exploring regional and global-scale past changes in the hydrological cycle, as well as for evaluating the ability of climate models that explicitly simulate water and carbon isotopes to capture hydroclimate variability through data-model comparisons. To address these issues and to increase the impact of speleothem research in general, the PAGES-sponsored SISAL (Speleothem Isotopes Synthesis and Analysis) Working Group is creating a systematic global synthesis of speleothem $\delta^{18}O$ and $\delta^{13}C$ records (Figure 1).

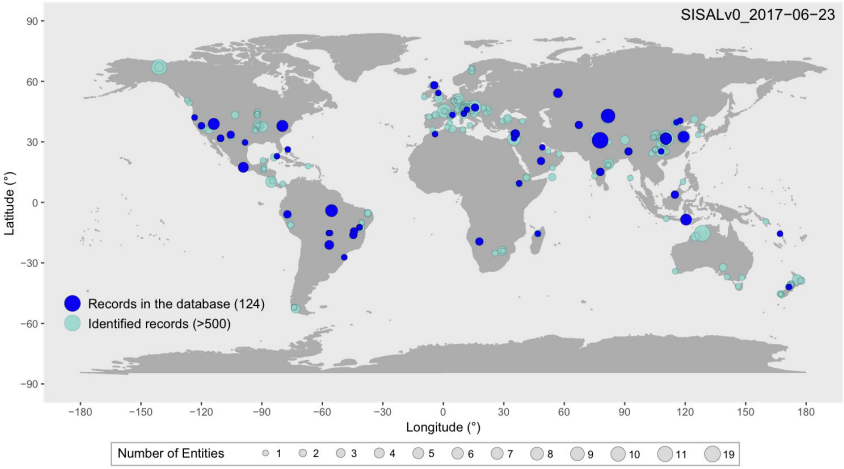

Figure 1. Global map showing the records uploaded to SISAL's database (n=124; dark blue) at the end of the workshop vs the 500+ records identified by SISAL members (n=556; cyan).

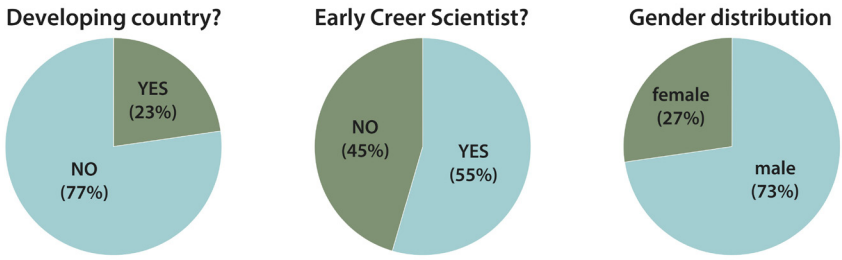

Figure 2. Global map showing the records uploaded to SISAL's database (n=124; dark blue) at the end of the workshop vs the 500+ records identified by SISAL members (n=556; cyan).

On 21-23 June 2017, 23 SISAL members (including 12 early-career researchers) met for the first SISAL workshop (Figure 2). The meeting took place at the UCD O'Brien Centre for Science in University College Dublin, Ireland and was coordinated by **Dr Laia Comas Bru** (University College Dublin, Ireland) and **Professor Sandy Harrison** (University of Reading, United Kingdom). Over three days, the workshop participants established the framework for the SISAL database, discussed potential data analysis projects and added entries to the database. On Day 1, speleothem scientists representing all continents (apart from Antarctica) presented reviews of speleothem research and existing records in their regions, and climate and karst/speleothem modellers also introduced how the SISAL database could be used by their communities.

These presentations were followed by an interactive introduction to the preliminary structure of the database that was prepared in advance of the meeting by SISAL steering committee members. During this working session led by **Kamolphat Atsawawaranunt**, the participants had the opportunity to test the structure and contents of the database by entering individual data sets and raising any questions or issues they had. Based on this feedback, Day 2 was dedicated to group discussions where workshop participants deliberated issues such as identifying the essential metadata needed for SISAL's purpose; dealing with ambiguous terminology and ensuring that the database includes the key parameters/information required for assessing age models. Further discussions on data collection strategy and forward planning of analyses served to shape the key points of the group's first scientific papers. Day 3 brought the workshop to a close with a recap discussion on our next steps towards SISAL's 2nd meeting in September 2017 (http://pastglobalchanges.org/ini/wg/sisal/meetings/127-pages/1711-sisal-2nd-wshop-17) and developing a timeline for the Working Group activities.

One important decision made during this 3-day workshop was the creation of "regional coordinators" who will liaise with authors publishing on speleothems from a given region and will be responsible for the initial quality control of records. We are confident that this approach will enormously facilitate data entry and also involve a wider group of scientists in the SISAL project, ensuring its success. A complete list of regional coordinators is available in our website.

SISAL welcomes paleoscientists interested in the curation of the database and encourages ideas for big data analyses that can be achieved with this new dataset. Those researchers with data to add to the database are encouraged to contact the regional coordinator for the geographic area of their stalagmite record. The first version of the database closes in December 2017. For more information about SISAL or how to get involved, visit our website at http://pastglobalchanges.org/ini/wg/sisal

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STABLE ISOTOPE MASS SPECTROMETRY USER GROUP MEETING

5th – 7th July 2017, Nottingham

The fourteenth meeting of the Stable Isotope Mass Spectrometry User Group (SIMSUG) was held at the British Geological Survey and hosted by the NERC Stable Isotope Facility in early July 2017. The conference was organised by **Melanie Leng**, **Jack Lacey**, and **Carol Arrowsmith**, with help from the Stable Isotope Facility team. SIMSUG meetings bring together scientists, instrument engineers and manufacturers, and suppliers of mass spectrometry equipment to discuss new applications and developments in stable isotope research, techniques, and analytical instrumentation. The meeting was attended by over 80 delegates representing a broad spectrum of disciplines and affiliations from both UK and European universities, research institutes, academic journals, and mass spectrometry companies. The meeting was co-sponsored by the Quaternary Research Association, which afforded postgraduate research students the opportunity to attend at a greatly subsidised rate.

Wednesday 5th July

The first day of SIMSUG commenced with a tour of the British Geological Survey and geochemistry laboratories, which highlighted the research undertaken at the BGS and showcased its world-class facilities. Delegates were able to journey back through three billion years of Earth history on the Geological Walk (including the Quaternary-aged boulder and cobble flagstone) and see the National Geological Repository core store; the largest core facility in the UK containing extensive

drill-core and biostratigraphical collections. The tour then moved on to the stable isotope, geochronology, inorganic, and organic geochemistry laboratories, where delegates could see the wide array of mass spectrometry equipment and instrumentation the facilities use to drive research across a comprehensive range of geoscience, health, and environmental science areas undertaken at the BGS.

Thursday 6th July

The main scientific programme of the conference incorporated a diverse agenda of talks and posters organised into overarching themes, including sessions on methodological advances and systems innovation, tracing terrestrial and marine palaeoenvironmental change, and palaeodietary studies. The first session on 'Methodological Advances and Calibration Studies' included talks on advances in phosphate oxygen and clumped isotope ratio measurements, as well as the effects of different cleaning methods have on isotope and trace element data from ostracods. The following session on the 'Palaeoclimate of the Terrestrial Realm' looked at how proxy data can be better integrated with climate models, the isotope analysis of stromatolites carbonate to investigate the termination of the African Humid Period, and reconstructing changes in the structure of food webs using carbon and nitrogen isotopes of invertebrate remains. The next session, 'Advances in Stable Isotope Geochemistry', got underway with the first keynote presentation of the conference given by **Dr Peter Wynn** (University of Lancaster) on using isotopes to better understand subglacial methane sources and sinks. The presentation discussed the importance of subglacial methane generation, its characterisation and measurement, and significance in a warming world. The final session of the day brought together several talks from industry on 'Systems and Software Innovation' covering new hardware and improvements to analytical capability, as well as giving useful insight into the application of metrological principles to isotope ratio analysis. After the final presentation of the day, discussions continued at the conference dinner held at the National Justice Museum in Nottingham city centre. Delegates were able to enjoy the iconic surroundings and had an informative and interactive tour of the historic courthouse and jail. Dinner was followed by a guided walk through the city.

Friday 7th July

The last day of the meeting began with a session on 'Palaeodiet and Provenance', in which **Dr Tamsin O'Connell** (University of Cambridge) gave a fascinating keynote presentation on how stable isotope analyses of archaeological remains have transformed our understanding of past human subsistence. The subsequent and final session of the conference collated presentations on the theme of 'Isotopes in the Marine Realm', which included talks on reconstructing ocean oxygenation across several Atlantic Ocean sites, and using bivalve carbonate to resolve isotopic

temperature data at the seasonal scale to identify the causes of marine climate change. Following the close of the science programme, a prize ceremony for postgraduate research students was held. The quality of all student presentations and posters was very high and all presenters received commendation from the judges. The award for best overall presenter went to **Benjamin Bell** (University of Manchester), best talk to **Hal Bradbury** (University of Cambridge), and best poster to **Kim Wood** (SUERC).

Thank you to the QRA for supporting the event, alongside our industry sponsors Thermo Fisher, Elementar, Sercon, Elemtex, Isoanalytical, Goss Scientific, and Elemental Microanalysis. Thank you also to the presenters and participants who all contributed to the great success of the conference, which was full of stimulating and constructive discussion. The next SIMSUG meeting will be held in 2019 at the Life Sciences Mass Spectrometry Facility at the University of Bristol.

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22ND ANNUAL QRA POSTGRADUATE SYMPOSIUM

11th – 13th September 2017, Royal Holloway, University of London

Just before the start of the new academic year, 46 delegates, from 20 institutions, attended the 22nd Annual QRA Postgraduate Symposium hosted by the Centre for Quaternary Research (CQR), Department of Geography at Royal Holloway, University of London and the Natural History Museum, London. The three-day event was an enormous success thanks to the organisational efforts of Ash Abrook, Dave Arnold, Rachel Devine, Angharad Jones, Julian Martin and Lizzy Peneycad. The symposium offers postgraduate researchers from any level the chance to present their work in a friendly and open environment and #QRAPG17 was no different, with excellent oral and poster presentations from a diverse range of Quaternary Science sub-disciplines, touching on records from around the globe.

Figure 1. The symposium attendees in the Founder's Building quad, Royal Holloway, University of London (Photo credit Chris Francis).

Monday 11th September

The first day of the symposium began with a brief welcome by CQR Director **Professor Danielle Schreve** who, as a long standing senior figure in the QRA, highlighted the special place that the QRA Postgraduate Symposium has in not only the QRA calendar, but also the hearts and minds of many a QRA member. Following a brief introduction by the organising committee, the first of two keynote presentations was delivered by **Professor Ian Candy**. His talk took us not only through some of his research, but also through his career as he mapped out his

own journey from student to professor. As always, he offered excellent advice on a career in Quaternary Science after the PhD, whether that be in academia or in the wider world. It also was a chance for Ian to involve the audience for a bit of brainstorming which is so often a feature of his excellent interactive lectures. It was good to know that presenting research was a key career skill and this boded well for the following oral presentation sessions. The first session on Pleistocene and Holocene Palaeoecology included five talks that took us from Britain to Siberia, via lake sediments from Greece and we eventually ended up on a Welsh bog. These were an excellent start to the symposium covering mammalian palaeontology, stable isotope analysis and the use of microfossils, highlighting the broad range of techniques applied in Quaternary palaeoecology. The second session of talks took things a little more recent with a focus on Holocene palaeoecology and presentations included palaeoecology in estuary management, ecological tipping points and a rewilding/reintroduction perspective. The day concluded with the traditional ice-breaker event which comprised a drinks reception and a BBQ. We would like to thank Tom Stock for giving up his time to impress us with his chef skills. The tradition of Royal Holloway drinks receptions continued with a late-night finish, which the organising committee feel is a testament to a successful ice-breaker!

Tuesday 11th September

Postgraduate talks continued on the second day with the first session of speakers full to the brim with palaeoclimate records. Again, we had quite a journey from Scotland to Chile, via North Africa with research presented on a number of different methods including tephrochronology, OSL dating and some novel talks on a speleothem database and the developing proxy of long-chain diols. A small break from tradition followed, with an equipment demonstration by Van Walt who sponsored the symposium. Without their generosity the symposium wouldn't have been possible and who doesn't want to try their hands at percussion coring?

The next session brought us back to what some long-standing QRA members may call 'traditional' Quaternary Science, with presentations on glacial and lake systems. We had an excellent overview of the Baltic Ice Lake, quantification of bed roughness and rounded off with a talk on the role we Quaternary Scientists play in the engineering world. The room for the poster session was bursting at the seams with research from Masters and PhD students and anyone scanning the room would catch glimpses of glacier modelling, several exotic antelopes, and many a core stratigraphy. The quality of posters was excellent and none would be out of place at the largest of international conferences. Presentations on sea-level change and a sea-spray wind proxy finished the symposium's postgraduate presentations. Things then got heated in the QRA Postgraduate Annual General Meeting with voting for the best oral and poster presentations. The committee collected the votes and frantically began re-enacting a General Election count to reveal the winners. The landslide victory for best oral presentation went to **Alex Whittle** of the University of Exeter for his talk entitled "Ecology of Testate

Figure 2. Delegates getting hands-on experience using field coring equipment during the Van Walt equipment demonstration (Photo credit Chris Francis).

Amoebae in a salt-spray influenced sub-Antarctic peatland: A novel proxy for reconstructing Southern Ocean westerly wind behaviour?'. The winner of the best poster presentation was **Julian Martin** from Royal Holloway, University of London for his work entitled 'Reconstructing past glacial environments, dynamics and drivers at Monte San Lorenzo, Patagonia'. The election of QRA Postgraduate Representative was next as sadly Laura Crossley's two-year term had come to an end. Kristy Holder from Swansea University was elected the new representative, joining Rachel Devine from Royal Holloway. In a not-so-nailbiting competition as was seen last year, the University of Glasgow won the right to host #QRAPG18, without anything picked out of a hat. Festivities continued at the conference dinner, held at Prezzo in Egham and the networking continued in QRAPG style over some great food and drinks.

Wednesday 13th September

The semi-traditional field trip of the symposium was reinvented this year as a visit to the Natural History Museum (NHM), London for the second keynote and to see behind-the-scenes. This was possible thanks to the departmental links with the NHM through the London NERC DTP and the invaluable assistance of Dr Eileen Cox. The highlight of the symposium was the second keynote presentation from **Professor Adrian Lister** who presented his new findings on the chronology of woolly mammoth extinction. As it wouldn't be a QRA event without the mention of a mammoth of some kind, we were only too pleased to see an excellent and engaging Q&A session on a palaeoecological topic that even the sedimentologists enjoyed. We are very grateful to Adrian for giving up his time

to speak to us. The afternoon at the NHM began with a brilliant talk by Head of Conservation, **Lorraine Cornish**, about the removal of Dippy and installation of Hope the blue whale in the NHM's Hintze Hall. The symposium concluded with a trio of behind-the-scenes tours of the Pleistocene Mammals collection, the Micropalaeontology collection and the conservation department. We would like to thank **Dr Pip Brewer, Dr Tom Hill** and the conservation team for giving up their time to provide delegates with brilliant tours.

Figure 3. A tour of the micropalaeontology collections from Dr. Tom Hill at the Natural History Museum, London (Photo credit Chris Francis).

Once again, thank you to our sponsors (Quaternary Research Association UK, Van Walt Monitoring, Centre for Quaternary Research, Department of Geography, Royal Holloway University of London), the organising committee, Chris Francis for the excellent photography and of course everyone who attended and made the event such a success. It was especially great to see so many Masters students and early year PhD students present their work. We look forward to #QRAPG18 and Glasgow, let's see if you can beat our record number of delegates!

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QUATERNARY RESEARCH ASSOCIATION

The Quaternary Research Association is an organisation comprising archaeologists, botanists, civil engineers, geographers, geologists, soil scientists, zoologists and others interested in research into the problems of the Quaternary. The majority of members reside in Great Britain, but membership also extends to most European countries, North America, Africa, Asia and Australasia. Membership (currently *c*. 1,200) is open to all interested in the objectives of the Association. The annual subscription is £20 with reduced rates (£10) for students and unwaged members and an Institutional rate of £35.

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

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

President: ***Professor Neil F. Glasser***, Professor Neil F. Glasser Institute of Geography, Aberystwyth University, Aberystwyth, SY23 3DB, Wales (email: president@qra.org.uk)

Vice-President: ***Professor David Bridgland***, Department of Geography, University of Durham, South Road, Durham, DH1 3LE (e-mail: d.r.bridgland@durham.ac.uk)

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

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

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