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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 1st 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 (500 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 or .jpg format. In case of the latter, a 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: Detailed guidelines on the formatting of contributions are now available via the QRA webpage and from the editor, including an EndNote style file to help with the formatting of bibliographies for submissions to *QN.*

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COVER PHOTOGRAPH
Fieldtrip participants walking up a large fluting at the head of Deepdale, Eastern Lake District (Photo: Josh Chambers; see related field meeting report in this issue)

EDITORIAL

I hope you all had a productive summer. Now that my term as editor of QN is drawing to a close slowly but surely, I wanted to take this penultimate opportunity to part with a few thoughts, my own and those of the QRA Executive.

I will deal with the latter first. The QRA Executive is considering a move to electronic distribution of QN from 2017 onwards. This is not a decision that can be taken lightly, and the topic has been debated at numerous meetings over the last few years. The arguments both for and against this change have merit, so the Executive has decided to poll members on this matter in order to establish a broader consensus. The key considerations are as follows:

QN is a tangible benefit of membership. This is especially the case for members who, for various reasons, cannot engage regularly with the QRA via its other activities such as meetings or the awarding of grants. Personal preference also seems to polarise the argument here: some members simply prefer to read QN as a physical document and would be less inclined to read an electronic version on a screen, while others do not mind.

Finance. The annual cost of posting QN to the membership has almost doubled since 2012 to £6300 and now outstrips that of printing the Newsletter. These costs could be offset to some extent by seeking additional revenue through carrying adverts in the Newsletter itself, which is being trialed in the first issue of 2016. However, if a significant proportion of the membership chose to receive QN electronically, then the not-insignificant savings could be used to support other QRA activities.

Editorial and aesthetic. An electronic version of the Newsletter would provide increased flexibility, such as enabling us to include colour figures at no charge and give us an easier, more immediate means of distribution (at present, the delay between collating each volume and members receiving QN – through printing and posting – is about 3-4 weeks). It would also allow the inclusion of reports that are maybe a little more detailed than the current page restriction allows.

We will continue this discussion throughout 2016 and will actively seek and encourage input from our members. We will start the ball rolling at the AGM in January and outline our consultation strategy with the full membership in the February Circular.

On another note, relating to the 50-year anniversary in 2014, the Top 50 Quaternary sites in Britain booklet (which actually contains >80 sites and is a very stimulating read!) has now been published and can be obtained here: https://www.qra.org.uk/top-50-quaternary-websites/

Many thanks to Barbara Silva and Emrys Phillips for collating the sites and overseeing the proofreading etc. – the booklet, which will be continuously updated, is a fantastic resource and a very enjoyable read!

Probably the most exciting news of this summer is that our President, Pete Coxon, and a team involving many IQUA and QRA members, won the bid for the next INQUA Congress, which will be hosted in Dublin in 2019. Congratulations to Pete and his team!

Back to more solemn QN-matters, this issue contains two articles: The first, by John Gordon, is a review of recent advances in geoconservation and the position statement of our association. The second, by Brian John, is a splendid example of where Quaternary Science can contribute to a more balanced understanding of sites with potentially archaeological significance – a classic interface between different disciplines seeking to further our understanding of the palaeo-environment, and an example of where two disciplines that often join forces (archaeology and geomorphology, in this instance) had gone separate ways – perhaps I should add 'hitherto' in this instance?

The next issue will see a review article on a similarly important theme, namely on engineering geology of Quaternary sediments, incidentally also the theme of the ADM that will be held in Durham in 2017.

As always, I hope the range of articles, reports and reviews is as stimulating to you as they have been to me when reviewing and editing them in my role as editor – and I hope the current printing-induced delay will actually make it even more pleasant reading as the start of term will be over for the academics amongst you.

With the best wishes,

Sven Lukas

ARTICLE

RECENT DEVELOPMENTS IN GEOCONSERVATION AND A POSITION STATEMENT BY THE QUATERNARY RESEARCH ASSOCIATION

John E. Gordon

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Abstract

The QRA and its members have contributed significantly to geoconservation in the UK. In a recent position statement the QRA recognises the present and future scientific, educational and wider values of geoconservation. The position statement demonstrates the commitment of the QRA to progress geoconservation and to support active engagement and outreach in addressing the new challenges and opportunities offered by the developing conservation agenda. Priorities for action include: enhancing site conservation through maintaining and updating the Geological Conservation Review, advising on best-practice management and defending threatened sites; providing the evidence base for marine geoconservation; contributing to assessments of ecosystem services and trends; improving understanding of the links between geodiversity and biodiversity; and promoting geoconservation through interpretation, outreach and evidence-based responses to policy consultations.

Introduction

In an earlier article in *Quaternary Newsletter*, Burek (2012) highlighted the importance of Quaternary geoconservation, emphasising the visibility, value and vulnerability of Quaternary features. The Quaternary Research Association (QRA) and its members have played a significant part in geoconservation activities, as summarised by Brown *et al*. (2014) in the volume celebrating the 50th Anniversary of the QRA (Catt and Candy, 2014). In a timely development, the QRA has now adopted a position statement on geoconservation (Quaternary Research Association, 2014)[1], recognising the present and future scientific, educational and other values of Quaternary sites, landscapes and fossil materials. The aim of the statement is to set out the QRA's commitment to geoconservation. This is important at a time when Quaternary sites are under pressure from development and other human impacts, and also when there are significant challenges and opportunities to deliver geoconservation benefits for Quaternary science and society (Prosser *et al*., 2011, 2013; Gordon *et al*., 2012; Gray *et al*., 2013). In particular, there is a need to promote the conservation and appropriate management of Quaternary sites and landscapes, especially those that have value for scientific studies, use as outdoor classrooms, enhancing public understanding of science, recreational use and geotourism. Moreover, there is growing recognition of the need for action to raise the profile of geoconservation since it is often undervalued or overlooked in international, national and local planning and policies for nature and the environment. This is part of a wider picture of limited awareness and understanding of geoheritage values among politicians, policy makers, the business community and society generally, and is also reflected in the dominance of biodiversity in nature conservation (Crofts, 2014). This article outlines recent developments in geoconservation, the geoconservation values of Quaternary features, the main elements of the QRA's position statement and some priorities for the future.

Recent developments in geoconservation

Geodiversity includes the variety of rocks, minerals, fossils, landforms, sediments, soils, hydrological features and topography in an area, together with the natural processes which form and alter them. Geoconservation involves action to protect those elements of geodiversity that have geoheritage value (for definition and discussion of terms and concepts, see Burek and Prosser, 2008; Gray, 2013; Prosser, 2013; Crofts and Gordon, 2014). Traditionally, geodiversity has been valued principally for geoscience research and education, and this is reflected in the assessment of key terrestrial sites for the Geological Conservation Review (GCR) in Great Britain and the Earth Science Conservation Review in Northern Ireland (Enlander, 2001; Ellis, 2011), which underpin the series of geological Sites of Special Scientific Interest (SSSIs) and Areas of Special Scientific Interest (ASSIs), respectively. While site protection remains at the core of geoconservation in the face of a wide range of threats including urbanisation, infrastructure development, mineral extraction, changes in land use and coastal protection (Crofts and Gordon, 2015), a broader discipline is now emerging (Henriques *et al.*, 2011; Gray, 2013). This recognises how geodiversity links with landscape and biodiversity conservation, economic development, climate change adaptation, sustainable management of land and water, historical and cultural heritage, people's health and well-being, geotourism and the delivery of socio-economic benefits for local communities (Stace and Larwood, 2006; Prosser *et al.*, 2011, 2013; Gordon *et al.*, 2012; Gray, 2013). Therefore as well as scientific and educational values, growing emphasis is now placed on the wider intrinsic, cultural, aesthetic and ecological qualities of geodiversity and its contribution to a range of ecosystem services and environmental management (Gordon and Barron, 2013; Gray 2013; Gray *et al.*, 2013; Crofts and Gordon, 2015).

These wider values were explored in the proceedings of two benchmark conferences in 2010 and 2011 involving contributions by QRA members (Gordon *et al.*, 2012; Hansom, 2013; Prosser *et al.*, 2013) and are reflected in the publication by the voluntary sector, with government endorsement, of *Scotland's Geodiversity Charter* (Scottish Geodiversity Forum, 2013) and the *Geodiversity Charter for*

England (English Geodiversity Forum, 2014), and also in the UK Geodiversity Action Plan (http://www.ukgap.org.uk/). They have also been recognised at an international level, for example by the International Union for the Conservation of Nature (IUCN) in its resolutions and protected area guidelines (Dudley, 2008; IUCN, 2008, 2012; Crofts and Gordon, 2015), the formation of an IUCN Geoheritage Specialist Group under the World Commission on Protected Areas (https://www.iucn.org/about/work/programmes/gpap_home/gpap_biodiversity/gpap_wcpabiodiv/gpap_geoheritage/), the activities of ProGEO, the European Association for the Conservation of the Geological Heritage (http://www.progeo.se/) and by the growth of the Global Geoparks Network assisted by UNESCO (McKeever *et al*., 2010). Nevertheless, although many individual countries have progressed geosite conservation particularly in Europe (Wimbledon and Smith-Meyer, 2012), there is no systematic international listing of key geoheritage sites and landscapes, although the international importance of some is acknowledged through their inscription on the UNESCO World Heritage List and inclusion within Global Geoparks (Larwood *et al*., 2013). While much of the focus has been on the conservation of terrestrial sites and features, a further important development is the recognition of the value of marine geodiversity, both for its scientific interests and for its role in supporting biodiversity in marine protected areas and in informing marine spatial planning (Burek *et al*. 2013; Brooks *et al*., 2013; Gordon *et al*., 2013).

Geoconservation values of Quaternary features

Learning from the past has an essential part to play in understanding and dealing with the challenges faced by society today, such as climate change adaptation, loss of biodiversity, sea-level rise and sustainable economic development, both on land and offshore (Gordon *et al*., 2012; Gray *et al*., 2013). Progress in Quaternary science and the benefits it delivers for society and the environment depend on the availability of key sites and areas for research and education. Such sites are an essential component of the UK's internationally important geodiversity and a vital part of its environmental assets, natural capital and rich geoheritage. Against this background, the conservation of Quaternary geodiversity and geoheritage is crucial for a number of reasons.

1. Geodiversity is an integral part of nature, and in the same way that plants and animals merit conservation for their intrinsic value, so too do abiotic features.
2. Conserving Quaternary sites (geosites) of international, national or local significance for science and education (at all levels from schools to life-long learning) is important for: current and future research; developing new techniques and theories; educating and training the scientists of the future; and historical value (history of science). Sites in this category occur both onshore and offshore. They include: type localities for particular events or time periods such as Quaternary glacial and interglacial stages; key reference localities for

reconstructing the Quaternary history of the UK; representative sites with sediments, landforms, deposits or fossils indicative of past environmental conditions, geomorphological processes and landscape evolution; and areas with classic textbook features.

3. Some Quaternary sites and landscapes have strong cultural associations or aesthetic qualities, including links with historical events and archaeology, or have been sources of inspiration for literature, art, poetry or music. Many Quaternary sites are tourist attractions and provide economic benefits.

4. Geodiversity is a vital component of ecosystems in which biotic and abiotic components form an interacting whole. Most species depend on the abiotic 'stage' on which they exist, not only rare or specialised ones (e.g. those associated with limestone pavements). Consequently there is growing interest in 'conserving nature's stage', an approach involving the use of geodiversity as a coarse filter to support biodiversity conservation (Anderson and Ferree, 2010; Beier *et al*., 2015). As part of this approach, the conservation of geodiverse, heterogeneous landscapes should underpin the development of robust protected area networks that help to maintain the resilience and adaptive capacity of biodiversity in the face of climate change and hence the delivery of long-term biodiversity targets (Anderson *et al*., 2014).

5. Geodiversity also provides many additional ecosystem services and environmental goods that deliver valuable economic, social and environmental benefits for society, including carbon sequestration, water quality regulation, aggregates (both terrestrial and marine), natural forms of coastal defence and assets for recreation (Gray *et al*., 2013). Understanding Quaternary geodiversity and developing Quaternary science and its applications is directly relevant to many current challenges that face society: for example through helping to mitigate natural hazards and informing the management of land and water (e.g. providing data on historical flooding); providing information on past climate and environmental change to inform forecasting (e.g. on rates of change, extreme events and impacts on marine and terrestrial ecosystems); and evaluating past human impacts (e.g. ecosystem responses to past changes represented in palaeoenvironmental records).

Recognition of the value of geoconservation is therefore vital both to enable the field-based research and education that are essential to advance Quaternary science, and also for the wider benefits for the environment and society.

The QRA and geoconservation: a position statement

Geoconservation is not exclusively the responsibility of the statutory conservation agencies. Professional bodies, their members, the voluntary sector and the public also have a significant role. The QRA and its members have made a major contribution to understanding and conserving Quaternary sites (Brown *et al*., 2014) and promoting outreach (Anderson and Brown, 2010). In particular, they have:

- co-ordinated and advised on site assessments and written scientific site reports for the Quaternary volumes of the GCR;
- provided expert advice for the conservation of key sites, including advice on site notifications and management (Figures 1 and 2);
- defended important sites when threatened (e.g. as a result of development, inappropriate management or coastal protection), including the provision of written scientific evidence in support of the conservation case in response to planning developments, appearing as expert witnesses at public inquiries and undertaking exploratory and rescue excavations;
- organised benchmark scientific conferences, in partnership with other bodies, that have communicated and advanced understanding of the values of Quaternary geodiversity, and included geoconservation within QRA discussion and field meetings;
- promoted conservation awareness through interpretation and outreach, including through QRA field meetings and publications; and
- contributed to the work of local geoconservation groups, including local geodiversity audits, designating local sites and practical site conservation.

Figure 1. Easton Bavents, part of Pakefield to Easton Bavents SSSI, Suffolk. Members of the QRA supported the conservation case when the renotification of the site was the subject of legal challenges in 2008 and 2009. Photo © Eleanor Brown.

Figure 2. The Parallel Roads of Glen Roy. The QRA provided a written submission to Scottish Natural Heritage to support the retention of the site as a National Nature Reserve when it was being considered for delisting in 2015. Photo © John Gordon.

It is therefore highly appropriate that the QRA has adopted a position statement on geoconservation. In this statement, the QRA recognises the present and future scientific, educational, cultural, aesthetic, ecological and ecosystem values of geoconservation and the needs of Quaternary science and society. In particular, the QRA:

- supports geoconservation activities to recognise and protect Quaternary sites, landscapes and museum collections, including the designation and appropriate management of statutory sites for their scientific and educational values;
- recognises that many sites also have cultural or aesthetic values or offer the potential for supporting local and regional development through geotourism activities;
- advocates the development of partnerships and strategies at national to local levels for designating, maintaining and enhancing Quaternary sites and landscapes;
- endorses the aims and objectives of *Scotland's Geodiversity Charter*, the *Geodiversity Charter for England* and the UK Geodiversity Action Plan (UKGAP);

- supports UK participation in UNESCO's Global Network of National Geoparks and World Heritage Site designation of appropriate Quaternary sites;
- promotes outreach and positive actions to enhance the conservation of Quaternary features; and

encourages responsible fieldwork and sample collection that adhere to recognised codes of best practice.

Priorities for action

In terms of actions, and building on past efforts, the QRA and its members in the future must continue to play an important role in three major areas of geoconservation, as detailed in Brown *et al*. (2014). The first area is supporting site conservation, including contributions to maintaining and updating the GCR, providing the evidence base for marine geoconservation, advising the conservation agencies on site management and supporting the conservation case when sites are threatened. The GCR is the foundation of site-based conservation, but the site networks and the science that underpins them, as published in the GCR volumes, need to be updated through partnership working between the statutory conservation agencies and the geoscience community. In particular, the Quaternary community should take greater 'ownership' of the Quaternary GCR blocks, and as part of Knowledge Exchange and Pathways to Impact work proactively support the statutory agencies in reviewing site networks and advising on the updating, replacing or deletion of sites because of new interpretations or evidence. The ongoing collaboration between the BRITICE-CHRONO members and the statutory agencies in this respect is a good example. Given the often challenging issues (Burek, 2012; Bridgland, 2013), partnership working will be essential to ensure that appropriate site management is put in place, with best-practice case studies promoted through the conservation area of the QRA website, in *Quaternary Newsletter* and in *Earth Heritage* magazine (http://www.earthheritage.org.uk/). Similar site assessments and management specifications are required for offshore Quaternary interests as part of marine protected areas and marine spatial planning. As well as for normal development pressures, advice will be required for difficult management issues arising from climate change, particularly in the case of dynamic sites (Prosser *et al*., 2010; Brazier *et al*., 2012). There are also potential benefits for the scientific community where the management of sites that are subject to current or future research plans, or will be visited as part of QRA field meetings (e.g. Brown, 2013), can be prioritised accordingly. A further key area for collaboration is with the archaeology community to deliver mutual benefits for Palaeolithic heritage protection and Quaternary geoconservation (Last *et al*., 2013). Partnership working also applies at a local level where the QRA and its members have a role in liaising with local geoconservation groups (Anderson and Brown, 2010; Burek, 2012) and ensuring that Local Geodiversity Action Plans (LGAPs) incorporate Quaternary interests (Burek, 2012).

The second area is providing the scientific underpinning to help develop the geoconservation agenda. Conservation drivers are dynamic, and the wider rationale for conservation generally has evolved over the last half century from an exclusive science-based and site-based focus to place greater emphasis on ecosystems and benefits for society (UK National Ecosystem Assessment, 2011), and latterly to an inclusive approach that more closely reflects the links between people and nature (Mace, 2014). For the geoscience and geoconservation communities this means engaging in new conservation priorities, such as evaluation of natural capital and ecosystem services and trends and developments in marine conservation. It also means recognising the wider relevance of geodiversity to society and applying geoconservation principles in the sustainable management of protected areas and their wider ecosystems (Gray *et al*., 2013; Crofts and Gordon, 2014), and improving understanding of the links between geodiversity and biodiversity as part of a more holistic approach to nature conservation and environmental management (Brazier *et al*., 2012; Gray *et al*., 2013; Hjort *et al*., 2015). At the same time, there are new opportunities for research and its applications, for example through the contribution of palaeoecological records to understanding ecosystem history and long-term trends in ecosystem services (Dearing *et al*., 2012; Jeffers *et al*., 2015). QRA conferences and workshops, in partnership with other organisations as appropriate, are an important means to discuss and promote such developments.

The third area is in developing outreach and providing the evidence base to influence policy. Outreach (Anderson and Brown, 2010) involves engaging with others to raise awareness of Quaternary geodiversity, its values and the need and to take positive action for its conservation. Audiences include politicians, decisions makers, university students and schools, industry and the general public. Examples of activities include integration of geoconservation in university courses, liaison with schools and producing teaching resources in an area where fieldwork is being conducted or QRA field meetings are being held, liaising with examination boards and contributing to conferences or workshops for teachers working in primary and secondary education. Engaging with Geoparks and local geoconservation groups is particularly important. QRA members can help by sharing their expertise, identifying important sites and helping others understand their relevance to local landscapes and communities and involving local group members in QRA field meetings. In order to engage wider audiences and stimulate a sense of wonder, interpretation and popular publications on sites should focus on telling stories not simply communicating information (Stewart and Nield, 2013; Gordon and Baker, 2015). At a policy level, the QRA and its members can also help to further geoconservation by pursuing a more active role in providing evidence-based responses to Government consultations on planning, policy and environmental strategies where there are Quaternary issues. Convincing use of examples of how geoconservation has policy relevance (Gordon and Barron, 2012) and has added value to land-use planning, advanced understanding of geological processes and potential for hazards, or contributed to economic growth can be persuasive, as can examples of how overlooking geodiversity has resulted in costly and damaging consequences. Finally, there is an important role for the QRA to engage with, and support, the international geoconservation agenda (Larwood *et al*., 2013), for example through INQUA and IUCN.

Conclusion

The QRA and its members have already contributed significantly to geoconservation in the UK, particularly through the GCR process and the provision of support to the statutory conservation bodies when sites have been threatened by development proposals. The adoption of a position statement, the inclusion of a Conservation Officer on the QRA Executive Committee and the incorporation of geoconservation within Discussion and Field Meetings demonstrates the commitment of the QRA to progressing geoconservation. The evolving geoconservation agenda opens up new challenges to ensure better recognition for geodiversity as part of a more integrated approach to nature conservation and decisions about a sustainable future, as well as new opportunities for research. In addition to the protection, management and updating of GCR and local geosites, this will mean addressing changing conservation priorities, such as ecosystem services, marine conservation, the links between geodiversity and biodiversity and informing protected area management and biodiversity adaptation to environmental change. A more active approach to outreach and education and the development of partnerships will be fundamental to the success of Quaternary geoconservation. At the heart of this are better collaboration between the geoscience and conservation communities and more effective communication with decision makers and wider society (Larwood *et al*., 2013; Stewart and Nield, 2013; Crofts, 2014). In particular, the headline messages and stories must have relevance for their respective agendas (Wood, 2013). The QRA's position statement therefore represents a benchmark in recognising the values of geoconservation for the field-based research and education that are essential to advance the science, and also for delivering wider benefits for the environment and society. In adopting the statement, the QRA lends significant weight to the geoconservation effort and provides a framework to support active engagement and outreach by the membership.

Acknowledgements

I am grateful to Eleanor Brown for a helpful review that improved the article and to members of the Executive Committee for their support during my period of office as QRA Conservation Officer.

Footnote

[1]The position statement is located in a new geoconservation area in the outreach part of the QRA website (see https://www.qra.org.uk/geoconservation/). This includes additional information on geoconservation and links to further resources. QRA members are encouraged to contribute and share best practice examples.

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QUATERNARY EVENTS AT CRAIG RHOSYFELIN, PEMBROKESHIRE

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Abstract

The Afon Brynberian valley is claimed to contain Britain's most important Neolithic quarry, used for the extraction of bluestone orthostats destined for Stonehenge. Archaeologists argue that an exposed rock face within a meltwater channel at Craig Rhosyfelin is a quarried surface, and that an eight-tonne block found five metres away was prepared for transport but then abandoned. Site investigations have revealed scoured surfaces, faceted and abraded erratic boulders, glacial till, fluvioglacial sands and gravels, and widespread rockfall and solifluction deposits. All the features associated with the "proto-orthostat" are considered to be natural. There are currently no visible prehistoric landforms or sediments that are demonstrably anthropogenic in origin.

Introduction

Craig Rhosyfelin is a rocky spur in the valley of the Afon Brynberian (SN117362) on the northern flank of Mynydd Preseli in Pembrokeshire, UK (Figure 1). The spur is aligned approximately NE-SW. It is about 80 m long and 15 m wide, tapering to a narrow tip at its downslope end. A central ridge of fractured rhyolite bedrock is surmounted by fragile and precarious outcrops from which many large slabs and sub-angular blocks have fallen. Summit slabs are currently being broken up by biological and other processes. Rock exposures are visible on both flanks, but the SE flank is heavily vegetated.

The site has gained recent notoriety in archaeological circles because an unusual foliated rhyolite, exposed on a series of sub-planar fracture surfaces and on detached blocks, has been matched to some "bluestone" fragments in the debitage at Stonehenge (Ixer and Bevins, 2011, 2013, 2014). The NW flank of the spur has been postulated as a "Neolithic bluestone quarry" from which orthostats were carried to Stonehenge around 5,000 years ago (Parker Pearson, 2012; Ixer, 2012). We have examined the site and the surrounding landscape and have assessed the evidence for human quarrying activity, and this paper reports our observations.

One major benefit from a five-year archaeological dig is that it has provided a unique opportunity both to study an unusual volcanic outcrop and to consider some of the processes, landforms and sediments typical of the north Pembrokeshire Quaternary. On the cleared and excavated rock face of the Rhosyfelin crag there

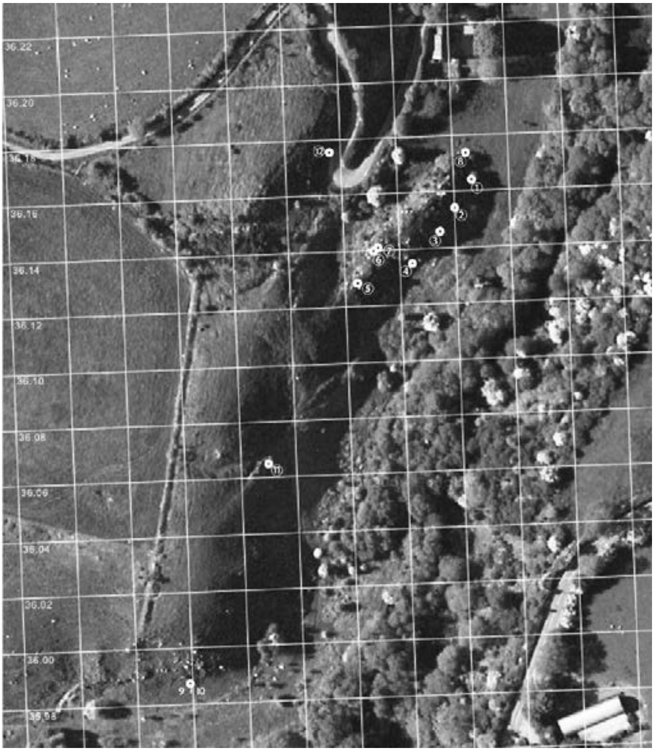

Figure 1. Satellite image of the Afon Brynberian channel, the Craig Rhosyfelin rhyolite spur and the subsidiary meltwater intakes near the bend in the road. The sampling points used by geologists Rob Ixer and Richard Bevins in 2010, prior to the archaeology dig, are also shown. (Acknowledgement: Richard Bevins)

is ample evidence that many different processes have contributed to its current appearance, to the widening of joints and to the accumulation of fallen rock debris. Within the confines of the archaeological dig (Figure 2) there are also layered and intercalated sediments up to 3 m thick, suggestive of a complex history over a great period of time. On the basis of its geomorphological interest, a notification has been submitted for RIGS designation.

Background

During the Quaternary north Pembrokeshire has been affected by both Welsh and Irish Sea Glacier ice. Mynydd Preseli may at some stages have supported a small cold-based ice cap (Patton *et al*., 2013), similar to that proposed for Dartmoor by Evans *et al*. (2012). It may also have been affected intermittently by ice flowing W or SW from the Welsh Ice Cap (Hubbard *et al*., 2009). However, most of the glacial field evidence (relating to striae, erratic transport and sedimentology) in

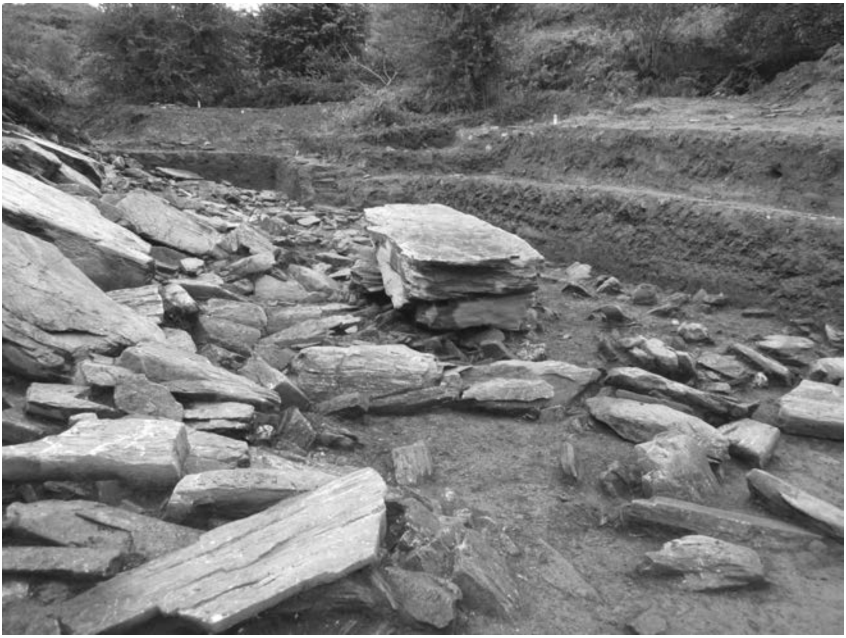

Figure 2. The upper part of the dig site in 2012. The rock face on the flank of the spur is just off the left edge of the photo. The litter of broken blocks was completely buried beneath rockfall and slope deposits prior to the commencement of the dig in 2011. The large elongated block in the centre of the photo is the "proto-orthostat" which has attracted much attention. In the foreground the upper surface of the till layer is exposed.

West Wales relates to an ice stream flowing onshore from the N and NW. It is widely accepted that the Irish Sea Glacier, Britain's largest ice stream, flowed across the county and was thick enough to submerge even the highest parts of the landscape during the Anglian Glaciation (Campbell and Bowen, 1989; Walker and McCarroll, 2001). During the LGM, Irish Sea Glacier ice was less extensive, but it affected much of the northern coastal strip of Pembrokeshire and inundated the landscape around Rhosyfelin (Hambrey *et al*., 2001; McCarroll, 2001; Etienne *et al*., 2005).

For most of the Quaternary, glacier ice was not present in Pembrokeshire, and there were frequent climatic oscillations involving interglacial or interstadial conditions and long episodes during which periglacial conditions dominated. The Quaternary stratigraphy of Pembrokeshire, as revealed in BGS mapping, is characterised by periglacial slope accumulations close to the surface with many expanses of glacial, fluvioglacial and glaciolacustrine deposits preserved in favourable locations (BGS, 2010). Coastal sediment sequences tell a consistent story, at least to the north of Milford Haven (John, 1970a). However, it is rare to find inland exposures that can be tied in with confidence. Rhosyfelin provides such an opportunity.

The Rhosyfelin spur

The crags visible along the valley of the Afon Brynberian near Rhosyfelin are erosional remnants of Fishguard Volcanic Group outcrops (Thorpe *et al*., 1991; BGS, 2010; Downes, 2011). The spur at Craig Rhosyfelin is the most substantial of these features, with rock exposures on both flanks. The rhyolitic lavas are splintery blue rocks which weather to a light grey colour. They are of Mid Ordovician (Llanvirn) age. Some substantial quartz veins are also visible. Here the lavas dip steeply north-westwards at about 75°, and examinations of the exposures reveal deep almost vertical intersecting fractures with numerous horizontal cross fractures which give rise to sharp-edged clasts ranging in size from flakes to blocks and slabs more than 3 m long. The largest visible block, measuring 3.8 m x 1.3 m x 0.6 m and weighing about 8 tonnes, is located about 5 m from the rock face, where prior to excavation it was embedded in slope deposits. It has a flat upper face, and is best described as an elongated slab. It has been referred to by archaeologists as a "proto-orthostat" (Figure 2). Abundant rock debris, accumulated at the foot of the steep rock face, has been uncovered during a recent archaeological dig. The focus of associated geological research (Ixer and Bevins, 2014) has been an unusual flinty foliated rhyolite with a planar or lensoidal "Jovian" fabric. The rock face at Rhosyfelin is referred to as a "foliation plane" but it is actually made up of facets of several distinct fracture planes, some of which project <150 cm beyond others. The impressive rock face is the feature that has led the archaeologists to assume, after clearing away trees, shrubs and many tonnes of debris, that it is a worked quarry. However, it can be argued that the rock face as it presently appears is simply an "archaeological artifice" unlike anything that might have existed in the past. Ixer and Bevins (2014) claim that they have fixed the provenance of certain rhyolite fragments at Stonehenge to within a few metres close to the tip of the Rhosyfelin spur. On that basis Parker Pearson (2012) and Ixer (2012) claim to know where at least one Stonehenge bluestone has come from.

Meltwater channels

Craig Rhosyfelin is situated close to a bend in the Brynberian river gorge. The main valley runs N towards a confluence with the Afon Nyfer, which has had a complex history of meltwater erosion and glacial diversions (Gregory and Bowen, 1966). The Brynberian gorge currently contains a "misfit" stream and it is suggested that it has been cut by glacial meltwater through several phases. As seen in Figure 1, there is a small subsidiary dry channel with two intakes on a col to the W and N of the crag. These features are reminiscent of many humped and arcuate channels within the Gwaun-Jordanston meltwater channel system, suggestive of subglacial meltwater flow under great hydrostatic pressure within subglacial conduits (John, 1970a). Within the channels, as on many of the tors in the area, there are signs of ice smoothing and block removal; a litter of rhyolite blocks (some in excess of 1 m long) can be seen in the sediments on the valley floor. Streamlined and moulded forms are common, especially near the tip of the spur and on the col (Figure 3). There are also traces of crescentic gouges on some of the solid rock outcrops on channel walls and on loosened blocks which are incorporated into sediments. Close to the enigmatic 8-tonne elongated slab the archaeologists have exposed sections of what appear to be the channel's rock floor, partly masked with compressed broken rock debris up to 30 cm thick. This is the lowest visible layer (numbered 1 in Figure 4) in the sediment sequence.

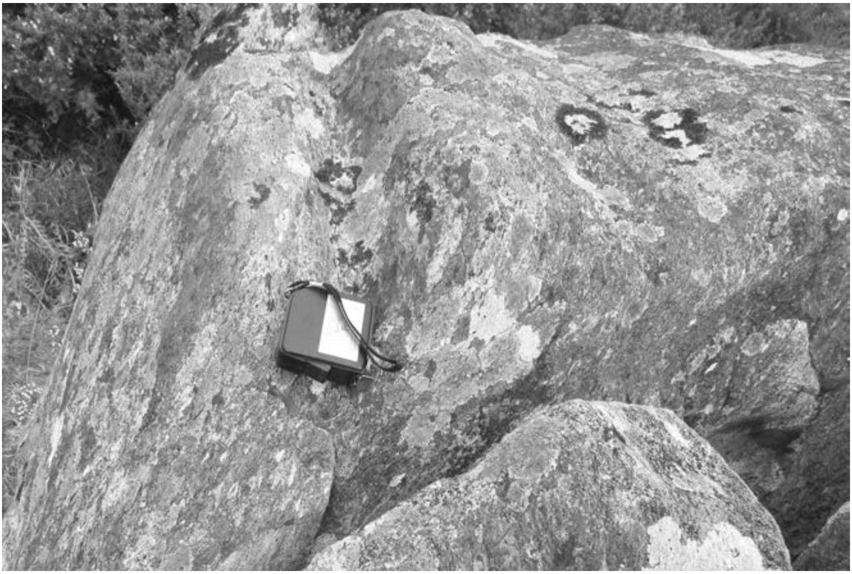

Figure 3. Moulded rock surface in the col between the main meltwater channel and the subsidiary channel - at the SW extremity of the rhyolite ridge.

Glacial sediments

During the 2013 and 2014 archaeological excavations, an extensive layer of coarse-grained diamicton was exposed (numbered 2a in Figure 4). It is similar in texture to the "local till" found on the S side of the St David's Peninsula (John, 1970b; Campbell and Bowen, 1989). It appears to rest partly on the channel's bedrock floor, and partly on rockfall material beneath the rock face. Sandy and gravelly materials predominate in the matrix, but in some locations towards the upper end of the dig site there are higher proportions of silt and clay. There are incorporated clasts of many shapes, sizes and lithologies (Figure 5). Many of the stones are faceted, and some are grooved and striated. They are also “fresh” in appearance, unlike the clasts in the “rotten” till and fluvioglacial gravels at Llangolman, on the south side of Mynydd Preseli. Most of the local rhyolite stones and boulders are bluish in colour, and they are angular or sub-angular in shape indicating that they have not travelled far. Some quartz pebbles are rough and angular, having been derived from immediately adjacent bedrock outcrops, possibly as rockfall following extensive frost weathering. There are also abundant dolerite and volcanic ash boulders and pebbles -- some of them well-rounded. The majority of erratics have come from the Fishguard Volcanic Series, from outcrops to the N and W. On the basis of the foregoing, the deposit at the base of the crag is interpreted as a local till. Where its surface is exposed there is heavy staining

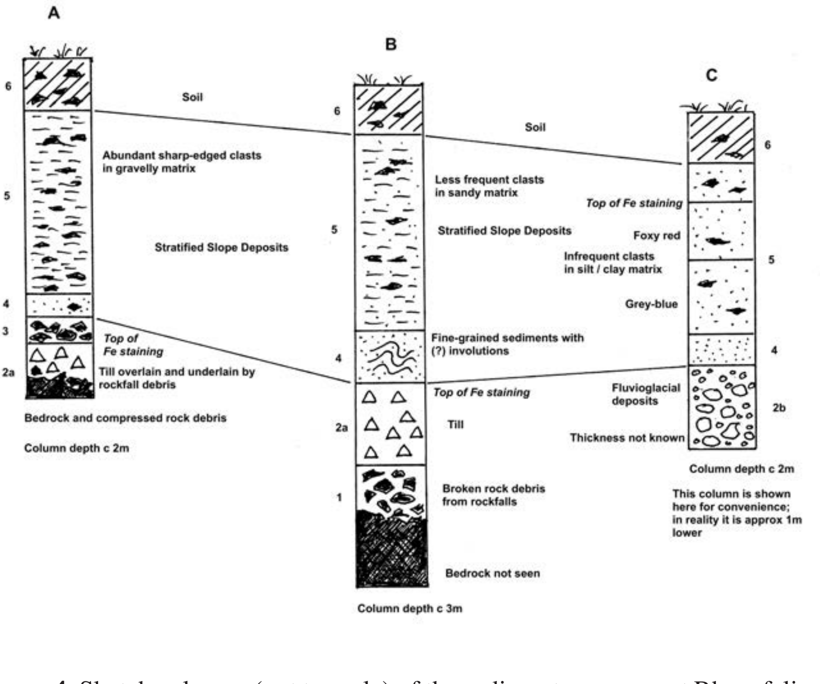

Figure 4. Sketch columns (not to scale) of the sediment sequence at Rhosyfelin, at three sites *c*. 6 m from the rock face. Both vertical and horizontal relationships are generalised. Locality A is close to the “proto-orthostat”. Locality B is some 10 m downslope. Locality C is on the valley floor, near the tip of the spur. Rockfall horizons are discontinuous, suggestive of intermittent rockfall events. Columns A and C are *c*. 3 m deep, and column B is *c*. 3 m deep. Column C is in reality *c*. 1 m lower than shown. The Fe-stained “surface” has a continuous slight downslope gradient.

by iron and manganese oxides, a crumbly structure and traces of a crust or pan. The foxy red colour of the visible exposures is reminiscent of that seen on the surface of the Irish Sea till at Abermawr, where oxidation has occurred beneath a cap of permeable fluvioglacial sands and gravels and is consistent with exposure to postdepositional weathering observed elsewhere in sediments formed during the Last Glaciation in Britain (Eyles and Sladen, 1981)).

Fluvioglacial sediments

Near the end of the spur the frequency of rounded cobbles and boulders increases, and the local till grades laterally into a poorly-sorted meltwater deposit of gravels with incorporated erratics which include tuffs, agglomerates, gabbros and sandstones (2b in Figure 4). The matrix is variable. In places it incorporates much silt and clay, and elsewhere it comprises sands and gravels. There are no exposures showing that it is underlain by till. Detached rock slabs in contact with this deposit are heavily abraded, and it is suggested that at least some of this abrasion is attributable to high-velocity and turbulent meltwater flow. These gravels are stratigraphically comparable to the fluvioglacial materials described

Figure 5. Devensian till exposed on the floor of the 2014 archaeological dig at Rhosyfelin. At this point it has a gravelly matrix and contains clasts of many different lithologies including dolerite boulders.

by Bowen (1982) and Hambrey *et al*. (2001) in the Cardigan - Monington area, but here they are much coarser, including some boulders over 1 m in diameter. It is likely that they were laid down very close to a wasting ice edge, with true glaciogenic and fluvioglacial deposits laid down contemporaneously. The archaeologists working on this site have referred to rounded "hammer stones" which in their view have been used in the quarrying process. However, those we have examined are typical of the rounded and sub-rounded clasts commonly found in glacial and fluvioglacial sediments. A search has not revealed a single "hammer stone" with the percussion marks that might be expected on a well-used Neolithic stone-working tool. Parker Pearson (in a 2014 public lecture) has also referred to the discovery of a river bank and semi-circular "revetment" made of large boulders in the fluvioglacial materials near the spur tip, linked by a routeway to the supposed quarrying area. He has suggested that this is where quarried bluestone orthostats were loaded onto rafts or sledges. However, these speculations are not supported by any stratigraphic differences between the supposed dry land and riverine environments. Recent excavations suggest the presence of a clay-rich horizon beneath some of the fluvioglacial material, but exposures near the water table are poor and are subject to flooding.

Rockfall debris

The most noticeable sedimentary features at this site are the scree and accumulated rockfall debris banked up against the rock face (Figure 2) (numbered 3 in Figure 4). Some blocks are fractured and sharp-edged, and others are smoothed and rounded as a result of glacial and fluvioglacial erosion. Close to the rock face, there is no readily-observed junction or "surface" between the till and the rockfall debris, suggesting that on parts of this site at least, the two deposits are contemporaneous. In places it is possible to observe the fractures that have occurred on grounded slabs and blocks as a result of percussive impacts associated with later heavy rockfalls. Many blocks reveal faces that are particularly heavily weathered and pitted; prior to dislodgment these faces were clearly those most exposed to the elements. There is a matrix of rubbly debris with organic inclusions and sharp-edged small rock fragments which are inferred to have moved downslope and accumulated during a long period of slope evolution punctuated by rockfalls. The finer sediments have been preferentially removed by the archaeologists in 2011-2014, leaving many of the larger blocks behind (Figure 2). We are not aware that these sediments have been logged and analysed before being removed to a large adjacent spoil tip, but the positions of the majority of large clasts have been accurately surveyed and recorded by the digging team (Parker Pearson, 2012). The 8-tonne "proto-orthostat" referred to above is in contact with the underlying till at its downslope end, and at its upslope end the till appears to be about 30 cm beneath its lower surface. It is in a fragile state: one fracture runs across its upper face, and there are various other fractures which can be traced on its sides and ends. If any attempt should be made to move it, it would probably disintegrate.

However, it has been left by the archaeologists "perched" on a base of underlying blocks following the removal of finer sediments and till. This assemblage of rocks of all shapes and sizes, some of which are broken by percussive impacts, is referred to by the archaeologists as a set of pillars, pivots, props and "railway lines" put into position by Neolithic quarrymen in order to ease the movement of the "proto-orthostat" downslope. However, there is nothing "artificial" about either the position of the large block or the stones beneath it, and since all were embedded within accumulated slope deposits and till, they all appear simply to be components of gradually-accumulated layers of glacial and post-glacial material by natural processes. Near the downslope end of the "proto-orthostat" there is a broken and elongated block of rhyolite with an upper surface displaying features described by Parker Pearson as "striations" caused by large blacks being dragged over it. On careful examination these "striations" are seen to be outcropping foliations like those seen on the edges of countless other blocks.

Solifluction sediments and colluvium

Interbedded with the rockfall debris and overlying the till and fluvioglacial deposits there is a layer of slope deposits up to 2.5 m thick (numbered 5 in Figure 4). The material exposed adjacent to the large slab is reminiscent of the "upper head" or stony solifluction layer found above Devensian glacial and fluvioglacial deposits in West Wales coastal sections (John, 1973). Exposures cut in the sediments in 2012 showed that more than 5 m from the rock face there is a clear contact between the till and the overlying pseudo-stratified slope deposits. Within the latter there are at least five different but discontinuous layers, with a *c*. 10 cm sandy/silty layer at the base. Above that, there are some layers of fine-grained sediments and others made up predominantly of elongated stones and flakes less than 10 cm in length. In addition to an abundance of sharp-edged local rhyolite fragments there are some large slabs and boulders and also, in the lower layers, rounded and sub-rounded erratics derived from upslope glacial materials. There are many signs of root penetration through this sequence, and the fine-grained layers contain many streaks of peaty organic debris. These materials have moved downslope predominantly from the NW, W and SW. There do not appear to be any ice wedge casts which might suggest the presence of permafrost at the time of accumulation or at a later date, but in lower horizons there are some signs of bedding disturbances possibly attributable to frost-heave processes.

Further downslope, where the surface gradient decreases, the stones in layer 5 become less abundant, and the sediment is predominantly made up of colluvial gravels, sands, silts and clays. Resting directly on the fluvioglacial deposits on the edge of the Afon Brynberian floodplain, there are at least three bands which are difficult to correlate precisely with the layers at the upslope end of the dig site. At the base (close to the valley floor water table) there is a blue-grey layer at least 30 cm thick. It is clay-rich but incorporates bands of gravels which appear in places to have been deformed either by loading or frost-heave processes. Above that is a layer up to 80 cm thick made up of sands, silts and clays but with some gravel and stone inclusions. It is buff-coloured, and there is no sharp junction between this and the underlying grey-blue sediment; texturally they appear to be related. In this deposit there are occasional fragments of charcoal, suggestive of either natural/accidental burning of woodland or scrub in the vicinity, or else human occupation. Passing upwards in this layer iron-staining becomes more and more prominent, until the sediment has a distinct foxy-red colour similar to that on the till surface elsewhere on the site. It is noteworthy that the iron-enriched band transgresses the junctions between stratigraphic layers, suggesting that it is a pedogenic feature related more to water table oscillations than to age (Iron "pans" are common in podzol soil horizons across north Pembrokeshire). Finally

Figure 6. The sediment sequence in the lower part of the dig site. This shows fluvioglacial gravels and contained clasts at the base, overlain by fine-grained sediments which are gleyed and oxidised, and then by dark-coloured colluvium and soil. Occasional angular clasts of local rhyolite occur throughout. Trowel for scale.

there is a grey-brown surface layer made of accumulated fine-grained slope materials, passing upwards into modern soil. There is a high content of organic matter, and more fragments of charcoal. This layer is up to 80 cm thick on the lower part of the site (Figure 6).

Discussion

Craig Rhosyfelin is related to many other tors made of Fishguard Volcanic Series rocks. The greatest concentration is to be seen on the upland ridge of Mynydd Preseli at locations including Carn Meini, Carn Breseb, Carn Alw, Carn Goedog and Cerrig Marchogion. On the lower northern slopes of Mynydd Preseli there are other tors at Carnedd Meibion Owen, in Coed Tycanol and at Felin y Gigfran. Some of these incorporate ice-moulded surfaces and perched erratic blocks, and some are so heavily denuded that they have almost disappeared (McCarroll, 2001). It is likely that Craig Rhosyfelin was once higher and more prominent than it is today: its upper surface is broken and irregular, with many loose blocks close to collapse and many others already incorporated into the rockfall debris on its flanks. Close to its tip there is much joint-widening and evidence of block detachment and collapse guided by fracture planes, strongly suggesting that it has also been reduced in length. There are no slickensides on the densely-jointed exposed rock faces, and this suggests that there has been little or no fault movement. It is therefore possible that the extreme fracturing is simply a result of ancient cooling and contraction. However, in the light of the scale of destruction of other Pembrokeshire tors, it is also possible that the fragility of Craig Rhosyfelin is partly a Quaternary legacy. Joint creation may have followed compression beneath thick and mobile glacier ice, during unloading and pressure release. This process is thought to have led to slope collapse and landsliding within the South Wales Coalfield (Woodland and Evans, 1964) and in West Wales at localities including Traeth Cell-Howell and Druidston (John, 2008). Glacial entrainment processes and large-scale block removal from "vulnerable" crags such as this are thought to have contributed to the long-term modification of the local landscape (John and Jackson, 2009), and it is probable that the most dramatic changes occurred during the Anglian glacial episode during and after a deep inundation beneath ice which was thick enough to maintain forward momentum at least as far as the coastlands of Somerset (Kellaway, 1971; Campbell and Bowen, 1989; Thorpe *et al*., 1991; Hubbard *et al*., 2009; Gibbard and Clark, 2011) .

On the matter of bluestone provenancing, and the claimed matching of rhyolite fragments at Stonehenge to a bedrock exposure within a "few square metres" near the tip of the spur, a degree of scepticism is in order. While not denying the care and the professional skill of geologists Richard Bevins and Rob Ixer, it appears to us that their sampling point density is inadequate for the degree of precision claimed; and a close reading of their published data suggests that some of the Stonehenge foliated rhyolite fragments might have come from other outcrops in the Pont Saeson area. Furthermore, they do not appear to have considered the possibility that the fragments at Stonehenge have come from parts of the crag which have been entirely removed by glacial erosion.

It is suggested that the Afon Brynberian channel is very ancient, having been cut during the glacial phase responsible for the Gwaun-Jordanston subglacial meltwater channel system which has its main intake some 6 km to the west (John, 1970a). Again, the Anglian glacial episode is the most likely candidate, since some channel mouths at the coast contain sediments that pre-date Late Devensian tills and meltwater deposits, and since the scale and the complexity of the humped channels are difficult to explain by reference to marginal and sub-marginal meltwater flow close to the Late Devensian ice limit. The main channel at Rhosyfelin and the subsidiary channel on the NW flank of the rhyolite ridge may have been modified during subsequent glacial episodes, but currently there is no firm evidence for dating any of the phases, apart from clear signs that the main channel has been deepened by at least 10 m below the intake point of the smaller channel. The rock face exposed during the archaeological dig is essentially a channel wall which carries evidence of high-velocity turbulent meltwater flow (Figure 3). It may be a relict Anglian feature, but it is likely that it was freshened during the Late Devensian ice wastage phase and that it is closely related to the bulk of the sediments at the site. This hypothesis is reinforced by the presence of many large sub-rounded and sub-angular locally-derived rhyolite blocks in the sediments.

The Rhosyfelin till, for reasons enunciated above, is interpreted as a product of a complex ice wastage environment. It is more likely to be a melt-out till than a lodgement till; but we have not been able to examine its internal structure or to ascertain whether it is *in situ*. In view of its position beneath a layer of slope deposits capped by modern soil, it is assumed to be the equivalent of the Late Devensian Irish Sea till exposed on the North Pembrokeshire coast (John, 1970a; John and Elis-Gruffydd, 1970). However, that till is composed partly of recycled sea floor sediments, with a large clay component (Rijsdijk and McCarroll, 2001). The inland till generally contains less clay in its matrix. As indicated above, abundant studies suggest that the Irish Sea Glacier flowed across the site of Craig Rhosyfelin and terminated close to the crest of the Preseli upland ridge (Campbell and Bowen, 1989; BGS, 2010).

Rockfall debris is incorporated into the till and also overlies it, replicating the situation in abundant Pembrokeshire coastal exposures (John, 1973). At some of those exposures, ice wedge casts and frost-heave features indicate that permafrost conditions persisted for at least part of the interval between the LGM and the Younger Dryas. Slope deposits from this time contain angular clasts and blocks dislodged by freeze-thaw processes on exposed cliffs and other rock surfaces. It is therefore suggested that at least some of the stratified slope deposits exposed beneath modern soil at Rhosyfelin have accumulated under periglacial conditions following the disappearance of glacier ice and at a time when vegetation was sparse. Further, there may well have been accelerated rockfalls here during the Younger Dryas (John, 1970a; Campbell and Bowen, 1989), at which time the climate was severe enough for glacier growth in the uplands and for pingos and other periglacial features to have been created in West Wales (Walker *et al.*, 2001). It is likely that rockfalls occurred intermittently during the Palaeolithic, Mesolithic, Neolithic and later periods. Because the 8-tonne "proto-orthostat" was not deeply buried, there is a possibility that it was emplaced within the past few thousand years. Nowadays biological processes associated with root expansion and plant debris accumulation in fracture cracks are responsible for triggering ongoing rockfalls. The crag is still being reduced in size.

The materials which overlie both the glacial and fluvioglacial materials, and which pass laterally into the rockfall accumulations, are not easy to interpret, but they appear to represent maybe 18,000 years of late-glacial and post-glacial climatic oscillations. More work is needed on these deposits, including the radiocarbon dating of scattered charcoal fragments and perhaps luminescence dating of the colluvium. It is suggested that some of the sediments at the base of the sequence might have accumulated in a temporary slack-water or lagoonal situation following ice retreat. There are no thick laminated silts and clays such as might be expected from a long-lasting pro-glacial lake (Hambrey *et al.*, 2001; Etienne *et al.*, 2006); but further exposures and systematic sampling at Rhosyfelin and on Brynberian Moor will assist in the interpretive process. Recent studies by one of us (BSJ) on Brynberian Moor have revealed the presence of thin slack-water sediments in some stream cuttings, but elsewhere bedrock exposures are not capped by laminated silts and clays, and lake deposits do not overlie or underlie till deposits where they are exposed in stream cuttings.

Regarding the colour variations in the finer-grained sediments, it is suggested that these are the result of gleying processes in a wet environment (cf. soil series Hafren, 0654a). The staining might be the result of a long period of surface weathering following ice retreat; but as indicated above, it is more likely to have been associated with pedogenic processes operating beneath an accumulating later layer of solifluction debris and colluvium.

It is evident from the slight terracing on the floor of the Afon Brynberian valley, and from the coarse gravels with erratics seen in the river banks, that there has been much Holocene reworking of older sediments as the river has changed its position on the flood plain.

Human Activity Traces?

As indicated above, there is a conviction among archaeologists involved in the recent dig that this is a Neolithic quarry site (Parker Pearson, 2012, 2013; Ixer, 2012), and that the rockfall debris has accumulated on a "quarry floor" as a result of human intervention. There is nothing that might qualify as a quarry floor or working surface, and there are no major unconformities or stratigraphic disruptions in the sediment sequence. All the features referred to by the archaeologists as proto-orthostats, hammer stones, wedges, sliding striations, pillars, props, fulcrums and railway tracks, are more convincingly interpreted as entirely natural features associated with multiple late-glacial and Holocene rock face collapses.

It is also argued by Parker Pearson that the Rhosyfelin rhyolite was revered or special enough to have justified a vast expenditure of time and effort on the part of Neolithic tribesmen, without metal tools, with a view to extracting bluestones and transporting them from this site to Stonehenge. However, Rhosyfelin rhyolite has not been used in any of the Pembrokeshire standing stone settings or burial chambers, so it was clearly not deemed to hold any mystical or magical properties or to have value for constructional purposes. Furthermore, as indicated above, the "proto-orthostat" which is the focus of so much attention is so fragile and seriously fractured (like other large stones at the site) that its chances of surviving even a short haulage expedition by land or sea would have been minimal.

The "proto-orthostat" appears to have fallen into its present position at some stage after the deposition of the Rhosyfelin till. The archaeologists appear to have identified the red-stained till surface as the putative quarry floor. Thus, if the archaeological hypothesis is correct, all of the sediments above the glacial and fluvioglacial layer at Rhosyfelin must have accumulated during the last 5,000 years. In other words, in this small valley with steep bounding slopes, there is no sedimentary record of the period between ice wastage and the end of the Mesolithic, spanning a period of *c*. 15,000 years. It is more likely that most of the sediments above the glacial and fluvioglacial layer at this site have accumulated gradually over a time-span of about 20,000 years, with the identified upper layers (Figure 4) representing a sequence of climatic oscillations yet to be quantified by radiocarbon and other dating techniques.

While there appears to be no landform, rock mechanics or sedimentary evidence that this was a Neolithic quarry site devoted to the extraction of bluestone orthostats destined for use at Stonehenge, we would accept the possibility that there may have been temporary Mesolithic, Neolithic or later camp sites here over a very long period of time, as in many other sheltered and wooded locations in north Pembrokeshire. Parker Pearson has reported (in public lectures) that a hearth and other occupation traces have been found near the tip of the spur, and it is anticipated that this will be confirmed by radiocarbon dating and artifact finds. Sites such as this may have been used in the context of a hunting, fishing and gathering economy involving seasonal migrations (Bell and Walker, 1992). It is also possible that rhyolitic raw materials from this site may have been used in the manufacture of blades and other cutting implements which changed hands during tribal trading activities (Pitts, 2013).

We trust that our initial observations at Rhosyfelin will stimulate further detailed research by those who have access to modern analytical and dating methods.

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REPORTS

QRA FIELD TRIP: THE QUATERNARY OF THE LAKE DISTRICT - 21-24th May 2015

Members of the QRA attended a 3-day field meeting in the Lake District to explore some of the ongoing investigations into the glacial landscape of the area. Major themes on the course included the recognition, timing and processes of large-scale rock slope failures (RSFs); glacial landforms; and understanding both Younger Dryas and pre-Younger Dryas glaciation style and extent.

The trip started with arrivals at the Blencathra Field Studies Centre via some heavy traffic. After dinner an introduction to the trip was given by **Dave Evans** and **Des McDougall**, and the group also listened to talks surrounding some of the contemporary questions around the RSFs at Clough Head and the Threlkeld Knotts, given by **David Jarman** (Mountain Landform Research).

Day 1

The next morning we set out in minibuses towards Hayeswater Valley to look at lateral and recessional moraines defining the downvalley limit of the Hayeswater glacier, and also the cross-valley asymmetry of moraines. The climb up to the Hayeswater Valley was broken by a short stop at which **Peter Wilson** (Ulster) discussed a small rock slope failure in the vicinity of Gray Crag, east of the Pasture Beck Valley. The contribution of the Gray Crag rock slope failure debris to the YD-age moraines is unknown (there are no exposures). The Gray Crag RSF must pre-date the Holocene due to the lack of RSF debris at its foot and may even pre-date the Last Glacial Maximum.

The group continued their ascent to the Hayeswater Valley, where there are some very impressive moraines. These are assumed to be Younger Dryas in age, based on their morphology and location, although it has been suggested that moraine morphology is an unreliable relative dating technique in some other parts of the eastern Lake District due to complex interactions between glaciers and topography over both space and time (McDougall, 2013). A potential solution is provided by the examination of soil weathering profiles on moraine crests, which appears to allow Younger Dryas features to be differentiated from older landforms, and this technique was demonstrated by **Hannah Bickerdike** and **Dave Evans** (Durham) in the field.

Peter Wilson (Ulster) discussed the likely impact of a small rock slope failure below The Knott on the development of a prominent fan on the lower slopes (Figure 1), and **Des McDougall** (Worcester) discussed the role of reworking on the fragmentary, steeply-sloping lateral moraines on the eastern slopes. Unfortunately, poor lighting conditions meant that these moraines and related landforms were difficult to identify. **Sven Lukas** (QMUL) queried the extent to which the geomorphological mapping supported the proposed ice margin configurations, specifically the proposed steeply-sloping ice margins on the eastern slopes (and supplied from the summits above). The resulting discussion soon changed tack to thrust moraines, following a comment from Mike Hambrey (Aberystwyth), although this was curtailed prematurely by the need to move on to the next site.

Figure 1. Peter Wilson discussing a rock slope failure located below The Knott, high on the opposite (eastern) valley sides of Hayeswater (Photo: Brian Whalley).

The planned visit to the Pasture Beck valley, which runs parallel to Hayeswater, was modified due to time constraints. **Dave Evans** found a good vantage point which allowed the group to look into the valley from midway up the eastern slopes. From here, **Des McDougall** discussed moraine development in the valley, and Dave Evans described the soil weathering profiles that he and Hannah have obtained. These indicate that Sissons' (1980) downvalley limit for this glacier is more or less correct.

The final stop of the day was at the Clough Head / Threlkeld Knotts rock slope failure(s), where **Tim Davies** (Canterbury, NZ), Stuart Dunning (Northumbria), **David Jarman** and **Peter Wilson** led the group around multiple sites. At the heart of the discussion was the question as to whether this is simply one giant, spectacular rock slope failure, as argued by Davies *et al*. (2013), or whether – as David and Peter argued in the field – this site is possibly more complex, comprising a series of smaller, more restricted rock slope failures, as well as being modified by glaciation (figure 2). Although there was no resolution of this debate in the field, the group enjoyed great views and some excellent geomorphological discussion during the visit.

Figure 2. Discussions in the field on Threlkeld Knotts (Photo: Des McDougall).

The evening talks centred on cirques in the Lake District (**Ian Evans**, Durham) and a summary of some Lake District rock slope failures (**Peter Wilson**). The discussions were then taken upstairs to the more sociable setting of the bar.

Day 2

The first stop of the day was at Honister Pass where, under a clear blue sky, **Des McDougall** briefly discussed the moraines that had been produced by outlet glaciers descending into the valley from the summits to the north and south. Although reconstructed ice margins demonstrated beyond doubt that these summits had been glacierised, the downvalley extent of this ice mass (presumably Younger Dryas age) is ill-defined because the moraines gradually fade out on the steep descent to the Borrowdale valley below.

The second stop of the morning featured a somewhat taxing 550 m climb to near the summit of Robinson, led by **Peter Wilson** and **David Jarman** (Figure 3). On the flank of Robinson is one of the largest RSFs in the Lake District by area, including an antiscarp complex. The RSF displaced the valley axis south by up to 100 m, along with other major landscape changes. It is thought that the majority of the failure took place pre-LGM, but some zones of the RSF may have been re-activated post-LGM.

Figure 3. Ascending Robinson, with Honister Pass in the distance (Photo: Des McDougall).

The final stop of the second day was at Wasdale Head, near Wastwater, where the group walked into the Mosedale Valley. Here, **Dave Evans** and **Vicky Brown** (Durham) discussed the impressive cirque, Younger Dryas moraines, and several depositional landforms including a boulder fan and a snow/slush avalanche pit (Figure 4). Numerical ice-modelling produces YD glacier extents consistent with the geomorphological evidence in this area. The modelling, however, indicates 2-3 ice readvances rather than just the one, with the later advances of a lesser extent but longer duration. In this area, the ice-reconstructions of Sissons (1980) are largely accurate given the alpine glaciation style. Numerical ice modelling also indicates that the Younger Dryas summit icefield fed snow/slush avalanches, which caused the proposed avalanche impact pit in the valley head (although this feature prompted plenty of discussion). The modelling and geomorphological evidence are further supported by soil weathering profiles.

Figure 4. Dave Evans discussing the snow/slush avalanche pit (behind), with the Younger Dryas moraines visible in the distance (Photo: Des McDougall).

The evening's talks were given by Brian Whalley (Sheffield), on ice-debris examples from around the world, and Rachael Avery (Southampton), on the potential of Windermere's annually-resolved Lateglacial sediment record.

Day 3

The final day featured a visit to Deepdale, a northeast-oriented valley with several landforms on its floor including flutings, moraines, ice-moulded bedrock and RSFs. **Des McDougall** and **Dave Evans** discussed geomorphological mapping, soil chronosequences and glaciological modelling, which all indicate that the downvalley limit of this Younger Dryas glacier corresponds with Sissons' (1980) mapping. However, further upvalley, ice thicknesses were greater, and the ice mass was contiguous with the one that occupied Grisedale to the west.

The first stop was at the proposed terminus of the Younger Dryas glacier which, unlike some other locations, is clearly and unambiguously defined by the landform record (moraines, with gullied slope failure deposits beyond). The group proceeded upvalley, past tracts of recessional moraines of varying development. Dave Evans suggested that the most prominent moraine belts were the result of a period of limited readvance and/or stillstand, which is consistent with the climatically-driven glaciological modelling output for Deepdale. The group then proceeded to climb up into Cawk Cove, where there were opportunities to look at ice-moulded bedrock (including impressive roches moutonnées) and, for those willing to climb

Figure 5. A large fluting at the head of Deepdale (Photo: Josh Chambers).

further still, some unusually large flutings (figure 5). The latter are thought to have attained their size through high sediment supply and fluvial gullying.

Overall the field trip was a successful learning experience for all, giving participants not only a deeper understanding of some of the geomorphological processes at play during the late Quaternary but also an excuse to spend a weekend enjoying some of England's most beautiful landscapes in the name of science! A big thank-you to Des McDougall and David Evans for organising the trip, and to the Blencathra Field Studies Centre for being such excellent hosts.

Figure 6. Group photo (Photo: Clare Boston).

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THE QUATERNARY OF SOUTHERN SOUTH AMERICA

School of Geographical and Earth Sciences, University of Glasgow; 2-3 June 2015

Introduction

A short meeting was held in June at the University of Glasgow to allow discussion on the broad theme of Quaternary research being conducted in southern South America (i.e. Patagonia, in southern Chile and Argentina). It was unusual in that it focussed on the work of UK academics in a geographical area outside of the UK, and the intention was to allow delegates to present ongoing research, identify knowledge-gaps, and discuss the potential for future work and collaboration. Such discussion has been challenging at previous, more general conferences.

The meeting was co-organised by **Alessa Geiger** (University of Glasgow), **Chris Darvill** (Durham University/British Antarctic Survey), **Tom Roland (University of Exeter)** and **Neil Glasser** (Aberystwyth University). In all, 37 delegates from 19 different institutions, including 12 postgraduate students, attended the meeting. There were 16 oral presentations, nine poster presentations and a keynote talk by **Frank Lamy** (Alfred Wegener Institut, Germany). The conference highlighted the broad range of research being conducted in this region by a large group of UK academics from numerous institutions. It is important to note that the meeting was not closed to foreign academics (though as a QRA meeting, it was perhaps inevitable that most delegates were from the UK) and was not ignorant of the high quality research being conducted by others around the world, including in Chile and Argentina.

The presentations were grouped into four broad sessions. The first day focused on tephrochronology and palaeoenvironmental reconstruction, followed by Frank Lamy's keynote talk and an excellent conference dinner in the evening. The second day started with a poster session, followed by talks on glacial geochronology and palaeo-glaciology. Plenty of time was allowed for discussion, and this highlighted a series of key research areas. Rather than give a chronological description of the conference, this report has been arranged around those research areas.

1. Understanding the dynamics of the Southern Westerly Winds

The Southern Westerly Wind (SWW) belt is a key component in southern hemisphere climate change, though its dynamics remain poorly understood, as was comprehensively outlined by **Frank Lamy** in his keynote talk. Principally, it is challenging to reconstruct changes in the SWW from proxy records, and robustly tying reconstructions to model predictions remains difficult. Furthermore, records over different timescales reveal different aspects of SWW dynamics. Frank suggested a number of key unanswered questions regarding the SWW: (1) how do long-term orbital-scale changes in the SWW differ between the northern versus the southern margins? (2) Can we reconcile records of the SWW from the west and east of the Andes range? (3) Is there a tipping point from north to south and east to west (and where and why)? (4) Critically, did the SWW shift or expand over time? The latter question is perhaps most pressing but also the hardest to ascertain.

Other presentations demonstrated a number of new and exciting methods being employed to reconstruct former SWW position and/or intensity over time, many of which are still under development. The PATAGON project has been working on reconstructing changes in the SWW in the southern reaches of South America. **Dmitri Mauquoy** (University of Aberdeen) described how testate amoebae can be used to reconstruct mire surface wetness and thus changes in the SWW, because weaker westerlies cause a drop in effective precipitation over raised peat bogs, such that the water table drops. Despite wide confidence intervals, peat cores indicate meridional shifts in SWW during the last 1000 years, with a poleward shift between ca. 1200 and 800 cal yrs BP followed by an equatorward shift between ca. 800 and 350 cal yrs BP. **Neil Loader (Swansea University)**, also working on the PATAGON project, presented accompanying C, O and H isotope data from sphagnum moss. The system is more complicated than previously thought, because plants are affected by evaporative enrichment, but records for the last 2000 years show variability in SWW over time.

Pete Langdon (University of Southampton) outlined his aim to develop palaeoclimate proxies for northern Patagonia to test local responses to climatic change and then use these to test regional synchroneity. Cores from close to the Nef valley, on the eastern side of the Andes in northern Patagonia demonstrate that lakes on the eastern side of the Andes are sensitive to Holocene climate change, with clear shifts around 5.5 ka and 2.7 ka. Chironomid records seem to show lake level changes, matching reconstructions from carbonate and organic matter records and highlighting the potential for reconstructing both SWW and broader climatic change. **Tom Bishop** (University of Southampton) also described how proglacial lake records from the Chacabuco valley may help to understand past changes in the SWW. The site is located in the middle of Patagonia and may be an ideal location to observe changes in SWW intensity, given that northern Patagonia experiences the boundary of the SWW and southern Patagonia is more influenced by the Antarctic system. However, whilst there is good evidence for reconstructing lake level change, the late glacial sediments contain few diatoms or pollen, and are difficult to date. Furthermore, it is difficult to disentangle precipitation and temperature signals anywhere in Patagonia – they are positively correlated in the north, negatively correlated in the south and show little or no correlation in the middle!

Steve Roberts (British Antarctic Survey) discussed work using several lake cores from across southern South America. For example, Laguna Parillar, near Punta Arenas, shows a switch at ca. 12 ka from a deeper ice-dammed lake to a shallower, wind-driven lake record, possibly linked to reduced SWW influence. Steve also outlined current work on Isla Hermite in the Cape Horn region, at the southernmost tip of South America. Diatom assemblages are being used to reconstruct conductivity over time related to sea-spray from the ocean into lakes, which is a proxy for SWW strength. By contrast, **Stephan Harrison** (Exeter University) advocated the use of ice sheet trimlines to determine ice sheet thinning over time given that this can be linked to migration of the SWW, particularly when thinning is shown to be rapid. However, a greater number of robustly dated 3D transects are required to achieve this, from both north to south and east to west across the former Patagonian Ice Sheet.

What is apparent from these studies is the need (and often difficulty) in separating local factors affecting proxy reconstructions – be they ocean, peat or lake cores, or vertical ice sheet limits – from a clear signal of SWW change, and then definitively identifying whether this relates to a shifting or expansion/contraction of the SWW belt. Though a number of studies are making real progress in reconstructing past changes in the SWW, there remains more work to be done.

2. The application of tephrochronology to constrain the timing of events

Southern South America is host to a number of volcanoes known to have been active during the Quaternary period, some of which are still active today. Given the need for tight chronological constraint on all climatic and environmental reconstructions, tephrochronology in this region has the potential to be a useful tool. **David Pyle** (University of Oxford) presented a comprehensive summary of research into Quaternary tephrochronology of the southern volcanic zone. There is evidence for large scale post-glacial modification of the system after ca. 17 ka, and a key question is the effect of the removal of ice-load on volcanic activity. From David's review of the literature, 25-30 tephra deposits are known with reasonable age models, though few are north of the Hudson volcano in the Chilean Lake District. The properties of these tephras can help to indicate the explosivity and magnitude of past volcanic eruptions, and his data indicate large eruptions of evolved lava after removal of ice, followed by post-glacial relaxation of the system towards an eruptive equilibrium.

Two localised studies from the Chilean Lake District were also presented. **Steve Roberts** showed a 600-year eruption record of Volcan Villarrica from a 14 m Holocene core in Lago Villarica. Micro-XRF core scanning was able to distinguish tephra-fall layers, run-off cryptotephras and lahar deposits in the lake. Meanwhile, **Stefan Lachowycz** (University of Oxford) focussed on the eruptive history of Volcan Hudson, south of Chiloe. There is a record of four large eruptions within the last 20 ka, as well as tens of smaller eruptions over this time. Most of the associated tephras have narrow geochemical compositions, but consecutive deposits have similar signatures, such that caution should be used in correlating Hudson tephras at different locations.

Whilst the capacity for tephrochronology to help tighten stratigraphic age models in the region is clear, these presentations also highlighted the need for clearly distinguished regional tephra deposits and improvements in both the spatial and temporal framework of tephra studies across Patagonia.

3. Linking oceanic and terrestrial archives

Oceanic records can inform regional temperature reconstructions, but two presentations also demonstrated the value of combining such information with the terrestrial changes recorded in marine sediments. **Frank Lamy** presented a range of studies on changes in the Patagonian Ice Sheet, ocean currents, and sea surface temperatures. A record from the Pacific side of southernmost South America shows changes in ice rafted debris associated with fluctuations of western, marine-terminating glaciers. There is capacity for further work in the marine realm to assess changes in ice rafted debris and constrain the size of the western portion of the ice sheet by searching for submarine moraines. Frank also discussed the use of sortable silt in assessing changes in ocean current velocity, extending northward previous work on the Antarctic Circumpolar Current. The flow of this current was strongly reduced during the LGM, and greater constraint on changes will improve our understanding of Southern Ocean circulation more broadly. Finally, foraminiferal and alkenone-derived sea surface temperature reconstructions have shown strong LGM cooling along the west coast of Patagonia, revealing the extent to which the Subantarctic Front can migrate over time. A record for the last 65 ka shows millennial variability in phase with Antarctic ice cores, but also evidence for early melting of Magellanic glaciers, possibly due to early warming.

This work ties in closely with that by **Jenny Roberts** (University of Cambridge/ British Antarctic Survey). She presented a record from the Falkland Trough in the southern Atlantic, using a combination of alkenone biomarkers and foraminiferal oxygen isotopes to track changes in water source over time. The marine core shows a freshwater signal due to sea ice melt during the last glacial maximum, continental glacial freshwater during deglaciation, and marine saline conditions during the Holocene. Importantly, the record shows that the Pacific and Atlantic signatures were very different during deglaciation, with the latter showing freshwater pulses indicative of large proglacial lake drainage events, possibly from the Strait of Magellan. Another event during the ACR could represent a previously unmapped glacial outburst flood around 14 ka. Jenny was also able to extend her record back to show that sea surface temperatures were around 5°C cooler during MIS 6 than MIS 2. However, ascertaining whether such differences relate to regional climate or the movement of ocean fronts remains challenging.

Overall, incorporating evidence from marine records can improve our understanding of terrestrial changes, such as ice sheet fluctuations and glacial meltwater floods. Furthermore such records can provide information about changes in ocean currents and sea surface temperatures. These are invaluable in assessing regional climatic change but require a greater number of records to more effectively reconstruct regional variability.

4. The timing of glacial advances

A number of presentations used new approaches to dating methods to enhance our understanding of the timing of glacial advances associated with the former Patagonian Ice Sheet. Glacial limits associated with the 'Greatest Patagonian Glaciation' have previously been dated to around 1.1 Ma, but **Andy Hein** (University of Edinburgh) used cosmogenic nuclide depth profiles through outwash plains to demonstrate that moraines associated with Loma Chipanque in northern Patagonia, date from around 2 Ma. These are some of the oldest moraines dated in southern South America, and indicate that piedmont style glaciation may have occurred prior to the Greatest Patagonian Glaciation.

Four different presentations gave evidence for glacial advances during the last glacial cycle, but prior to the global Last Glacial Maximum. **Rachel Smedley (Aberystwyth University)** used new luminescence dating techniques on outwash sediments associated with the Lago Buenos Aires lobe in northern Patagonia to demonstrate glacial advances around 34-31 ka. Similarly, **Chris Darvill** (Durham University/British Antarctic Survey) used cosmogenic nuclide depth profiles from outwash associated with the Bahía Inútil lobe in Tierra del Fuego to demonstrate that the glacial limits are much younger than previously thought, including a clear, extensive advance around 31 ka, prior to a much less extensive glacial limit associated with the global Last Glacial Maximum.

Two studies used glacial trimlines to constrain the timing of ice sheet thinning. **Stephan Harrison** presented cosmogenic nuclide data from the Pueyrredón lobe in northern Patagonia that showed rapid thinning during deglaciation, likely linked to migration of the westerly winds. Likewise, **Alessa Geiger** (University of Glasgow) presented an ice thickness record from the Viedma lobe region highlighting early ice sheet growth from 77-47 ka, followed by thinning after 40 ka. An intriguing alternative to trimline evidence was presented by **Stefan Lachowycz**, whereby the characteristics of lithofacies associated with former glaciovolcanism can be used to reconstruct ice sheet thickness. At Volcán Sollipulli in the Chilean Lake District, the landforms show a transition from ca. 110 ka to 66 ka indicative of ice covering the caldera.

The story that emerged from these presentations is of glacial expansion across Patagonia during the last glacial cycle, but prior to the global Last Glacial Maximum. This is contrary to some of the established age models across the region and requires more testing, principally by targeting pre-'Last Glacial Maximum' limits associated with a range of glaciers.

5. Glacial dynamics over a range of timescales

As mentioned above, a number of presentations discussed the timing of glacial activity in southern South America, with implications for the nature of glacial advances. In addition, several talks presented data that improves our understanding of the dynamics of glacial change in Patagonia. **Jacob Bendle** (Royal Holloway, University of London) presented initial work on varve sequences from Valle Fenix Chico at Lago Buenos Aires. This work builds on the pioneering work of Caldenius, 80 years ago, but uses new sedimentological techniques to improve our understanding of ice sheet change in the region. Importantly, this has the capacity to examine continuous glacier response to climatic changes over decadal timescales, in a way that fragmentary dating of glacial moraine limits cannot achieve.

Harold Lovell (University of Portsmouth) compared detailed work on the glacial geomorphology associated with surging glaciers in Svalbard with the geomorphological record in places like the Magellan lobe in southernmost Patagonia. Whilst only an initial, tentative assessment, the study suggested evidence for palaeo-surges in southern South America. More work is required, but the paucity of evidence globally for palaeo-surges makes this an intriguing prospect and one that could improve reconstructions of former glacial advances. A comprehensive study of the dynamics of glaciers across Patagonia since 1870 was presented by **Bethan Davies** (Royal Holloway, University of London). It highlighted that 90.2% of glaciers have shown continued and accelerating shrinkage over this time, with greatest effect in small, land-terminating glaciers. Such a detailed study is only really possible over the timescale of 'modern', observational data, but it highlights the importance of understanding spatial differences in glacial dynamics when considering reconstructions over longer timescales.

Previous work on glacial activity in southern South America has often focused on dating glacial limits (although, as the previous section showed, this still needs refining!), but these presentations also highlighted the need for a greater understanding into how glacier dynamics varied over time across the former Patagonian Ice Sheet. This will improve glacial reconstructions and may help to interpret where there are spatial differences in the timing of former glacial advances.

6. Using vegetative records to reconstruct past environments

There is a long history of palaeoenvironmental reconstruction in southern South America, with UK researchers often contributing to this research. Presently, three PhD students are working on reconstructing vegetation changes in the region. **Emma Rice** (Plymouth University) is working on three peatland sites in Chile and the Falkland Islands to extract multi-proxy records from the core of the westerly wind belt. These will be used to reconstruct changes in the westerly winds during the late Holocene. Similarly, **James Blakie** (University of Stirling) presented work using palaeovegetation data from lake and peat records on a north-south transect between 47°S and 55°S to reconstruct temperature and precipitation changes during the late glacial and Holocene period. **Lauren McHardie (University of Aberdeen)** used a peat sequence from an ombotrophic bog in the Magellan area of southern South America to examine the relationship between biological and geochemical proxies in reconstructing late Holocene climate and vegetation. Whilst non-pollen palynomorphs likely respond to internal dynamics of the bog, pollen was found to be a more effective way of identifying external climate shifts. This work builds upon previous research and is vital for improving our understanding of both landscape and climatic change in the region.

The reconstruction of past vegetation can also help in understanding changes elsewhere in the world. For example, **Keith Bennett** (Queen's University Belfast) discussed a shift from tree to heather pollen around 3 ka in the Shetland Isles, but it is unclear if this was linked to human activity. Southern South America offers a similar cool oceanic climate containing a woodland-moorland mosaic on formerly glaciated terrain, but with minimal human interference. Small lake cores from across the Taitao Peninsula, Chonos Archipelago and Strait of Magellan were analysed for pollen assemblages. Although the direction of forest movement is still not altogether clear, the mosaic of woodland and moorland was established from around 10 ka and is stable, despite the cool, wet climate. Thus it seems that zonal shifts in vegetation in Shetland are likely related to human activity.

Conclusions

The principle aim of this conference was to bring together a range of people working in southern South America – likely tackling similar scientific problems – who would not normally attend the same meetings or have the opportunity to discuss their work with one another. The effectiveness of the meeting was discussed after the presentations, and it was agreed that it had been a novel and very useful exercise, and had achieved its aim. Many agreed that a follow-up meeting in a couple of years' time would also be advantageous, to allow the presentation of results from ongoing work and to solidify future collaborations. It was generally agreed that the conference had been a great success and had highlighted several key research areas that required further work.

I would like to extend my gratitude to my co-organisers of the conference, and particularly Alessa Geiger for her excellent logistical organisation at Glasgow. The meeting could not have taken place without the funding and support of the QRA, the British Society for Geomorphology, Van Walt, Beta Analytic and the School of Geographical and Earth Sciences, University of Glasgow.

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20TH QRA ANNUAL INTERNATIONAL POSTGRADUATE SYMPOSIUM - 2-4 September 2015, University of Cambridge

In early September 2015, over 45 delegates from 21 institutions across the UK and three international universities attended the 20th QRA Postgraduate Symposium hosted by the University of Cambridge at the Scott Polar Research Institute. The meeting was a resounding success thanks to the organisational efforts of Jenny Roberts, Julia Gottschalk, Michelle McCrystall, Ashleigh Massam, and Tom Williams. Over the course of three days attendees presented their work in oral and poster sessions covering a diverse range of Quaternary-related research, including datasets from ice, marine and terrestrial cores, and palaeoclimate reconstructions from the UK, Eurasia, and the Americas.

Wednesday 2nd September

On the first day #QRAPG15 began with a guided tour of the British Antarctic Survey (BAS). After an introduction given by Tim Moffat, the delegates were shown several key aspects of BAS research. The first visit was to the MAGIC office, or rather the Mapping and Geographic Information Centre, where Adrian Fox explained how BAS create maps of Antarctica (and the Arctic) at a variety of scales, as well as the challenges this presents. In addition to learning about research into penguin population surveys using satellite imagery, Adrian introduced the Bedmap project. This used 25 million measurements of ice thickness to show the subglacial landscape of Antarctica. Following MAGIC, we moved on to see the low-temperature marine aquarium containing fish and invertebrates brought back from Antarctic waters, such as sea anemones and star fish. Experimental work conducted in this controlled setting can help BAS scientists understand more about how polar faunas adapt to changing environmental conditions. At the third stop delegates were able to explore the rock store which archives a large proportion of specimens brought back from Antarctic expeditions over the years. There were exquisite examples of ammonites on show, preserving intricate floatation chamber walls. The final visit of the tour was to learn about ice core retrieval and see how the ice is processed back in the lab. Delegates were shown the coring equipment used in drilling operations and had the chance to go inside the core store. Here we saw examples of tephra layers embedded within recovered ice segments and thinly sliced core sections that visibly enclose the small bubbles of past atmosphere used in analyses. Later that evening an ice breaker event was held in the Sedgwick Museum of Earth Sciences at the University of Cambridge, allowing everyone to exchange introductions and catch-up amongst the splendid geological collections.

Thursday 3rd September

The second day of the symposium commenced with a keynote lecture from Robert Mulvaney, who leads the Ice Dynamics and Palaeoclimate science team at BAS and is responsible for ice core drilling operations in Antarctica. Dr Mulvaney presented the ice core evidence of climate change and deglaciation in the Weddell Sea region and discussed several glacial histories from the area, which provided a fantastic start to the day of talks and posters ahead. The first postgraduate presentation session, 'Ice cores and Antarctica', continued the polar theme and focussed on reconstructing glacial phases on the Antarctic Peninsula. Moving to the marine realm, the next session 'Ocean circulation' showcased research from the Southern and Atlantic oceans, both in a more recent context (last glacial period to Holocene) and also across the glacial-interglacial cycles of the Quaternary (back to 1.5 Ma). Within this session a keynote lecture was given by Babette Hoogakker from the University of Oxford, who discussed applying a novel proxy-method in the North Atlantic to determine past deep water dissolved oxygen concentrations. The third and final postgraduate presentation session of the day, 'Palaeoclimate reconstructions from the UK', included talks on the use of seismic data to investigate the geomorphological record of the Irish shelf and also on cores from the site of Lake Humber in the Vale of York being used to reconstruct British ice sheet dynamics during the Late Devensian. Following the talks, a poster session allowed more postgraduates to present their research and generated further discussion, advice and feedback. Late evening delegates were welcomed to the Riverside Restaurant for the conference dinner, where an extended banquet table played host to outstanding food and provided the opportunity to socialise and discuss the day's events.

Friday 4th September

The last day of the symposium continued on the theme of UK-based records from Thursday afternoon, with talks on characterising the relict forms of perennial frost mounds and the regional palaeoclimate significance of varved sediments from

Lake Windermere. The next session, 'Palaeoclimate reconstructions from Eurasia and Northern Hemisphere Quaternary', covered a broad range of research areas and analytical techniques, from an isotope record covering the Mid-Pleistocene Transition in the Japan Sea, to examining the effect of anthropogenic land use change during the Holocene using data generated from global climate model simulations. This session ended with a keynote lecture on funding opportunities, presented by Lucy Gonzalez from Anglia Ruskin University. Her engaging talk discussed the practicalities of acquiring funding, its importance and relevance to a future career in academia, and provided some great advice on how to get research funding, with a particular focus on the EU Horizon 2020 initiative. The final postgraduate session on equatorial palaeoclimate reconstruction described environmental change in Kenya, droughts in Amazonia, and the past movement of the South Pacific Convergence Zone.

As with previous symposiums, delegates were asked to vote for their choice of best oral and poster presentations; given the standard of research and effort shown by all contributors, there was tough competition. This year Francesca Falcini (University of York) was awarded a prize for her poster '*Roughness of palaeo-ice stream beds*' and Alwynne McGeever (Trinity College Dublin) was awarded a prize for her talk '*Population dynamics of Pinus and Ulmus in Europe during the Holocene*'. The symposium concluded with the Annual General Meeting, where Laura Crossley (University of Southampton) was elected as the new junior postgraduate representative on the QRA Executive Committee and Jack Lacey (University of Nottingham) takes over the role of senior postgraduate representative from Christopher Darvill (BAS/Durham University). Christopher has been an active member of the QRA community, and thanks are extended to him for all his work and commitment within the QRA.

The QRA symposium exists to provide postgraduate students a forum to present their research in a relaxed, supportive and enjoyable environment, and the University of Cambridge team did an excellent job of upholding this tradition. Thank you to all the delegates, this symposium was one of the largest and most successful to date with many postgraduates being new members and first-time attendees. We hope to see everyone again, along with many new faces, at the 21st QRA Annual International Postgraduate Symposium hosted next summer by the University of Nottingham.

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^{14}CHRONO AWARD

QUATERNARY PALAEOLIMNOLOGY AND ENVIRONMENTAL CHANGE IN THE SOUTH WOLLO HIGHLANDS, ETHIOPIA

Rationale

Until recently a significant knowledge gap has existed in Ethiopian palaeoclimatic research. The majority of research has focused on the Main Ethiopian Rift (Lamb *et al*., 2000), the Afar Depression (Gasse, 1977) and the southern highlands (Umer *et al*., 2007), creating an uneven spatial and temporal understanding of Ethiopia's Quaternary palaeoclimate and palaeoenvironment. Consequently, the climatically sensitive and drought-prone north has received less attention (Marshall *et al*., 2009). The study of Lake Hayq (Figure 1) is adding to a growing body of evidence examining the regional Quaternary climate of northern Ethiopia. A PhD study combining high-resolution diatom and sedimentary pigment analyses from the lake (as part of a wider, international, multi-proxy project) forms the basis for reconstructing the palaeolimnology of L. Hayq, from which regional climatic and environmental conditions can be inferred.

The QRA ^{14}CHRONO Centre Radiocarbon Dating Award has provided a chronology for the sedimentary record, against which changes in palaeolimnological proxies can be assessed in terms of regional and global climate events.

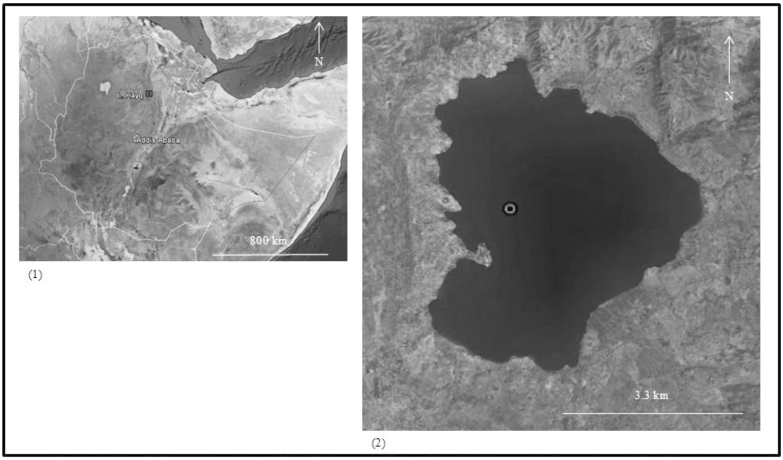

Figure 1. (1) Location of Lake Hayq on the eastern margin of the north-central highlands, Ethiopia (Google Earth). (2) Lake Hayq 11°20'53"N 39°42'32"E 1950m altitude. The circle indicates the location of the core, Hayk-01-2010, used in this study,

Results

In 2010 a 7.3 m sediment core was extracted from the northern basin of L. Hayq from 78 m water depth by Henry Lamb (Aberystwyth University) and colleagues from the University of Cologne. After sieving found insufficient terrestrial macrofossils for dating, three bulk sediment samples were analysed for AMS ^{14}C dating at the ^{14}CHRONO Centre Laboratory. At the base of the core (695.5-696.5 cm), sediment was dated to 15,388±60 cal BP. This late Pleistocene sample is characterised by an absence of diatoms in the sediment, suggesting arid conditions and possibly an intermittent, shallow lake. In the mid-core (428.5-429.5 cm), sediment was dated to 12,289±45 cal BP. At this time the lake was dominated by planktonic diatoms (*Aulacoseira granulata*, *Stephanodiscus parvus*) indicating deep, fresh, nutrient-enriched waters. The third sediment sample (175.5-176.5 cm) was dated to 3848±36 cal BP. This late-Holocene date is characterised by benthic diatom taxa (*Gomphonema parvulum*, *Fragilaria ulna* var. *ulna*), indicating a decrease in lake depth.

Significance

The radiocarbon dates indicate the sediment core has formed since the late Pleistocene. The period of time covered by the sediments include significant global climatic events known to have had regional impacts on lake systems and environments in East Africa (Barker and Gasse, 2003; Tierney and deMenocal, 2013), e.g. the Younger Dryas Stadial (~12.8- 11.6 kyr BP; Tierney *et al*. 2011), the termination of the African Humid Phase (~5.5 kyr BP; Gasse, 2006) and the 4.2 kyr BP drought (Gasse, 2000). By quantifying changes in palaeolimnology against a reliable chronology, it is possible to assess if and how L. Hayq responded to these climatic events. This is essential for identifying the timing and expression of climatic and abrupt droughts at L. Hayq, and for comparison to other regional records of climatic, environmental and cultural change in East Africa, further improving understanding of the complex mechanisms that govern regional climate.

Acknowledgements

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NEW RESEARCHERS AWARD SCHEME

ANTHROPOGENIC IMPACTS ON BIODIVERSITY AND PRODUCTIVITY OF SHALLOW LAKE ECOSYSTEMS OF THE SELENGA RIVER DELTA, SIBERIA

Background and rationale

Wetlands are productive transitional systems between freshwater bodies and their terrestrial watersheds. Shallow lakes are often an important component of wetland floodplains, and may comprise up to 50% of the total surface area (Brock *et al*., 2007). Lake Baikal is a World Heritage Site in Siberia, with high levels of biodiversity and endemicity. The Selenga River is the principal source of inflow to Lake Baikal, entering the lake through a floodplain wetland, the Selenga Delta. The Selenga Delta was designated a Ramsar Site in 1994 and provides crucial habitat for wildlife populations of migratory birds and spawning fish due to its high levels of habitat heterogeneity. The Selenga Delta contains hundreds of shallow lakes with varying levels of connectivity. Twentieth-century anthropogenic activities have increased the vulnerability of these lake ecosystems, through impacts from agriculture, mining activities, industrial pollution, hydrological modifications, introduced species and climate change (Thorslund *et al*., 2012).

Multi-proxy palaeoecological reconstructions from sediments of shallow lakes of the Selenga Delta (52°14'N and 106°30'E), combined with contemporary data, will allow for the examination of ecosystem impacts and sensitivity related to human-mediated pressures. The New Research Workers' Award (NRWA) contributed to fieldwork in August 2014, during which fifteen Selenga Delta lakes were sampled for contemporary physical, chemical, and biological properties, and sediment cores were extracted from one lake (SLNG05) for palaeoecological analysis. Additionally, the NRWA funded radioisotope (^{210}Pb, ^{137}Cs) dating of one sediment core from SLNG05, which will allow for observed sediment record changes to be placed in the context of anthropogenic activities in the region. This is the first palaeoecological study ever to be undertaken on the Selenga Delta shallow lakes.

Results

SLNG05 sediment core chronologies and sedimentation rates were calculated using the corrected CRS (constant rate of ^{210}Pb supply) dating model (Appleby, 2001). The corrected CRS model calculated chronologies by referring sediments at 24.75 cm depth as formed in 1963, as suggested by the ^{137}Cs record, which is the oldest date calculated for the SLNG05 core.

SLNG05 loss-on-ignition (550 °C and 950 °C) and concentrations of As, Mn, and Fe increased to maximum values in the early 1960s, then declined rapidly to minimum values by the mid-1970s. Wet and dry densities and concentrations of Ni, Cu, Zn, Pb, Al, and Ti declined to minimum values in the early 1960s, then increased soon-after to maximum values by the mid-1970s. Recent decades show little change for all records, with values similar to the early part of the record (Figure 1).

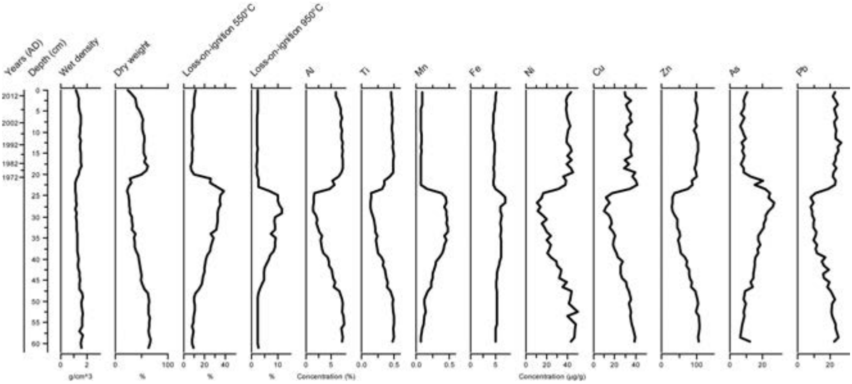

Figure 1. Wet density, dry weight, loss-on-ignition, and selected trace metal concentration profiles from SLNG05, plotted against both depth (cm) down the sediment core and the corrected ^{210}Pb and ^{137}Cs age-model (Years AD).

All lakes are dominated by submerged aquatic macrophytes, which occupy an average of 44% of the total water column across sites, with between 7 and 14 species present at any single site. Further, Chl *a* concentrations across all lakes range from 1.70 to 26.23 μg/l. Mean mercury concentration in lake water across sites is 6.8 ng/l.

Significance

The variation in Chl *a* between lakes indicates oligotrophic, mesotrophic, and eutrophic sites are represented in this study. However the high abundance of submerged macrophytes at all sites likely indicates minimal levels of nutrient enrichment. Contemporary contamination from mercury is fairly low throughout Selenga Delta lakes.

The observed changes in the SLNG05 sediment record coincide with the construction of the Irkutsk Dam on the Angara River (Lake Baikal's outflow) between 1959 and 1964, which resulted in extensive flooding of low-lying land surrounding the lake. The largest impacted land area was more than 350 km^2 of the Selenga Delta, which was flooded at the time (Pinegin *et al*., 1976). It is likely that changes evident in the SLNG05 record reflect alterations to the hydrological connectivity of the lake within the Selenga Delta, and that prior to the flood events SLNG05 was a closed-basin, infilling lake. These results highlight the importance of hydrology and connectivity within the floodplain delta wetland and the sensitivity of these systems to changes in hydrology and regional anthropogenic activities. SLNG05 palaeoecological analyses are currently ongoing, and include diatoms, algal pigments, and macrofossil remains. Palaeoecological analyses will elucidate the ecological sensitivity of Selenga Delta shallow lakes to changes in hydrology, and indicate other possible recent anthropogenic impacts.

Acknowledgements:

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BOOK REVIEWS

TIM HOLT-WILSON (2015) . *TIDES OF CHANGE: 2 MILLION YEARS ON THE SUFFOLK COAST.*

Touching the Tide Landscape Partnership Scheme.
Price £2.00 (to order: http://www.touchingthetide.org.uk/our-guides)
or free pdf-download from: http://www.touchingthetide.org.uk/assets/Documents/Tides-of-Change-2-million-years-on-the-Suffolk-coast.pdf

This 32 page booklet has been produced by the Touching the Tide Landscape Partnership Scheme (http://www.touchingthetide.org.uk), which is based in Suffolk and supported by the Heritage Lottery Fund from 2013 – 2016. The aim of the Touching the Tide Landscape Partnership is to look after the distinctive and dynamic landscapes of the Suffolk coast and explore how they change, in order to help people make well-informed choices about their future. The *Tides of Change* booklet is one of a series of three publications; the others cover the archaeology of Barber's Point and Suffolk coastal art.

The inside cover of *Tides of Change* advises the reader on how to use the booklet, which has an overall objective of introducing the reader to the environmental changes that have taken place on the Suffolk coast over the last 2 million years. The back cover includes a map of the area with visitor and access information about the sites described in the book, with website details, grid references and car parking information. A link is also provided for looking up tide tables.

The introduction uses powerful language to communicate the concept that the Suffolk coast is a very changeable landscape, where lands are both created and destroyed. It also points out that in geological terms, the landscape is one of the youngest in Britain. Different geological times have left their mark, with diverse environments from ice sheets to tropical seas represented in the rocks and sediments. A strong link is made with climate change and the concept of the Anthropocene Epoch is introduced in relation to humans leaving their own mark on the landscape.

The second section discusses the origins of the landscape, and the relationship of the Suffolk coast with the North Sea and the landscapes it once used to contain when sea levels were considerably lower than today. Sea level change is discussed along with the relationship of people to their environment since the last ice sheets retreated. This section concludes with the reminder that we are now entering another chapter in the evolution of the Suffolk coastline and that we will need to adapt yet again to environmental change, as we have done many times during human history.

The remainder of the booklet focuses on 14 key sites along the Suffolk coast, from Pakefield cliffs in the north to Felixstowe in the south. Each site has one or two pages of text and images dedicated to it, and the very varied illustrations range from photographs of fossils to old postcards of the coast, and an artist's impression of the area 2 million years ago. The sections on Benacre Ness, which has moved north about 4km over the last 200 years, and Orford Ness, are used to demonstrate how dynamic the coast is today. Chapter 13 discusses modern erosion rates and sea defences, and describes the impact of the rock armour on the coast at East Lane, Bawdsey. Here, an embayment has now been created which exposes the London Clay, Red Crag (with its amazing deformation structures) and the overlying Anglian till. Classic Quaternary sites such as Easton Bavents and Pakefield are described over two pages each, which outline in very accessible terms the evidence they contain of past environmental change and early human occupation.

The booklet concludes with a very thorough glossary over two pages, where short but very helpful descriptions of the geological time periods, geomorphological features and fossils described at the different sites are provided. For example, the Cromer Forest-bed is described as yielding evidence of the earliest human occupation of northern-Europe, and a picture is painted of longshore drift moving beach sediments up or down shore in a zigzag fashion. This glossary could have been augmented by a simplified geological timescale that befits the geology of the Suffolk coast.

There are only a few criticisms of this very well written and copiously illustrated publication. Firstly, one slight surprise was that after the expressive introductory chapters and concise summaries of key sites, there is no conclusion to this booklet. Secondly, the visitor information inside the back cover gives suggestions for car parking, but no details of sustainable transport options such as cycle routes or public transport were included. Thirdly, the text and images in the A5 printed version are quite small; the pdf version online is better, however when printed out on A4, some of the photographs do seem to be a bit blurred. Finally, although the inside-cover of the booklet urges readers to follow the Countryside Code and respect nature, there is no advice given about geological conservation and responsible fossil collecting. Within the site descriptions, fossil collecting is often implicitly and sometimes explicitly mentioned, for example looking for fossil fish and teeth in the London Clay at Bawdsey. Given this, the lack of advice about responsible fossil and artefact collecting and reporting finds, including a link to the fossil collecting code, is a notable omission.

Although the author has clearly tried to moderate the amount of technical jargon, has explained complex concepts clearly and has included a comprehensive glossary, there is still a fair amount of geological language. This booklet is therefore most likely to appeal to the amateur geologist, archaeologist or historian, along with students, teachers and those with a keen interest in the natural environment and its conservation and management. One concern is that the booklet is quite well hidden within the Touching the Tide website, so casual browsers are unlikely to stumble across it. Hard copies of the booklet are available from the Suffolk Coast and Heaths Area of Outstanding Natural Beauty (AONB), local bookshops and tourist information centres.

In conclusion, despite a small number of what can be described as more administrative omissions which are probably due to space constraints, this is a well-researched and very eloquently written publication. The point is made up front that the Suffolk coast should be viewed as a point in time rather than a fixed line on a map, and the reader is really left with a sense of the fragility of the coast as we perceive it today. The interplay between climate change, coastal processes, wildlife and people over the last two million years have all left their impression in the rocks, sediments and landscapes of the Suffolk coast, and will continue to do so in the future. The narrative approach used really brings the history of this dynamic coast to life, and fully accords with the method advocated by Stuart and Nield (2013) of using stories in earth science outreach to engage people. The author expresses the hope that readers will discover new places and appreciate the timescales involved in creating the landscapes of the Suffolk coast. For those that manage to get hold of a copy of this attractive booklet and tuck it into their rucksack, I think they will!

Reference

Stewart, I.S. and Nield, T. (2013) Earth stories: context and narrative in the communication of popular geoscience. *Proceedings of the Geologists' Association*, 124, 699 - 712

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BRIAN S. JOHN (2014). *ACTS OF GOD*. Greencroft Books, Newport. ISBN: 978-0-905559-99-5. 296 pp, £7.99; Kindle edition: ISBN 978-0-905559-53-7, £1.99.

When I received an email from Brian asking me whether I would know of anybody who would like to review his new book *Acts of God*, I was initially taken aback as I didn't think it would be relevant for QN – until I read the background to the book, which made me reconsider my initial hunch.

Based in Greenland, drawing heavily on his own experiences of an Oxford University expedition to East Greenland in 1962 and written with the background of someone who knows their glacial geomorphology (the seminal textbook co-authored with David Sugden in 1976 will be familiar to many members), yet has also changed career to become an independent fiction and popular science author, this tickled my interest. I had seriously planned to find someone to review it – until I started reading the first few paragraphs, which are full of foreshadowing, and found myself, a few hours later, still reading. Given I don't normally read much fiction, captivating is indeed a word I find rather fitting in this context as I found it hard to put the book down, especially as it approaches the grand finale.

The book itself starts by switching between ominous events involving two Russians landing in East Greenland and the description of the main characters of the story: on the one hand, there are the members of an Oxford University expedition to Greenland (one can perhaps imagine who served as the sources of inspiration for some of the characters!), on the other some of the local population in East Greenland and the (mainly military) staff of a US outpost through which the expedition receives logistical support and backup. The story is set in the early years of the Cold War, and this theme is cleverly kept alive by several references to the political climate at the time that make the book appear realistic even to those, like me, who were fortunate enough to capture only the latter, calmer half of that post-war period or none of all that. The chapters are arranged in chronological order, starting in early July of 1962, which adds to the dramatic nature of the finish later on. Throughout, the story takes several unexpected twists and turns and keeps a fairly complex story arc alive. The latter is easy to follow due to the diligently and realistically-described landscape setting, the geomorphological processes occurring in it and through incorporating realistic and well-planned character traits of the expedition members and the other players.

In addition to aforementioned story arc, this is probably the most realistic fictional account of a high-Arctic landscape in a crime-novel context (is it sad to admit that reading frequent references to 'crevasse', 'moraine' and 'sediments' in a fictional novel made it more appealing?). From the perspective of someone with extensive field experience in cold regions (albeit not Greenland, yet!), this makes the reading even more interesting and brings to life the similarities, but also differences, between fieldwork back then and today. Through its autobiographical elements, rooted in Brian's own Arctic expedition experiences, the book has a historical element by bringing to life how much more easily accessible the northern regions have become and how backup is now somewhat (!) easier due to easier communication systems (Iridium phones, emergency beacons, lighter equipment, denser network of research stations etc.) that did not exist back then. At the same time, the natural hazards (and otherwise) are portrayed just as realistically, and the detailed description of these in a very informed way hammer home the key roles of planning and awareness in doing successful fieldwork in the Arctic and other remote cold and mountain regions.

To summarise, I can only recommend *Acts of God* to anyone interested in reading a well-informed, entertaining and, I say it again, captivating historical crime novel set against the backdrop of early-Cold-War Greenland. A very worthwhile read!

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ABSTRACT

THE LONG-TERM DEVELOPMENT OF PEATLANDS IN PERUVIAN AMAZONIA

Thomas J. Kelly (PhD)

Amazonian peatlands are carbon dense ecosystems which also contribute to the biological diversity of the western Amazon. Their existence remained unconfirmed until scientific studies in the last decade revealed extensive peatlands in the Pastaza-Marañón basin of Peru. This study sought to investigate the palaeoecological history and hydrological behaviour of peatlands in the Pastaza-Marañón basin. The aims of the study were to determine the key drivers of past vegetation change in two Amazonian peatlands, to produce the first explicit conceptual model of Amazonian peatland development, to improve our understanding of the hydrological behaviour of Amazonian peatlands, and to improve interpretations of the late Quaternary tropical pollen record.

Field data were collected in order to determine the saturated hydraulic conductivity (*K*), an essential parameter for hydrological models, in three Amazonian peatlands. Measured *K* at 50 cm depth varied between 0.00032 and 0.11 cm s^{-1}, and, at 90 cm, it varies between 0.00027 and 0.057 cm s^{-1}. Simulations using a simple hydrological model suggest that under current climatic conditions, even with high *K*, peatlands would be unable to shed the large amount of water entering the system via rainfall through subsurface flow alone. An annual record of water table variation from one site, Quistococha, shows that the water level can fall rapidly (*c*. 1.6 cm d^{-1}) in the absence of rainfall. The main conclusions to be drawn from this part of the study are that most of the water leaves these peatlands via overland flow and/or evapotranspiration, and that regular rainfall is essential for maintaining the moist conditions necessary for continued peat accumulation.

Palaeoecological data were collected from two peatlands: Quistococha and San Jorge. The data from Quistococha constitute the first multiple-core study of an Amazonian peatland, and form the basis of a developmental model. These data show that a well-placed single core can represent the main vegetation changes, although multiple cores add valuable detail to the picture of site development. Lateral growth mostly occurred through 'primary mire formation', where peat begins accumulating simultaneously across a site: the expansion of Quistococha therefore differs from many temperate and sub-arctic peatlands, where primary mire formation is mostly confined to coastal areas. Differences in the subsurface

topography are shown to have affected vegetation development, and likely resulted in higher beta diversity than present during the early stages of Quistococha's development. At San Jorge, radiocarbon dating has revealed a period of slow accumulation between 1300 and 450 cal yr BP which is also associated with a major change in vegetation from a *Pistia* dominated aquatic pollen assemblage to a *Mauritia* and *Mauritiella* dominated palm swamp assemblage. This is amongst the first evidence suggesting an effect of late-Holocene climatic change on ecosystems in the western Amazon, but will require confirmation through further work at other sites in the region.

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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:

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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