UK TOP QUATERNARY SITES: A COMPILATION TO CELEBRATE THE QRA'S SEMI-CENTENNIAL YEAR

Edited by B.Silva and E.Phillips

Quaternary Research Association

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Cover Illustration: a montage of photos published within this volume.

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This volume would not exist without the support, enthusiasm and work of the Quaternary community. Initially when Emrys proposed the idea of a collection of the 'Top 50 Sites', we were unsure of the response we would get. We were overwhelmed by the number of submissions (over 80) and subsequently decided that they all deserved publishing as it would be near impossible to justify accepting some and not others. So, we would very much like to thank all those who took the time and effort to submit their favourite site (or sites!!).

CONTRIBUTORS

J.R.L. Allen FRS
Dept of Archaeology, University of Reading, Whiteknights, PO Box 227, Reading, RG6 6AB.

Keith Barber
Palaeoecology Laboratory (PLUS), Geography and Environment, University of Southampton, SO17 1BJ. Keith.Barber@soton.ac.uk.

Mark Bateman
Geography Dept, Sheffield University, Winter St, Sheffield, S10 2TN. m.d.bateman@sheffield.ac.uk.

Rick Battarbee
Environmental Change Research Centre, University College London, Gower St, London, WC1E 6BT. r.battarbee@ucl.ac.uk.

Martin Bell FBA
Dept of Archaeology, University of Reading, Whiteknights, PO Box 227, Reading, RG6 6AB. m.g.bell@reading.ac.uk.

Jenny Bennett
4 Crockernwell Court, Crockernwell, Exeter, EX6 6NA. jenny.a.bennett@open.ac.uk.

Andrew Bicket
Wessex Archaeology, Coastal & Marine, Portway House, Old Sarum Park, Salisbury, SP4 6EB. a.bicket@wessexarch.co.uk.

John Birks
Department of Biology, University of Bergen, PO Box 7803, N-5020 Bergen, Norway. john.birks@bio.uib.no.

David Bridgland
Dept of Geography, Durham University, Lower Mountjoy, South Road, Durham, DH1 3LE. d.r.bridgland@durham.ac.uk.

Eleanor Brown.
Natural England, Mail Hub Block B, Whittington Road, Worcester, WR5 2LQ. eleanor.brown@naturalengland.org.uk.

Cynthia Burek
University of Chester, Parkgate Road, Chester, CH1 4BJ. c.burek@chester.ac.uk.

Stewart Campbell
Natural Resources Wales, Chester Road, Buckley, Flintshire, CH7 3AJ. stewart@imaggeo.eclipse.co.uk.

Ian Candy

Dept of Geography, Royal Holloway, University of London, Egham. TW20 0EX. ian.candy@rhul.ac.uk.

John Catt

Department of Geography, University College London, Pearson Building, Gower Street, London, WC1E 6BT. j.catt@ucl.ac.uk.

E.R. Connell.

Dept of Geography, Environment and Earth Sciences, University of Hull, Cottingham Road, Hull, HU6 7RX. rodger_connell@yahoo.co.uk

Andrew Crossley

Haulwen, 6, Maes Brynglas, Peniel, Carmarthen, Carms, SA32 7HF. ancrossley@ancrossley.plus.com.

Bethan Davies

Dept of Geography, Royal Holloway, University of London, Egham, TW20 0EX. bethan.davies@rhul.ac.uk.

Sue Dawson

Geography, School of Environment, Nethergate, Perth Road, University of Dundee, Dundee, DD1 4HN. s.dawson@dundee.ac.uk.

Peter Ealey

Cornwall Conservation Group. 8, Minster Fields, Manaccan, Helston, Cornwall, TR12 6JG. pealey01@tiscali.co.uk.

Stephen Gale

School of Geography, Earth Science and Environment, The University of the South Pacific, Fiji. gale_s@usp.ac.fj.

John Gordon.

School of Geography and Geosciences, University of St Andrews, St Andrews, Fife, KY16 9AL, Scotland. jeg4@st-andrews.ac.uk.

David Graham

Polar and Alpine Research Centre, Dept of Geography, Loughborough University, Loughborough, LE11 3TU. d.j.graham@lboro.ac.uk.

Chris Green

Dept. of Archaeology, University of Reading, Reading, RG6 6AB.

Adrian Hall

Dept of Physical Geography and Quaternary Geology, Stockholm University, SE-106 91, Stockholm. adrian.hall@natgeo.su.se.

E.Y. Haworth.

The Freshwater Biological Association, Windermere.

Zoë Hazell
Historic England, Fort Cumberland, Eastney, Portsmouth, PO4 9LD.
zoe.hazell@HistoricEngland.org.uk
Peter Hoare
26 Victoria Street, Ely, Cambridgeshire, CB7 4BL.
pgh@ventifact.co.uk.
Robert Hosfield
Dept. of Archaeology, University of Reading, Reading, RG6 6AB.
r.hosfield@rdg.ac.uk.
Frank Howie
Cornwall Geoconservation Group. Five Acres, Allet, Truro, Cornwall, TR4 9DJ. fmp-howie@msn.com.
David Jarman
4/18 Lanark Street, Glasgow G1 5PY. david.jarman914@virgin.net.
Brian John
Trefelin, Cilgwyn, Newport, Pembs, SA42 0QN.
brianjohn4@mac.com.
Martin Kirkbride
School of the Environment, University of Dundee, Dundee, DD1 4HN, Scotland, UK. m.p.kirkbride@dundee.ac.uk.
Jasper Knight
School of Geography, Archaeology & Environmental Studies, University of the Witwatersrand, Johannesburg, South Africa.
jasper.knight@wits.ac.za.
Harry E Langford
16 Magnolia Avenue, Longthorpe, Peterborough, PE3 9QT.
h.e.langford@ntlworld.com.
Jonathan Lee
British Geological Survey, Keyworth, Nottingham, NG12 5GG.
jrlee@bgs.ac.uk
Antony Long
Sea-Level Research Unit, Department of Geography, Durham University, Durham, DH1 3LE. a.j.long@durham.ac.uk
Tom Lord
Lower Winskill, Langcliffe, Settle, North Yorkshire, BD24 9PZ.
tomlord@daelnet.co.uk.
Sven Lucas
Queen Mary University of London, Mile End Road, London E1 4NS. s.lukas@qmul.ac.uk.

Alison Macleod
Dept of Geography, Royal Holloway, University of London, Egham. TW20 0EX. a.macleod@rhul.ac.uk.
Clive R. Maton
Department of Earth & Planetary Sciences, Birkbeck University of London, Malet Street, London WC1E 7HX. clive.maton@live.co.uk.
A. M. McCabe MRIA
Dept. Of Environmental Science, University of Ulster, Cromore Road, Coleraine, County Londonderry, Northern Ireland. BT52 1SA. m.mccabe@ulster.ac.uk
Jon Merritt
British Geological Survey, Murchison House, West Mains Road Edinburgh, EH9 3LA. jwm@bgs.ac.uk
Nicholas Midgley
School of Animal, Rural & Environmental Sciences, Nottingham Trent University, Brackenhurst Campus, Southwell, Nottinghamshire, NG25 0QF. nicholas.midgley@ntu.ac.uk.
Phil Murphy
School of Earth and Environment, University of Leeds, LS2 9JT. p.j.murphy@leeds.ac.uk.
Julian Murton
Permafrost Laboratory, Department of Geography, University of Sussex, Brighton, BN1 9QJ. j.b.murton@sussex.ac.uk.
Frank Oldfield
University of Liverpool; 5 Barn Hey, Meols Drive, Hoylake, CH47 4DF. oldfield.f@gmail.com.
Matthew Owen
Department of Geography, University College London Gower Street, London, WC1E 6BT. m.owen@ucl.ac.uk.
Adrian Palmer
Dept of Geography, Royal Holloway, University of London. Egham, Surrey, TW20 0EX. a.palmer@rhul.ac.uk.
Emrys Phillips
British Geological Survey, Murchison House,West Mains Road, Edinburgh, EH9 3LA. erp@bgs.ac.uk.
Matt Pope
Institute of Archaeology, 31- 34 Gordon Square, London, WC1H OPY. m.pope@ucl.ac.uk.

Colin Prosser
Landscape and Geodiversity Team, Natural England, Unex House, Bourges Boulevard, Peterborough, PE1 1NG. colin.prosser@naturalengland.org.uk.
Neil Roberts
School of Geography, Earth and Environmental Sciences Plymouth University, Plymouth PL4 8AA. cnroberts@plymouth.ac.uk.
Pat Sargeant
14 Carn Brea Village, Redruth, Cornwall. TR15 3BL. patricksargeant@outlook.com.
Danielle Schreve
Dept of Geography, Royal Holloway, University of London, Egham. TW20 0EX. d.schreve@rhul.ac.uk.
Katharine Scott
St Cross College, Oxford, OX1 3LZ. katharine.scott@stx.ox.ac.uk.
Ian Shennan
Sea-Level Research Unit, Department of Geography, Durham University, Durham, DH1 3LE. ian.shennan@durham.ac.uk.
Allan Straw,
University of Exeter, 31 Tilmore Gardens, Petersfield, Hants, GU32 2JE. allan.straw@btinternet.com.
Eileen Tisdall
Biological and Environmental Sciences, School of Natural Sciences, University of Stirling, Stirling, Scotland, FK9 4LA. e.w.tisdall@stir.ac.uk.
Louise Tizzard
Wessex Archaeology, Coastal & Marine, Portway House, Old Sarum Park, Salisbury, SP4 6EB.
Martyn Waller
School of Earth Sciences and Geography, Kingston University, Penrhyn Road, Kingston upon Thames, Surrey, KT1 2EE, UK. m.waller@kingston.ac.uk.
Tony Waltham
11 Selby Road, Nottingham, NG2 7BP. tony@geophotos.co.uk.
Peter Wilson.
Environmental Sciences Research Institute, School of Environmental Sciences, University of Ulster, Coleraine, Co. Londonderry, BT52 1SA. p.wilson@ulster.ac.uk.

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INTRODUCTION

As part of the 50th year celebrations of the QRA, it seemed fitting to highlight some of the key sites and localities that have been fundamental to our understanding of the Quaternary landscape around us.

During 2014, we looked to compile a list of the 50 favourite Quaternary sites within the Britain Isles as nominated by the Quaternary community. After an overwhelming response, over 80 sites were submitted and these are covered in these pages. We fully recognise that these form a subjective selection of sites, reflecting the interests and passions of the 'nominator'.

This collection is in no way aiming to be a comprehensive review of Quaternary sites, rather, we view this as a light-hearted celebration of the sites that are considered important by QRA members in 2014. It would be fascinating, if the exercise were repeated in the QRA's 75th year, to see which sites remain 'key' and which new sites would be added to this list.

These sites will be also be published as a web-based resource through the QRA web site. It is planned that this web resource will be built on and added to over time, resulting in a dynamic collection of Quaternary sites in the British Isles.

We very much hope you enjoy this volume!
Barbara Silva and Emrys Phillips

DISCLAIMER

Please be aware that some of these sites may be on private land and permission may be required for access. Do check what access restrictions, if any, exist before visiting. Please also note that the site descriptions published within this volume reflect the views and knowledge of the authors ('nominators') and not the editors.

ABBREVIATIONS USED IN THIS VOLUME

SSSI - Site of Special Scientific Interest
NNR - National Nature Reserve
GCR - Geological Conservation Review
MIS - Marine Isotope Stage

FOREWARD

In 1976, I joined the Quaternary Research Association and embarked upon a marvellous journey visiting Quaternary sites that is still ongoing today. My trip began with an undergraduate degree at Sussex University with Rendel Williams and other geomorphologists taking us on field excursions and then continued with a PhD in the Subdepartment of Quaternary Research at Cambridge with Richard West. During my undergraduate studies, we had been exposed to geomorphological mapping, soil science and a limited number of Quaternary sections but it was only during my PhD that I started to realise the huge range and variety of information available to us in the Quaternary record. Field trips with Richard West, Phil Gibbard, Chris Bates, Jim Rose, John Birks, Brian Huntley, Mary Edwards, Richard Bradshaw and many more revealed to me to a plethora of Pleistocene and Holocene sequences.

Some of these sites made a marked impression on me and there is nothing like field experience to widen one's interests; the Chicago University excavations at Hoxne, sieving for small mammal bones with Tony Stuart and the Zoology undergraduates at West Runton, coring the East Walton pingos, visiting the Wolston pits with Fred Shotton and David Bowen on a QRA excursion –all gave me great experience and left me wanting to visit even more sites.

In 1978 I accompanied Tony Stuart on a number of brilliant field trips recording all of the Quaternary sites in East Anglia for the Nature Conservancy Council –we visited 10s of sites a day covering 100s of km and thoroughly enjoyed the experience. Over the next 35 years, the QRA Annual Field Meetings and 'Short Field Meetings' provided me with more insight into the incredible Quaternary record of Britain and Ireland (and further afield).

Everyone has their favourite Quaternary angle –be it a submerged moraine discovered in more recent years, a cliff section with glacigenic sequences 100s of metres long, a landform, a bog, a buried landscape, an interglacial deposit stuffed with bones, a raised beach, a 'golden spike' or a car park/ embankment that once had something interesting to see in it.

The initial inspiration behind the gazetteer of sites was provided by the QRA@50 celebrations in 2014 and an aim to cover 50 "top sites" in Britain. The resulting compilation of sites has been hard won from scientists keen to share their enthusiasm but busy and the authors are to be congratulated on amassing an amazing collection of sites – in fact, over 80 are present in this first edition, far surpassing the original total. Readers may not find every site included but if gaps are noted, this should simply inspire them to contribute to future editions.

To say that the sites here are the most significant in our Quaternary record is always going to be open to debate –again, members are encouraged to submit new site profiles so that the portfolio continues to grow as a useful and stimulating resource.

Peter Coxon
QRA President
April 2015

ABERMAWR, Pembrokeshire, Wales [NGR: SM 883 347]
Nominated by Brian John

This is the most comprehensive exposure of Late Pleistocene deposits in West Wales. There are exposures at both ends of the bay. Storms have revealed an Ipswichian raised beach on a rock platform remnant, and above that there is a sequence of periglacial deposits made up of angular bedrock fragments, but incorporating far-travelled erratics. Above that is a clay-rich Irish Sea till of Late Devensian age and containing striated clasts, fragments of carbonized wood and sea shells. The main components of the till are sea-floor deposits, dredged up by glacier ice moving across the old coastline and later laid down by lodgement and shearing. There are also flow-tills, and the glacial deposits are capped by glaciofluvial materials, an upper head (referred to in the past as "rubble-drift"), sandy loam and modern soil. The deposits represent a complete advance/retreat cycle close to a glacier margin. In the upper head there are fossil ice-wedges and involutions of Late Glacial age. Beneath the storm beach there are peat beds and remnants of the "submerged forest", and these organic-rich sediments can be examined in the marsh on the landward side of the storm ridge. There is a continuous stratigraphic record here, probably stretching back *c* 100,000 years.

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Left*: the northern exposure in Abermawr Bay, in which a complete glacial advance – retreat cycle is represented; and* **Right***: contact between Early/Middle Devensian slope deposits and the overlying Irish Sea till. (Both images: Brian John, 2014).*

AREA 240 [NGR: TG 648 015]
Nominated by Andrew Bicket and Louise Tizzard

The Palaeo-Yare river system encompassing the onshore Rivers Yare, Wensum and Waveney flowing into Breydon Water and the North Sea at Great Yarmouth has been traced 30 km offshore and a range of estuarine, fluvial and intertidal sediments deposited during the Saalian, Devensian and Holocene are preserved. Marine aggregates licence area 240, situated within the lower reaches of the Palaeo-Yare, has provided the first direct evidence of Neanderthal submerged prehistory in the UK and is globally significant in this regard (Bicket *et al*. 2014). Over 120 *in situ* and near *in situ* lithic artefacts including many handaxes, and a significant proportion of Levallois artefacts (Tizzard *et al*. 2014), are now 30m underwater in the southern North Sea. The likely source of the artefacts have been constrained to a floodplain sequence of sands and gravels dating to the Middle Saalian, around 250ka, reflecting the colder conditions on the warming limb of MIS 8/7. This offshore site provides critical northerly context for Middle Palaeolithic hominin activity and highlights the importance of submerged palaeogeography for understanding early prehistory in the southern North Sea and beyond.

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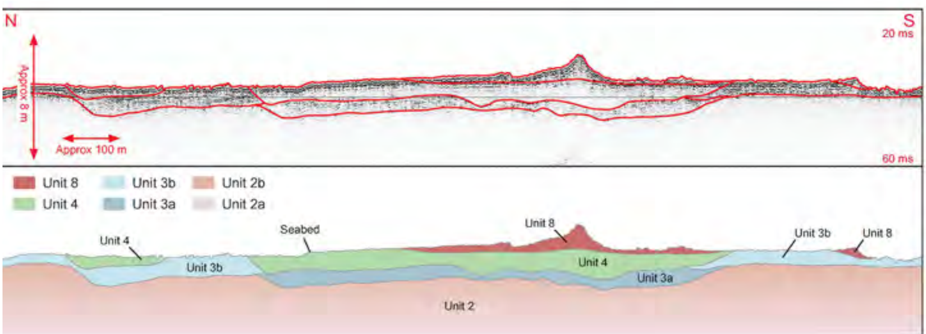
Geophysical data example from Area 240 illustrating in-filled channels. Unit 2: Cromerian Complex delta top/marine deposits; Unit 3a: Possibly MIS 12 or MIS 10 glaciofluvial deposits; Unit 3b: MIS 8/7 lithic artefact-bearing glaciofluvial floodplain deposits; Unit 4: MIS 5c fluvial deposits; Unit 8: recent marine deposits.



ARISAIG: From the Ru Peninsula to Mointeach Mhor, Inverness-shire, Scotland [NGR: NM 63 83 to NM 87 90]

Nominated by Ian Shennan & Antony Long

Isolation basins, raised tidal marshes, dune systems and coastal wetlands around Arisaig, NW Scotland, produce a record of relative sea-level (RSL) change from ~16ka BP to present. This is the longest RSL record in the UK and one of the longest, near-continuous records on Earth. It has been used to provide rigorous constraints on a range of Glacial Isostatic Adjustment models and parameterise the viscosity profile of the upper mantle. It has been central to efforts that have sought to develop models of the Late Quaternary history of the British-Irish Ice Sheet, including debates regarding the scientific significance of glacial trim lines in Scotland and Ireland as constraints on ice sheet thickness and margin extent. The close vertical spacing of isolation basins during the Late Glacial mean that the Arisaig RSL data also provide powerful constraints on global meltwater pulses and associated sea level jumps as the polar ice sheets disintegrated following the Last Glacial Maximum. Lastly, the Arisaig RSL record has helped improve understanding of several important coastal landforms in NW Scotland, notably the age and origin of the "Main Rock Platform" and the "Main Postglacial Shoreline".

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Ru Peninsula, looking north to Arisaig village; two isolation basins, in the foreground, one completely infilled, and lower down, Loch Torr a'Beithe; isolated from marine influence as sea level fell 14 – 13 ka BP. (Photo: Ian Shennan).

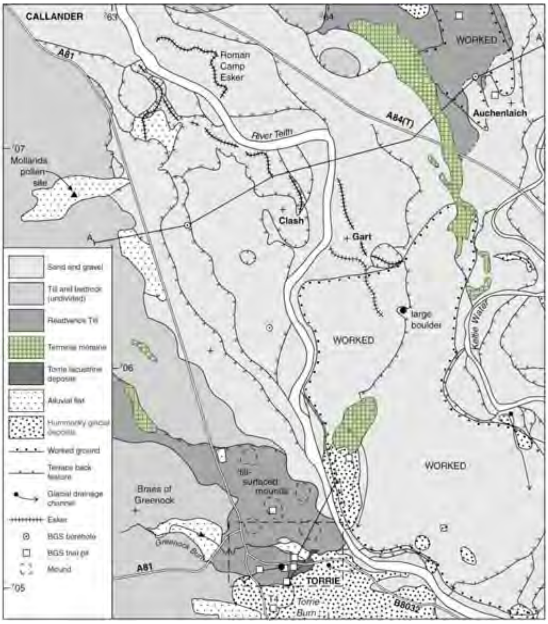
ASKILLAUN, south side of Clew Bay, County Mayo, Ireland [IGR: L 773 815]
Nominated by A. M. McCabe MRIA

The eroded drift mound at Askillaun is part of a critical ice limit which can be traced across western Ireland from the high level Gilbert deltas in the south at Killary Harbour, north to the margins of the Clew Bay ice lobe at Askillaun and Furnace Lough, and northwards across the lowlands of east Mayo into Donegal Bay. The marginal moraines of this system are linked by well-defined patterns of subglacial bedforms including the unique barkhanoid forms at the head of Clew Bay. The system is dated to 15.6±0.4 cal ka BP and occurred during the Killard Point Stadial (within Heinrich Event 1). The spread consists mainly of massive and stratified diamicts with beds extending laterally for tens of metres and consistently dip westwards. Stratified beds are common throughout the sequence and often grade into diamict forming critical sediment continuua. Critically, debris flows form most of the sequence though cobble lines one clast thick with striated upper surfaces are present and testify to periodic ice overriding the growing sediment pile. Westwards dipping beds and shallow gravelly channel scours are primary. They are not deformed and record progressive sediment release and build-up from an ice marginal efflux related to the ice lobe pinned on rock at Louisburgh immediately to the east. The presence of westerly dipping glaciomarine beds indicates high (≥45m OD) relative sea levels at the margin of the Clew Bay ice lobe which is consistent with the HRSLs recorded from similar ice sheet limits to the south around Killary Harbour and at the mouth of the Glenummera river.

Erosional remnant of a glaciomarine spread, Askillaun south shore of Clew Bay, western Ireland. Minimum sediment thickness is 45m and 500m is exposed. Internal geometry dominated by beds of diamict (debris flows) sloping gently westwards towards the open Atlantic Ocean. Stratified interbeds are common together with cobble and boulder lags which may be striated. Large lonestones common. Dark figure (1.6 m high) at base for scale. (Photo: A. M. McCabe)

AUCHENLAICH OR ‘CALLANDER’ MORAINE (south-east of Callander), Stirling, Scotland
[NGR: NN 642 077 to NN 638 051])
Nominated by Eileen Tisdall

The Auchenlaich or Callander moraine is one of several exceptionally preserved glacial landforms present in and around the town of Callander, Perthshire. Other landforms present include eskers, kame terraces and kettleholes (see map below). When viewed together these features allow for the interpretation of the nature, timing and extent of ice at the southern limit of the Loch Lomond Re-advance (Lowe 1993). This suite of easily accessible landforms is perhaps unique in the UK, offering visitors and locals alike the chance to experience a landscape where the presence of ice is tangible and easily understood. For researchers and students, the extensive range of glacial landforms offers the opportunity to unlock a sequence of glacial processes and events and to determine the required climatic changes. Integral to that understanding is the study and analysis of these sites in the field. The threat to these landforms is continuous with proposed housing development on the northern moraine and quarrying for sand and gravel ongoing at the moraine and kame terraces to the south. A listing in the QRA50 sites would give the Auchenlaich moraine and its associated landforms the recognition and raised awareness that they deserve.



A map of the Auchenlaich or ‘Callander’ Moraine (Source: Everest, 2005)

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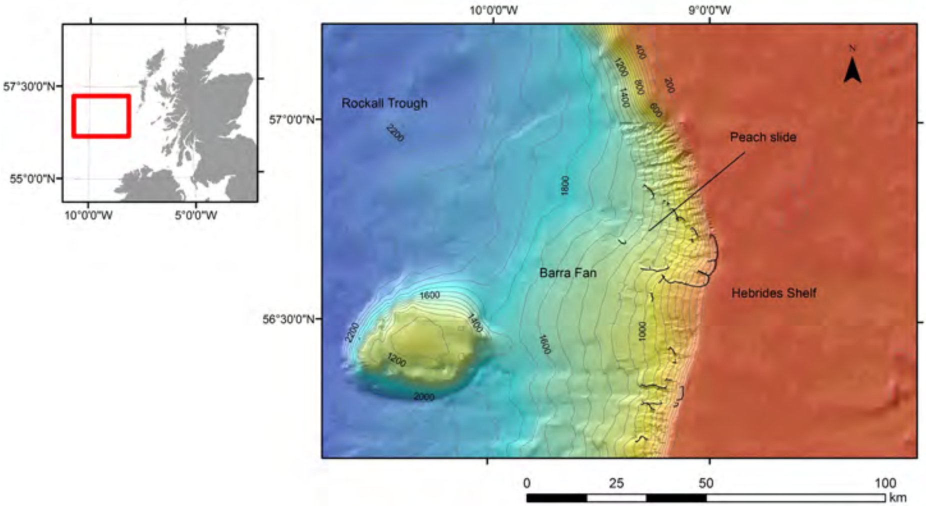
BARRA FAN [56°40’N 9°30’W - Offshore location]
Nominated by Matthew Owen

Approximately 100 km west of the Hebrides, the Barra Fan is the largest glacial deposit on the western British continental margin. It has developed since the mid-Pliocene (Dahlgren *et al,* 2005) and pre-dates northern hemispheric glaciation by circa 1 Ma. Glaciogenic sediments have been deposited on the fan since 2.5 Ma (Stoker *et al,* 2005) and sediments from the fan contain a record of the British and Irish Ice Sheet’s western flux throughout the Quaternary. Studies on the fan’s sediments have: constrained the marine ^{14}C reservoir effect during the Younger Dryas (Austin *et al*, 1995); revealed Late Glacial ocean circulation changes (Kroon *et al*, 1997; Knutz *et al*, 2001); and documented the advance and retreat of the British and Irish ice sheet (Knutz *et al*, 2001; Hibbert *et al*., 2010). The fan is also geomorphologically fascinating, containing the largest landslide in the British Isles: the Peach slide (Holmes *et al,* 1998). The final stages of this event may have been initiated by the ice sheet’s last retreat (Owen, 2013).



Barra Fan and regional setting from LOIS SES and GEBCO bathymetric datasets

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BLAKENEY ESKER, Norfolk, England [NGR: TG 04]
Nominated by Peter Hoare and Stephen Gale

The Blakeney ridge in northern East Anglia is the best-preserved esker in lowland Britain. The esker forms part of a complex assemblage of Quaternary landforms and drift deposits found within and around the lower Glaven valley in north Norfolk. These have been the subject of debate for more than a century, with the ridge successively interpreted as morainic in origin; as having been eroded out of a much larger spread of outwash sands and gravels; and as the fill resulting from subaerial meltwater flow to the northwest along intersecting rectilinear fractures in an ice sheet. Careful analysis and interpretation of the ridge and its deposits have revealed that the flows that formed the Blakeney esker were subglacial. They took place from northwest to southeast along the length of the ridge, with at least the final phase occurring under hydrostatic pressure. The esker conduit functioned largely as a Röthlisberger channel, although there is evidence of simultaneous incision of the glacial bed. The esker and an underlying buried bedrock valley may form the distal component of one of a series of north–south aligned subglacial valleys that were trenched across the southern North Sea Basin in Middle Quaternary times. The complex assemblage of proglacial glaciofluvial landforms found to the south of the esker may represent the products of transport along these valleys. The esker developed during a glacial stillstand within MIS 10 and under steep hydraulic gradients close to the ice sheet terminus.

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Low-angle oblique view southeast along the Blakeney Esker (University of Cambridge Collection of Aerial Photographs: copyright reserved).

BLELHAM TARN AND BOG NNR, Lancashire, England [NGR: NY 367 005]

Nominated by Frank Oldfield

Blelham Bog provides a rare example of palaeo-ecological research explaining the origin and status of an National Nature Reserve (Oldfield, 1970). Subsequent research included a superb Late Glacial sequence (Pennington, 1970) and the present lake has been the subject of many studies (e.g. Evans, 1970, Pennington, 1976), including pioneering research on short-lived radioisotope dating (Pennington, 1976), close comparison between algal

Blelham Tarn and Bog, North Lancashire (Photo: E.Y. Haworth)

records and diatom stratigraphy (Haworth, 1980), analysis of late Holocene accelerated erosion (van der Post *et al*., 1997) and the mass balance of weapons-testing derived radioisotopes (Appleby *et al*., 2003).

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BOLTON FELL MOSS AND WALTON MOSS PEATLAND COMPLEX, Cumbria, England
[NGR: NY 510 670]
Nominated by Keith Barber

Bolton Fell Moss and Walton Moss are key sites in the palaeoecology and palaeoclimatology of the Holocene. They are virtually contiguous and have produced a wealth of high resolution palaeoenvironmental records significantly contributing to our understanding of past ecological and climatic change as well as human impact in the landscape of northern Britain, and further afield. It is likely that no other peatlands in the world have been so thoroughly investigated and used in palaeoenvironmental research.

Bolton Fell Moss is an internationally important stratigraphic site comprising of an ombrotrophic bog sequence dating back to the Early Holocene. Early work here by Barber (1981) disproved the theory of ‘autogenic cyclic peat-bog regeneration’ and demonstrated that climate was the driving factor in changes of the peat-forming communities and that these changes could therefore be used to track past climate change. Walton Moss, arguably the most intact ombrotrophic raised mire in England, has also produced a record of natural and cultural change dating from the Early Holocene and is comparable to Bolton Fell Moss. Both sites contain evidence for millennial-scale cycles of wet shifts that show a striking concordance with oceanic records of ice-rafted debris events, suggesting the possibility of ocean-driven forcing of the regional climate. Between them they show climatic shifts to a wetter / cooler climate at c. 7800, c. 5300, 4410–3990 (2σ range), c. 3500, 3170–2860 (2σ range), 2320–2040 (2σ range), c. 1750, c. 1450, c. 300 and c. 100 cal. BP. Walton Moss is also a key site in the precise dating of the Glen Garry tephra to 2176 cal. BP, a marker horizon for northern Britain.

Bolton Fell Moss in 1968 showing hand-cut ditches (Photo Keith Barber).

Walton Moss coring 1995 (Photo Keith Barber).

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BOULDNOR CLIFF, Isle of Wight, England
[NGR: SZ 374 905]
Nominated by Zoë Hazell

Bouldnor Cliff is an underwater cliff in the western Solent, just off the coast of the Isle of Wight. Finds from the site were first noted by fishermen in the 1980s, and since the 1990s the site has been subject to multiple recording and sampling investigations (led by the Hampshire and Wight Trust for Maritime Archaeology), and the subsequent dating and palaeoecological analyses of the sediments (see Momber *et al*. 2011). Bouldnor Cliff contains remains of the prehistoric landscape that existed prior to Holocene inundation and provides valuable information on the region's palaeoenvironmental development and sea-level history, as well as on its Mesolithic human occupation. The cliff site itself consists of three 'peat' beds separated by marine clays; the oldest peat layer (*c* 6500-6300 cal BC; Early-Middle Holocene) is at -11 m OD. At the base of the cliff is an old land surface with a Mesolithic occupation site, from which archaeological evidence – including freshly-struck flint flakes, burnt flints, worked wood, charred hazel nutshells and prepared fibres – have been recovered.

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BOXGROVE, West Sussex, England [NGR: SU 923 087]
Nominated by Matt Pope

Boxgrove is an internationally important location for our understanding of human behaviour in the Middle Pleistocene. It represents the best known locality along the recorded 26 km stretch of the Arundel-Westbourne Raised Beach. Overlying this beach are two sets of deposits: the well-preserved marine, intertidal and terrestrial sediments of the Slindon Formation dating to MIS 13 and the periglacial brickearths and gellifluction gravel of the Eartham Formation dating to MIS 12. Both sediment bodies preserve exceptional traces of human activity and palaeoenvironmental records including well-preserved mammalian fauna.

In-situ flint artefacts were first discovered at the site by Andrew Woodcock in the 1970s. Subsequent excavations through the 1980s and into the mid-nineties were undertaken by a multidisciplinary team including Mark Roberts, Simon Parfitt and Martin Bates. During this work, they investigated and recorded over 90 separate localities within the two large gravel quarries of Amey's Eartham Pit. Many of these localities encountered and sampled a single isochronous land surface with exceptional preservation of flint knapping scatters, butchered faunal remains and abundant finished bifacial tools.

In 1993, the discovery of a human tibia attributed to *Homo heidelbergensis*, and followed by further finds of human incisors, sealed Boxgrove's position as a globally significant locale for human evolutionary studies. Subsequent mapping in the early 2000s brought the widespread distribution of the Slindon Formation under more detailed understanding and demonstrated the full extent

of the preserved landscape. While other localities with artefacts and preserved land surfaces exist along the line of the Arundel-Westbourne Raised Beach, Boxgrove remains the core of this archaeological landscape and will continue to set the benchmark for high-resolution archaeology for the foreseeable future. There is perhaps no site in Europe, possibly the world, which brings together exceptional sedimentary context, diverse aspects of early human behaviour and palaeoenvironmental evidence in such sharp and illuminating focus.

Excavation Area Q1/B (The Hominin Locality) under excavation in 1996. (Photo: The Institute of Archaeology)

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BOYNE QUARRY, Aberdeenshire, Scotland [NGR: NH 613 659]

Nominated by Jon Merritt

The superficial deposits exposed at Boyne Quarry [NH 613 659], a Geological Conservation Review (GCR) site 7.5 km west of Banff, in north-east Scotland, include a sequence of diamicts and ice-marginal lake deposits that underpin theories of the complex glacial history of the Moray Firth. Exposures at Boyne change as quarrying continues, but generally include basal, partly weathered, locally-derived till (Boyne Castle Till Formation) thought to predate the last (Ipswichian) interglacial, a glacitectonized package of units including subglacial traction till, glacitectonite and glacial rafts carried onshore by ice from the floor of the Moray Firth (Whitehills Glacigenic Formation), and an uppermost subglacial traction till including troctolite erratics derived from inland. The latter provide evidence of final offshore ice flow. The rafts, which are associated with channelized bodies of sand and hydrofractures, are derived mainly from shell-bearing, cold-water marine Quaternary sediments and Mesozoic mudstone. Amino-acid epimerization ratios and radiocarbon dating on shells suggest that the onshore ice movement post-dates the early part of MIS 3 and most likely occurred during an early phase of the last glaciation (LGM) when a major ice divide formed along the Atlantic seaboard of the North-west Highlands. Ice emanating from the Great Glen and Central Highlands was consequently forced to flow eastwards along the southern coast of the Moray Firth, then south-eastwards towards Aberdeen and the North Sea basin. During deglaciation, a series of lakes and sandar formed along the coast at the margin of ice remaining in the Moray Firth basin.

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BREAD AND CHEESE COVE, St Martin's, Isles of Scilly, England [NGR: SV 940 159]
Nominated by Pat Sargeant

Bread and Cheese Cove is located on the north-east side of the island of St Martin's in the Isles of Scilly. Scourse (1998) describes it as the most important Quaternary site in the islands as it provides key evidence for the glaciation of the northern margins of the archipelago during the Late Devensian. The stratotypes of both the Scilly Till and the Bread and Cheese Breccia are also located here.

The sequence of till and outwash gravels in the low cliffs at the back of the cove were described in detail by Mitchell and Orme (1967).When Scourse (1991) carried out further research on the sequence he discovered lacustrine organic sediments at the very base of the section. Despite possible contamination that made specific dating difficult, the fossil pollen was that typical of an open grassland habitat present over much of Scilly about 30 ka

BP, and predates the glaciation of the islands.

The basal breccia horizons are overlain by a very distinctive dark brown clay rich in glacial erratics of diverse, mainly non-granitic, mineralogy, all indicating an offshore source to the north of the islands (Scourse, 1991). Many of the erratic pebbles exhibit distinctive fresh striations. This is the stratotype of the Scilly Till, thought to be *in situ* and giving a probable date of Late Devensian for the glaciation of the northern parts of the islands

The overlying Bread and Cheese Breccia contains erratic materials and is interpreted by Scourse (1991, 1998) as a separate periglacial solifluction deposit at this, its stratotype, location.

This tiny isolated location is crucial to the interpretation of Devensian events on Scilly as well as elsewhere across south-west Britain. Many people still cannot believe that the glaciers reached this far south that is, until you hold a clast of freshly striated Scilly Till in your hand!

Bread and Cheese Cove, St Martin's, Isles of Scilly: Striated erratic fresh from the Scilly Till (Photo: P. Sargeant)

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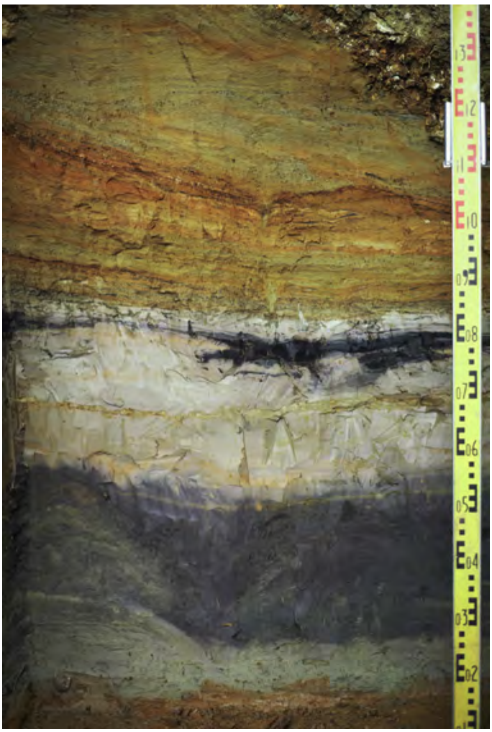
BROOM, Devon, England
[NGR: ST 326 020 (Railway Pit), NGR: ST 328 025 (Pratt's Old Pit) and NGR: ST 328 024 (Pratt's New Pit)]
Nominated by Robert Hosfield & Chris Green

Broom is a key site for our understanding of the factors that controlled the diversity of river response to Pleistocene climatic variability. Terrace preservation in the Axe Valley is poor, and recent investigations at Broom demonstrated that the most extensively preserved terrace is systematically lower than age-equivalent terraces in neighbouring valleys such as the Exe and the Otter. Bedrock geology is the key to understanding this situation.

The highly erodible valley floor bedrock (Triassic mudstone and Jurassic clays, silts, and sands), combined with the ready availability of an erosive chert and flint bedload, caused an unusually rapid lowering of the valley floor during Middle Pleistocene low sea level episodes. The erodibility of the bedrock in the valley also explains the poor preservation of the terraces. The history of Pleistocene river development recorded in the terrace sediments at Broom shows that the Axe valley is a type in a wide spectrum of possible outcomes dependent on the relative influence of climatic, tectonic and geological factors.

The Broom site is also noteworthy for its late MIS 9 pollen record and for its rich assemblage of late Lower Palaeolithic artefacts, predominantly chert handaxes, which highlight possible regional variations in the lithic technologies produced in Britain between c. 300,000 and 250,000 years BP.



Late MIS 9 pollen-bearing deposits (Wadbrook Silts and Sands Bed) in the Railway Pit, Broom (Photo: C. Green)

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THE CAIRNGORMS, Scotland [NGR: NN 990 990]
Nominated by John Gordon

The Cairngorm Mountains comprise the largest continuous area of high ground above 1,000 m in Britain. They have evolved over many millions of years under a range of tropical, temperate-humid, ice-age and temperate climate conditions. The diversity of landforms present provides exceptional insights into long-term processes of granite mountain evolution and environmental change in a maritime, mid-latitude setting in the northern hemisphere.

The Cairngorms are considered to be one of the finest examples in the world of glaciated granite mountains, notable for their distinctive plateau surfaces, tors, weathered bedrock and glacially sculptured features that together form a classic landscape of selective glacial erosion. The adjacent slopes and glens support a diverse assemblage of periglacial landforms, glacial meltwater features, glacial deposits, rock slope failures, river terraces and active gravel-bed rivers. On the northern and southern flanks of the Cairngorms there is evidence for active recession of the last (Late Devensian) ice sheet, while several corries contain excellent examples of boulder moraines formed during the Loch Lomond Stadial. Late- and post-glacial climate changes and vegetation development are recorded in the plant remains and pollen grains preserved in lochs and peat bogs.

The geodiversity of the Cairngorms also forms the foundation for the internationally important habitats and biodiversity of the area, evident both in the large-scale habitat variations across the area and in the local mosaics of vegetation communities. The occurrence of such a diverse assemblage of features in a relatively compact area is quite exceptional.

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The Cairngorm Mountains form a classic landscape of selective glacial erosion. Extensive plateau surfaces with summit tors have generally been little modified by glacial erosion and contrast sharply with adjacent, deeply incised glacial troughs such as Loch Avon. This contrast reflects the former presence of active, warm-based glaciers in the glens, whereas the ice covering the plateaux was cold-based and relatively inactive. (Photo: J. Gordon).

CEMLYN BAY, Anglesey, North Wales
[NGR: SH 327 936]
Nominated by Emrys Phillips

The site at Cemlyn Bay on the northwest coast of Anglesey occurs within a well-developed drumlin field which formed beneath the Late Devensian (Weichselian) Irish Sea Ice Stream as it overrode the island. The size and shape of these subglacial landforms is highly variable, but they typically form low-lying elongate features with a prominent crest lines. They often occur as single isolated features with a long profile of up to a kilometre, but more complex features with marked, undulating crest lines are also present. The NE-SW-trending long axes of the drumlins and glacial striae identified on glacially smoothed bedrock surfaces in the western part of Anglesey record an overall SW-directed ice movement across this part of the island.

The site provides an excellent longitudinal section through an elongate drumlin and shows that it is composed of a 10 to 15 m thick sequence of weakly stratified diamictons resting on the polydeformed metasedimentary rocks of the Monian Supergroup which are exposed on the foreshore. The glacial sequence can be subdivided into two units; a lower bedrock-rich, dark blue-grey to green-grey diamicton (1 to 2.5 m thick) composed of angular to subrounded pebbles and rare boulders of locally derived schistose metasedimentary rocks, overlain by a brown to orange-brown, stratified sandy diamicton – the so-called Irish Sea Till. This upper diamicton contains far travelled clasts including granite, volcanic rocks, Carboniferous limestone and sandstone. Both diamictons are hard and compact (overconsolidated) consistent with them having been overridden by ice.

The lower part of the sequence is cut by a number of SW-dipping, sediment-filled hydrofractures which have been interpreted as recording the injection of overpressurised meltwater and sediment into the bed of the Irish Sea Ice Stream during the later stages of drumlin formation.

Section through a drumlin at Cemlyn Bay, Anglesey (Photo: E. Phillips).

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CLACH NA GNUIS, Cairngorms, Scotland
[NGR: NJ 114 028]
Nominated by: Adrian Hall

Clach na Gnùis (Rock of the Faces) is a magnificent tor that stands at ~1000 masl on a remote spur of Beinn a' Bhuird overlooking the northern Cairngorms. The tor summit is the oldest known exposed rock surface in the British Isles, with a 10Be/26Al exposure history of >0.62 Myr. Clach na Gnùis displays no signs of glacial erosion despite multiple periods of ice sheet cover. The tor thus provides key evidence that plateau ice caps on the Cairngorms were always cold-based. In the ice-free periods of the Middle and Late Quaternary, the tor has been weathered into fantastical figures and forms.

Clach na Gnùis, northern Cairngorms (Photo: A. M. Hall).

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CLAVA, Invernesshire, Scotland [NGR: NH 766 442]
Nominated by Jon Merritt

Clava, a Geological Conservation Review (GCR) site located at about 150 m OD, 9 km east of Inverness, comprises several exposures along southern tributaries of the River Nairn. The complex glacigenic succession includes 'arctic' marine shelly clay, which has excited considerable controversy since the late Nineteenth Century, about whether this is an *in situ* deposit indicating glacio-isostatically induced submergence in front of an expanding ice sheet, or transported by ice from offshore as glacial rafts. The main body of essentially horizontal and undisturbed silty clay extends for at least 170 m, reaches 4.9 m in thickness and coarsens upwards into unfossiliferous sand. It contains well preserved, high-boreal to low-arctic, shallow-water marine shells and microfossils not younger than the mid-Devensian. The succession includes till and gravel underlying the clay, and folded bodies of pebbly diamict with fragments of *Portlandia arctica* indicating shallow-marine, fully arctic conditions. The marine deposits are overlain by various diamicts, including subglacial traction till, glacitectonite, cohesive debris flows and splendid sand-filled hydrofractures. Some related bodies of sand exhibit conjugate microfaulting and planes of glacitectonic décollement. There is strong evidence that the shelly deposits at Clava have been deformed by subglacial processes involving pressurized water and transported during an early phase of the last glaciation (Last Glacial Maximum) from the Great Glen, then a marine fjord. Many common features of glacial rafts and their host materials may be examined at Clava and there are several 30 m-high, multi-till sections to the south of the main site.

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COIRE AN LOCHAIN, Cairngorms, Scotland [NGR: NH 982 030]
Nominated by Martin Kirkbride

Coire an Lochain is unique in the British Isles in having cosmogenically-dated moraines from the Holocene, the best-dated Loch Lomond Stadial cirque moraine in Britain, and a large ice sheet readvance moraine nearby. It is the only known site of a possible Little Ice Age glacier in Britain and has been used to make comparative palaeoclimatic inferences for contrasting periods of glaciation (Kirkbride *et al*, 2014). The cirque is a fine example of cirque-in-cirque form cut into a preglacial plateau, and its unusual rock architecture has been explained by both schrundline erosion (Haynes 1968) and by Late Glacial rock slope failure (Ballantyne, 2013). This is the best site in Britain to observe the geomorphological effects of snow avalanching. Cosmogenic dating of cirque-floor boulders detects Holocene snow avalanche disturbance back to the mid-Holocene (Kirkbride *et al,* 2014). Well-displayed avalanche landforms include an impact pit and debris aprons, and varied small-scale disturbance features which change annually.

Coire an Lochain, showing late-Holocene moraines adjacent to the Great Slab on the backwall, and Younger Dryas bouldery till covering the cirque floor. (Photo: M. Kirkbride).

This unusually accessible high-altitude cirque is heavily used for promoting the understanding of earth science through summer guided walks by the Cairngorm Ranger Service and by undergraduate field excursions from several UK universities. It represents a superb location for field study and education.

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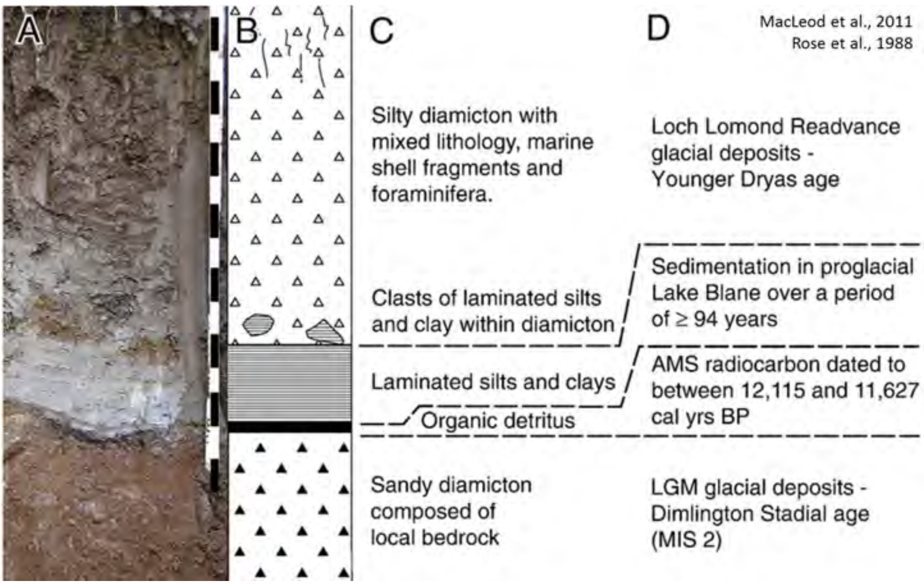
CROFTAMIE, Dunbartonshire, Scotland [NGR: NS 471 860]
Nominated by Alison Macleod

Croftamie is located 4.5km SE of the south eastern shore of Loch Lomond. Original work (Rose, 1981; Rose *et al*., 1988) identified a sediment succession affording evidence of two glacial episodes separated by an organic unit and laminated lacustrine deposits. The lower sand-rich till has been attributed to deposition during the Last Glacial Maximum, while the upper clay and shell-rich till was deposited during the Loch Lomond Stadial Readvance.



Glacial History at Croftamie: Till-Organics-Varves-Till. (Photo: Rose in MacLeod et al., 2011).

Coope and Rose (2008) obtained a beetle temperature record from the organic unit and these suggested mean annual temperatures of -5°C. MacLeod *et al.,* (2011) confirmed the lacustrine deposits to be annually laminated and a refined ^{14}C date on the organic unit suggests accumulation at c.12 ka BP. Combining this research provides a more precise picture of the climatic conditions and timing of ice expansion across this key stratotype region for the Loch Lomond Stadial Readvance in the UK.

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CWM IDWAL, Snowdonia, Wales [NGR: SH 64 59]
Nominated by Nicholas Midgley and David Graham

Cwm Idwal could be considered the classic Quaternary site in the UK and figured prominently in acceptance of the glacial theory. The glacial origin of the moraines was first recognised by Charles Darwin following his visit in 1840, arguing that it is ‘impossible for anyone who has read the descriptions of the moraines […] in the Alps, to stand on these mounds and for an instant to doubt that they are ancient moraines’ (1842). He described the ridges to the west of Llyn Idwal as lateral moraines and the ridge damming Llyn Idwal as a terminal moraine, both associated with ice sourced in Cwm Idwal. References to terminal moraines were also made by both Jehu (1902) and Seddon (1957). Escritt (1971) suggested that the western ridges were either lateral moraines or associated with pronival rampart development, but that those on the east were associated with ice originating from Cwm Cneifion (The Nameless Cwm). Gray (1982) proposed a subglacial flute origin, based upon the perceived ridge-crest alignment of the moraines. Addison (1989) attributed the moraines to a Cwm Cneifion glacier with the west side moraines formed by the ‘bulldozing’ of sediment across the floor of Cwm Idwal. Hambrey *et al*. (1997) and Graham and Midgley (2000) proposed an englacial thrusting model for moraine development based upon a Cwm Cneifion glacier flowing into Cwm Idwal with flow compression against a steep reverse bedrock slope, although this model has proved somewhat controversial (Lukas, 2005; Graham *et al*., 2007; Lukas, 2007)!

Panorama from within Cwm Idwal, showing moraines on either side of Llyn Idwal. (Photo: N. Midgley).

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DISS MERE, Norfolk, England [NGR: TM 116 798]
Nominated by John Birks

Diss Mere was the first 'lowland Britain' lake to be studied in a multi-proxy manner using pollen, diatoms, pigments, laminated-sediment structure and composition, and geochemistry. It provided the first detailed analysis of lake development and limnological responses to prehistoric and historic land-use (Fritz, 1993; Peglar, 1993). Analysis of individual years in its laminated mid-Holocene sediments show the 'elm-decline' occurred over 5–8 years, as a result of a pathogen aided by activities of prehistoric people (Peglar and Birks, 1993). Mercury content of its sediments (Yang, 2010) in relation to agricultural


Diss Mere, Norfolk (photo: John Birks)

history shows that despite recent agricultural changes, contamination from historic land-use persists. Diss Mere is a classic site for Quaternary science as it shows the value of a rigorous multi-proxy approach and of using annually-laminated sediments to estimate rates of change and to resolve likely drivers of a major pollen-stratigraphical event, the elm-decline.

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PASS OF DRUMOCHTER, Central Grampian Highlands, Scotland [NGR: NN 632 760]
Nominated by Sven Lukas

“Hummocky” moraine is one of the most cited, yet perhaps still somewhat enigmatic landform assemblages formed during the Younger Dryas (and perhaps also earlier cold periods) in Upland Britain. One of the most classic sites that is both accessible and well-researched is the Pass of Drumochter, Britain’s highest point reached by a main railway line in Britain, and incidentally also the highest point of the main glacial breach through the watershed that divides the Spey from the Tay catchments. In this area, and elsewhere in Scotland, 'hummocky' moraines had initially been interpreted as the product of widespread stagnation and mapped as broad areas, usually depicted by a stippled pattern. However, subsequent research employing detailed geomorphological mapping elsewhere in Scotland, and ultimately also at the Pass of Drumochter, has demonstrated that these moraines represent in fact successive ice-marginal positions occupied during oscillatory retreat, thereby demonstrating formation at the margins of highly dynamic, temperate glaciers. Postdepositional dissection by meltwater resulting from snowmelt and proglacial river discharge probably led to their 'hummocky' appearance. Sedimentologically, the moraines in the main valley around the Pass comprise loose, stratified diamicts that have been interpreted as terrestrial ice-contact fans, thereby corroborating aforementioned geomorphological interpretation; elsewhere in this area, larger moraines distinct from 'hummocky' moraines contain deltaic sediments and thus demonstrate the existence of an ice-dammed lake in Glen Garry to the SW of the Pass. Moraines around the Pass of Drumochter have been subject to a large amount of research over the years to elucidate the extent of glaciers in this area (e.g. Sissons, 1974; Lukas, 2003;

Oblique view of closely-spaced, dissected latero-frontal moraines (the classic Scottish "hummocky" moraine) trending obliquely downslope at the Pass of Drumochter. (Photo: S. Lukas).

Benn and Ballantyne, 2005) and have been visited during two QRA field meetings (Lukas *et al*., 2004; Palmer *et al*., 2008). Reconstructing the direction of ice retreat from these moraine sequences, both Lukas (2003) and Benn and Ballantyne (2005) agree that they were formed by ice sourced in the West Drumochter Hills, to the West of the A9 trunk road, by an ice cap unconnected to the Gaick Plateau to the East of the Pass, thereby calling into question the reconstruction of Sissons (1974) in its original form. Moraines from the Pass of Drumochter also feature prominently in key textbooks, for example Lowe and Walker (1997, 2014), making them one of the best documented and most visible cases of this classic landform that records Late Quaternary glaciation in Upland Britain.

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EASINGTON RAISED BEACH, Durham, England [NGR: NZ 443 453])

Nominated by Bethan Davies

The spectacular Easington Raised Beach, in Shippersea Bay, County Durham, is raised 33 m above sea level (Trechmann, 1931) and was formed during the MIS 7 interglacial (Bowen *et al*., 1991; Davies *et al*., 2009). Its bored, rounded, imbricated pebbles, temperate-climate gastropod fossils and well-sorted sands and gravels make it an excellent example of an interglacial raised beach, the most northerly to have survived the MIS 2 glaciation.

The raised beach is particularly interesting because of its unusual erratic suite. This erratic suite, comprising durable flint and granites, is distinct from the pebbles within the overlying Devensian tills (Davies *et al.,* 2009). The only currently extant source for these lithologies is the nearby Warren House Formation, a glaciomarine deposit containing flints, chalk and marl from the North Sea, and similar granites that may derive from Scotland or Scandinavia (Davies *et al.,* 2012). This suggests that the erratic suite within the beach may have been derived from littoral reworking of the Warren House Formation.

The Easington Raised Beach, County Durham (Photo: B. Davies).

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EASTON BAVENTS, Suffolk, England [NGR: TM 512 772]
Nominated by Ian Candy

The deposits exposed at the coastal site of Easton Bavents, Suffolk, contain evidence for shallow marine sedimentation during the Early Pleistocene. As well as being a key location for Quaternary vertebrate fossils that has greatly enhanced our understanding of the biotstratigraphy of earliest part of the Quaternary, it also contains the earliest diagnostic evidence for dramatic cooling and ice processes in Britain. The Baventian clay, representing marine regression under a cooling climate, contains pollen evidence for the replacement of deciduous woodland by open heath environment, whilst the heavy mineral suite preserved here contains evidence for the input of far-travelled lithological types. The mineralogy of this deposit has been suggested to reflect the first major episode of ice-rafting in the southern North Sea that is seen in Britain.

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FOUR ASHES PIT SSSI, Staffordshire, England
[NGR: SJ 914 083]
Nominated by Eleanor Brown

Four Ashes SSSI is the type site for the Devensian glaciation, and comprises river gravels with pockets of organic material which are overlain by glacial till deposited by the last British and Irish Ice Sheet. The datable organic material in the river gravels allows us to constrain the age of the advance of the last British and Irish Ice Sheet. Four Ashes was studied extensively in the 1960s and 1970s by A.V. Morgan (1973) and A. Morgan (1973). Sadly between the 1980s and 2010s this nationally important site became very overgrown and was inaccessible for fieldwork.

In 2011, Richard Waller (Keele) visited Four Ashes and made recommendations to Natural England for its future conservation. The BRITICE-CHRONO team also expressed an interest in conducting fieldwork. Natural England worked with the landowner and provided a Conservation Enhancement Scheme grant to remove the vegetation to allow access to the former pit faces, and improve drainage as often part of the site was under several feet of water. This geoconservation activity has enabled the BRITICE-CHRONO team to carry out their fieldwork.

This classic site tells us a significant story about climate and environmental change during the Quaternary, and it is being used by the BRITICE-CHRONO team to improve our understanding of the timing of the growth and demise of large ice sheets in the past, to help model the future. It also shows what can be achieved for geoconservation when scientists, conservation practitioners and landowners work together in partnership.

Four Ashes Pit SSSI pre clearance. (Photo: E.Brown).

BRITICE-CHRONO fieldwork. (Photo: E.Brown).

Four Ashes Pit SSSI post clearance. (Photo: E.Brown).

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THE GIANT'S ROCK, Porthleven, Cornwall, England [NGR: SW 623257]

Nominated by Pat Sargeant

The Giant's Rock is one of the largest and most enigmatic glacial erratics to be found anywhere in Britain. According to Campbell (1998) it might possibly also provide one of the oldest features of Pleistocene glaciation in south-west England. It is even more surprising as it is located on the south-west Cornish coast well south of the 'normal' glacial limit in Britain and even south of the glacier that came down the Irish Sea to reach the Isles of Scilly. This 50 ton erratic is resting in an eroded hollow on the intertidal platform cut across Devonian sediments just to the west of the fishing harbour of Porthleven overlooking Mount's Bay. The erratic is composed of a specific type of garnentiferous mica-schist which has no provenance in Britain.

The origin and source of the Giant's Rock has exercised the minds of earth scientists for over a century. It was first described by Flett and Hill (1912) and has attracted the attention of Quaternary scientists ever since. There are two main possible interpretations for the Giant's Rock - was it deposited directly from a glacier or was it floated here on an ice floe or iceberg? The history of the research and the various interpretations are detailed by Campbell (1998) in the 'Quaternary of South-west England'.

The Giant's Rock, Porthleven, Cornwall. (Photo: P. Sargeant).

The most recent interpretations suggest that Greenland could be a likely source. The same type of garnentiferous mica- occurs here and the massive erratic could easily have been transported in the toe of an iceberg or beneath floating ice sheets. This might then associate the Giant's Rock with a disintegrating Laurentide ice sheet sometime in the early Pleistocene (Campbell, 1998).

This would involve a journey of over 8000 km, making the 50 tonne Giant's Rock probably the largest and most far travelled glacial erratic in Britain and hence well worthy of inclusion in the Top 50 QRA Sites. Anyone wishing to view such a famous site has to plan their visit carefully. Normally the Giant's Rock is only visible and accessible for two hours either side of low-water before it disappears below the crashing waves and blue sea of Mount's Bay.

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GLANLLYNNAU SSSI, Gwynedd, Wales [NGR: SH 456 372]
Nominated by Stewart Campbell

Glanllynnau is one of Britain's most important Quaternary sites. It helped to establish the principle that multiple till sequences could originate from a single glacial episode. Coastal cliffs at Glanllynnau reveal tills (Llanystumdwy and Criccieth tills) separated by glaciofluvial deposits (Afon Wen Formation). Locally, the sediments are glaciotectonised. The inland area is studded with kettle holes. Some have been breached by the sea to reveal Devensian Late Glacial and Holocene silty clay, sand and peat beds. The sequence has featured in numerous reconstructions and correlations of Quaternary events. Some workers have suggested that possible weathering and frost-cracking between the tills indicates a significant hiatus in deposition. Boulton's (1972) seminal work on modern Arctic glaciers and their deposits, however, throws doubt on such interpretations. Instead, Boulton (1977) suggested that the lower (Criccieth) till was formed subglacially, with the overlying sediments originating as meltwater deposits and flow tills on and around buried ice ridges as the ice sheet downwasted. Critically, this model negates the need to invoke multiple glaciations and has had profound implications for reinterpreting similar complex glacigenic sequences elsewhere in Wales and farther afield.

Glanllynnau: Multiple till sequence and kettle holes at Glanllynnau, southern Llŷn. (Photo: S. Campbell).

Glanllynnau: Blue-grey Criccieth Till (weathered & frost-cracked?) overlain by a thin development of glaciofluvial sand (Afon Wen Formation) and the stony, cryoturbated Llanystumdwy Till at Glanllynnau, southern Llŷn. (Photo: S. Campbell).

The Devensian Late Glacial and Holocene deposits at the site have yielded coleopteran, pollen, plant macrofossil and radiocarbon evidence, enabling detailed reconstructions of climatic and environmental conditions and Late Glacial palaeo-temperatures. A radiocarbon date of 14,468 ± 300 BP (Birm-212) obtained from basal kettle-hole deposits is one of the earliest for the disappearance of Late Devensian ice in Wales. Glanllynnau is, accordingly, a Site of Special Scientific Interest.

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GLEN ROY AND GLEN SPEAN, Lochaber, Scotland
[NGR: NN 230 785]
Nominated by Adrian Palmer

Glen Roy is one of the most iconic sites associated with the early development of the Glacial Theory. During a visit by Agassiz and Buckland (1840), the world famous 'Parallel Roads' were interpreted for the first time as shorelines formed by ice-dammed lakes. Jamieson (1863) established the model explaining the interrelationships between the glacier margins and cols, which controlled the surface elevations of the lakes. Sissons then published papers between 1977 and 1983, providing evidence for the age of the shorelines (Loch Lomond Stadial; LLS), processes and rates of shoreline formation, regional pattern of glacier retreat, lake drainage by jokulhaup, and tectonically-induced dislocation of the shorelines. Peacock (1986) presented evidence that some of the fans, beautifully preserved within Glen Roy, were likely to have formed prior to the LLS. Subsequent research by Palmer (2010) established a varve chronology for these processes and events, which indicate that the lakes existed for 515 years, and also provide estimates for the timing and rates of shoreline formation and of advance and retreat of the glacier margins. Currently, Palmer *et al* (2010, 2012) and Fabel *et al* (2010) suggest that the lake systems formed, and therefore ice reached its maxima, toward the end of the Loch Lomond Stadial.

Glen Roy is a unique site within Europe for exploring the complex relationships between glacial, fluvial and lacustrine landforms and sediments,

Glen Roy from the flanks of Bohuntine Hill looking north with the Parallel Roads at 260m, 325m and 350m clearly cut into the hillsides. (Photo: A.Palmer).

which, in turn, provide unparalleled opportunity in developing our understanding of the rates of landscape response to abrupt climate change.

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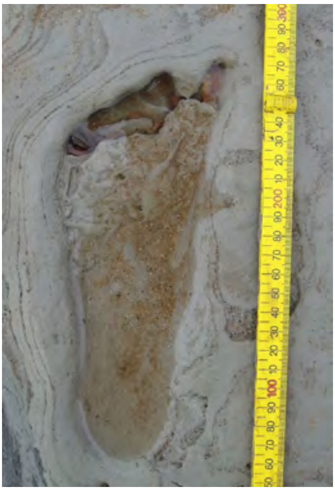
GOLDCLIFF, Severn Estuary, Wales [NGR: ST 375 821]
Nominated by Martin Bell and J.R.L. Allen

The Quaternary sediment sequence at Goldcliff has revealed a series of archaeological sites spanning 6,000 years, this has stimulated intertidal archaeology in many other areas. The Severn Estuary sedimentary sequence was established in many papers by Allen (eg Allen and Rae 1987). Allen (2001) identified a former island at Goldcliff surrounded by a last interglacial beach. An 11 m Holocene sequence around that island includes extensive dated Mesolithic submerged forests and four excavated Mesolithic settlement sites associated with human and animal footprints in annually banded sediments (Dark and Allen 2005; Bell 2007). Later sediments contain parts of a Bronze Age sewn plant boat, eight rectangular buildings and 16 associated trackways of the Iron Age (Bell *et al.,* 2000). Each site has been the subject of extensive palaeoenvironmental analysis, pollen, plant macrofossils, dendrochronology insects and sediments. Human activity can be related to marine transgressive/ regressive cycles and plant use and seasonal activity in prehistory has been identified. The site is protected as part of the



Goldcliff, Wales. The footprint of a young Mesolithic person aged 10-12 in annually laminated sediments c. 5,500 Cal BC. (Photo: M. Bell, Goldcliff Project).

Newport Wetlands Reserve and can be viewed from the seawall.

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GORTIN GLEN, north-central Ireland [IGR: H 250 384]
Nominated by Jasper Knight

The Sperrin Mountains in north-central Ireland was a key ice dispersal centre during the last deglaciation. The system of glaciolacustrine deltas and kettleholes preserved at Gortin Glen within a valley on the southern side of the mountain range can serve as an exemplar of the processes and controls on mountain ice retreat throughout upland UK.

The deltas have steep, rectilinear slopes and comprise a series of isolated, flat-topped hills that attain three different elevational levels at 256, 210 and 180 masl. The highest level surface is the most extensive and reaches the farthest distance north. Between these isolated hilltops are nine enclosed, water-filled depressions, interpreted as kettlehole lakes. Meltwater channels have incised into the delta fragments and a deep (<40 m depth) rock-cut channel is present immediately to the south. These landforms record phases of glacial lake formation and drainage during the last deglaciation. Sediments and meltwater were transported northwards through the subglacial meltwater channel (Nye channel) and deposited into a glacial lake that was impounded to the north by Sperrin ice. Topsets within the uppermost delta show a lake level at 256 masl.

The glaciolacustrine delta surfaces and kettlehole lakes at Gortin Glen, County Tyrone, Northern Ireland (Photo: Jasper Knight).

Subsequently, due to lake level fall, this delta surface was incised downwards and reworked and fresh incoming sediments formed the 210 m and then the 180 m delta level. These levels therefore record three stages of glacial lake drainage caused by the retreat of Sperrin ice that revealed progressively lower water outlets. The kettleholes were formed in delta sediments by melting of buried ice blocks, most likely at a calving rather than an ice-cored morainal margin. The Gortin Glen lakes is an excellent example of a glaciolacustrine system, has good access and parking, and is now a Nature Reserve.

GWAUN-JORDANSTON, Pembrokeshire, Wales
[NGR: SM 992353]
Nominated by Brian John

The 'Gwaun-Jordanston subglacial meltwater channel system' is one of the most complex and spectacular in the British Isles. Across an area of more than 100 km^2 there are seven main channels and many subsidiary ones, revealing features (including humped long profiles) associated with subglacial meltwater flow. There are also abundant Pleistocene and Holocene deposits within the channels.

Charlesworth (1929) argued that the channels were formed by meltwater spilling westwards from a series of pro-glacial lakes impounded against Mynydd Presely by Devensian ice which created the 'South Wales End Moraine'. The channels were designated as 'overflow channels'. However, as pointed out by Bowen and Gregory (1965) and John (1970), the key

features of these channels point to formation beneath wasting ice by meltwater under hydrostatic pressure. Campbell and Bowen (1989) argued that the channel system is Devensian, but John (1970) argued that it must be of composite origin and age. The channel complex was probably initially cut by subglacial meltwater flowing from NE towards SW. The Welsh Ice Cap must have been dominant at the time. The channel complex is both spectacular and important for the elucidation of Pleistocene history in Wales.

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HAPPISBURGH, Norfolk, England (NGR: TG 385310)
Nominated by Jonathan Lee

Happisburgh is arguably one of the most important sites within the British Quaternary contributing to our understanding of both early human occupation and the earliest known lowland glaciation of southern Britain. Exposures of the preglacial (Early to early Middle Pleistocene) sequence occur within the foreshore adjacent to Happisburgh village at low tide. Analysis of these sections, coupled with extensive trial pitting, has revealed a preglacial succession dominated by sediments deposited within coastal (e.g. tidal flats, river estuary and salt marsh) and fluviatile settings (e.g. overbank). Of particular significance is the presence of stone tools (cores, flakes and flake tools) and preserved human footprints within the fine-grained estuarine deposits. Based upon their reversed palaeomagnetic signature coupled with fossil evidence, these sediments are believed to be in excess of 800,000 years old and thus provide the earliest known evidence for human occupation in northern Europe and the oldest human footprints outside of Africa. A further point of interest is that the beds containing the archaeological evidence were laid-down under a cool boreal climate. It suggests that these early humans were able to inhabit the southern edge of the boreal zone having important implications for our understanding of early human behaviour and adaption.

Overlying the preglacial sequence adjacent to Happisburgh village is a well-exposed multi-layered glacial succession that can be traced southwards where it thickens through the core of a broad syncline in cliff sections to the south of Happisburgh lighthouse. The lower part of the glacial sequence comprises two sandy diamict units (including a subglacial till) and glaciolacustrine silts, clays and sands that record two separate ice-advances punctuated by a phase of ice-free conditions. Detailed lithological analyses of the diamict units demonstrate that they were laid-down by British ice flowing down the coast of eastern Britain, rather than Scandinavian ice as previously assumed. Collectively these lower units record the earliest known expansion of British ice into lowland England - the so-called ‘Happisburgh Glaciation’, however the age of this glacial event remains controversial. Opinions over the past 15 years have been sharply divided between: (1) a pre-Anglian glaciation – perhaps equivalent to MIS 16: (2) a conventional MIS 12 (Anglian) age; and more recently (3) a possible early MIS 12 glaciation separate from the main Anglian glaciation. Forming the top of the sequence at Happisburgh, are a chalky diamict (subglacial till) and outwash sand that crop-out within the core of the syncline to the south of Happisburgh lighthouse. They are widely believed to have been deposited during the Anglian (MIS 12) glaciation.

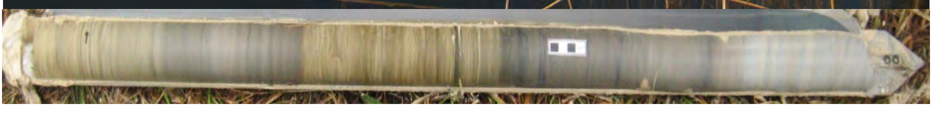
Southwards-dipping glacial units exposed on the northern limb of a syncline at Happisburgh. (Photo: Jonathan Lee).

HAWES WATER, Gait Barrows NNR, Lancashire, England [NGR: SD 478 766]

Nominated by Frank Oldfield, Jim Marshall and Liz Haworth

Since the first published paper, the Hawes Water sediments have yielded one of the most significant British records of Late-Glacial, early and mid-Holocene climate change. Detailed chrono-stratigraphic research has also revealed a valuable record of changing early-mid Holocene lake levels. The stratigraphic record of alternating micrites and peats is accessible and spectacular. Proximity to Gait Barrows limestone pavement, Silverdale Moss and Storrs (Leighton) Moss enhance the site's value.

Upper Photo - Hawes Water April 2012 – reeds on marginal shelf. (Photo: L. Haworth). Lower Photo - Late-glacial sediment core. From the base of the core (right): a. grey Devensian clays,b. buff-brown interstadial carbonates, c. grey Younger Dryas clays and d. lowermost Holocene carbonate (cm scale).



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HAWK'S TOR, Bodmin Moor, Cornwall, England [NGR: SX 150 748]

Nominated by Neil Roberts

Hawk's Tor is the site in Britain where the Late-Glacial climatic reversal was first recognised. Lying outside the Devensian ice sheet limits, Harry Godwin, Ann Connolly and colleagues from Cambridge University visited the Hawk's Tor site in 1935 and they recognised in the exposed sediment stratigraphy a sequence reminiscent of the Alleröd interstadial that had previously been identified in southern Scandinavia and northern Germany. In 1936 they sampled the Hawk's Tor sequence and began analysis of the sediments

Location of exposed sediments at the northern edge of flooded china clay pit at Hawks Tor. (Photo: N. Roberts).

for pollen and macrofossils. However, their work was interrupted by World War II, so that this was not completed and published until 1950. By this time, a similar reversal had been found in the sediments of Lake Windermere by Winifred Pennington, and so the Late Glacial interstadial in Britain came to be named after Windermere rather than Hawk's Tor.

The Hawk's Tor sequence comprises ~50 cm of woody peat and gyttja, including dwarf birch leaf impressions, overlying weathered granite. This lower peat is overlain by ~50 cm of clastic sediments (ranging from banded clays to fine gravels) which in turn are overlain by up to 300 cm of peat. Pollen analysis has shown that both of the lower two units are dominated by open habitat taxa (mainly Poaceae and Cyperaceae) and that mesic forest taxa only predominate from the base of the upper peat unit. Subsequent ^{14}C dating confirmed that the sharp contact between clastic sediments (partly soliflucted and of periglacial origin) and the upper peat represents the start of the Holocene interglacial.

The Hawk's Tor sequence, which is traceable laterally for over 200 m, thus reflects closely the remarkable and, at times, rapid shifts in climate that affected the British Isles during the Last Deglacial transition, including the Younger Dryas/Loch Lomond Stadial.

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HOLME FEN, Cambridgeshire, England [NGR: TL 203 893]
Nominated by Martyn Waller

Situated in the south-western corner of the Fenland basin, Holme Fen and Whittlesey Mere are associated with some of the most influential studies of Holocene deposits undertaken anywhere in the UK. Papers relating to this area by Sir Harry Godwin and his associates were amongst those which laid the foundations for the modern study of vegetation history and sea-level change. Godwin revisited the area towards the end of his career publishing detailed pollen diagrams and establishing a radiocarbon chronology. The Holocene deposits of the region include fen and oligotrophic peats, marine sediments and shell marls. Situated within a late Devensian thermokarst depression, the Holocene sequence at Holme Fen is locally 7.5 m thick and accumulated

Holme Fen: showing the old post established in about 1850 and the new 1957 post. There is no evidence to support the view that the old post derives from the Crystal Palace. (Photo: M. Waller)

from c. 7600 calendar years BP onwards. Wood peat is overlain by *Phragmites* and *Cladium* peat, a layer of birch wood peat and c. 1.50 m of ombrotrophic peat (with *Sphagnum*, *Calluna* and *Eriophorum*). Within the latter are thin clay layers. These were initially seen as representing the marginal extension of a marine incursion (the 'Fen Clay'), though were later reinterpreted by Godwin as being the product of middle Bronze Age soil erosion. Subsequent work has supported the former explanation. In addition, the site contains a unique record of peat wastage in the form of the Holme Fen post. Observations of this datum have been made over the last 160 years with a definitive account (to 1978) provided by Hutchinson. Since 2001 the site has formed part of the Great Fen restoration programme.

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INISHCRONE, County Sligo, Ireland [IGR: G 285 313]
Nominated by A. M. McCabe MRIA

At Inishcrone, a 10 m thick tectonic stratigraphy has been developed on top of competent beds of Carboniferous limestone. Their importance lies in the fact that the exposure captures the initial processes responsible for debris generation from competent sedimentary beds prior to deposition, later as 'mature' till facies. Facies from the base upwards consist of displaced and rotated beds of limestone, thrust bed-parallel detachment of limestone slabs, thrust ramps cutting intact limestone beds, cataclastic debris and comminution of bedrock, and thrust ramps cutting both the cataclastics and fine-grained diamict which formed to the lee of the growing tectonic pile. Deformation includes slip and brecciation along beds or shallow thrust ramps. Thrust duplication involving comminution and brecciation by cataclasis occurs in the upper fault zones. Processes of hydrofracture with high fluid pressures generated during tectonic movements may also be related to the

Disarticulation, compression and folding of limestone beds, Inishcrone. The folds occur on top of largely intact rafts of competent Carboniferous limestone which were shunted northwards with the same sense of fold vergence. The beds of limestone immediately above the lowermost rafts have started to pinch out and develop open folds and are a transitional cataclastic facies prior to intense compression, folding and shearing. (Photo: A.M.McCabe).

displacement northwards of a Tertiary dyke, 60 m along section. Importantly all of the processes of hydrofracturing, cataclasis and thrusting occurred at the same time and illustrate tectonic and erosional complexity at the base of this ice sheet. Tectonic stacking of this type can therefore generate thick *in situ* sediment piles. Because the internal tectonic structure is strongly form discordant, the final bedform outline is erosional with the rising thrust ramps continually being skimmed off into the base of overriding ice. Therefore the idea that processes of plucking generally provides the coarse fraction of tills is a misleading concept.

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KILKEEL STEPS, Northern Ireland [IGR: J 309 135]
Nominated by A. M. McCabe MRIA

Diamict facies at Kilkeel Steps record early deglaciation (≥ 22 cal ka BP) of the north Irish Sea basin when ice margins decayed around the flanks of the Mourne mountains. Subaerial channels incised into the diamict record isostatic uplift and emergence. Despite isostatic uplift the marine muds infilling the channels represent subsequent marine submergence associated with a far-field global meltwater signal ~19 cal ka BP. These facies are truncated by a regionally extensive Lateglacial raised beach which denotes final emergence during the Killard Point Stadial (max. 16.6 cal ka BP).

Although the facies sequence documents emergence, it is not a complete emergent sequence because tectonic deformation of parts of the mud facies is related to an overriding ice sheet advance from Dundalk Bay east as far as Kilkeel around 18.2 cal ka BP. In addition, marine truncation of the entire sequence associated with regionally extensive marine notches (max. 20 m OD) was contemporaneous with subaqueous outwash deposited at the maximum of Killard Point Stadial ice sheet limits at Cranfield Point. This meltwater pulse is related to Northern Hemisphere ice sheet meltwater pulses and cooling of the North Atlantic.

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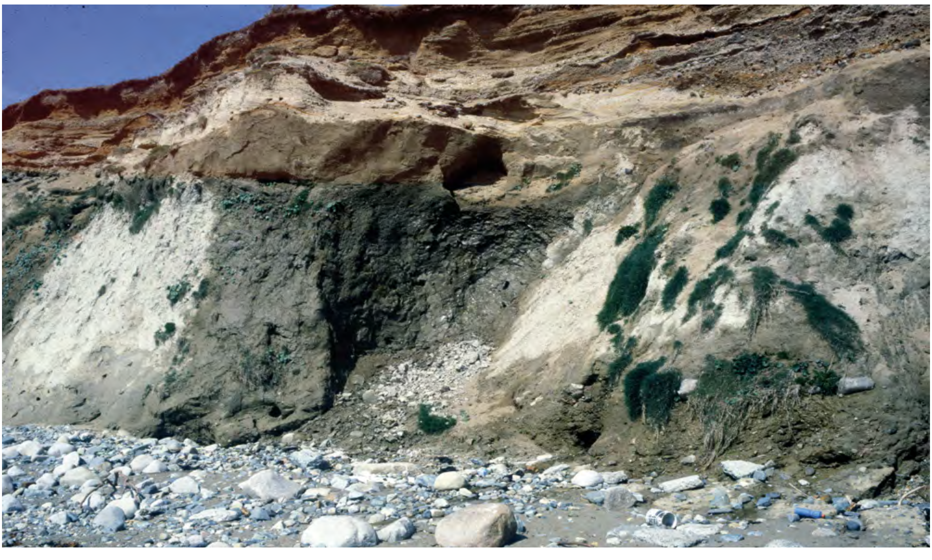
Top: Subaqueous marine outwash forming a flat spread containing lonestones released from floating icebergs. (Photo: A. M. McCabe).

Bottom: Marine mud deposited in a large channel cut into glaciomarine diamict and truncated by planar lateglacial beach gravel beds. Note that the channel margin is marked by a cobble lag in the lower right of the photograph. (Photo: A. M. McCabe).



KILLARD POINT, Co. Down, Northern Ireland [IGR: J 604 433]
Nominated by A. M. McCabe MRIA and Stephen McCarron

The Killard Point site is important for four main reasons.

First, it dates for the first time the major ice sheet readvance from the Irish lowlands which reached its maximum at this site at 16.6 cal ka BP and is correlated with part of the Heinrich Event 1 in the North Atlantic. It also provides a terrestrial record of millennial time-scale ice sheet oscillations that have been dated from most northern sectors of the Irish ice sheet.

Second, it is a critical example of a raised morainal bank (submarine outwash) consisting of diamict, sand and gravel facies. Marked upward sediment coarsening into deeper water occurred by high energy transfer mechanisms akin to gravels and resedimented pebbly mudstone facies known from deep sea canyons.

Third, the site located beneath the local hummocky ice-contact topography represents the eastern limit of the ice which readvanced from the north Irish lowlands into County Down. Southwestwards, the moraines can be traced for ~ 200 km into central Ireland as far as Athlone. In all cases the moraines are closely related (ie. at right angles) to the swarms of streamlined subglacial bedforms immediately to the north and represent the transfer and output of subglacial detritus.

Fourth, the fact that the ice margin ended at tidewater shows that deglaciation was accompanied by high regional sea-levels (HRSLs) contrary to most current numerical models. This sector of the Irish Sea basin must have been deeply isostatically depressed and stresses the role of HRSLs during deglaciation. The site and its regional correlatives also demonstrates that early deglaciation (≥22000 cal ka BP) of the northern Irish Sea basin and indeed about two thirds of the entire British/Irish ice sheet occurred prior to the readvance.

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Top: Caternary gravel infills within multistoried and cross-cutting channels, Killard Point, County Down, Northern Ireland. The channels were cut and infilled by powerful meltwater/sediment discharges from a grounded ice margin into a marine environment, northwestern Irish Sea Basin. (Photo: A.M.McCabe). Below: Marine red mud containing an Arctic marine microfauna interbedded with diamict beds (debris flows) forming beds of pebbly mud, Killard Point. (Photo: A.M.McCabe).

KINGSDALE, North Yorkshire, England [NGR: SD 694 753]
Nominated by Tony Waltham

Kingsdale provides a classic example of features associated with a recessional moraine dating from the Last Glacial Maximum. Across the mouth of the dale, the moraine forms the Raven Ray barrier ridge, 30 m high and 600 m long, between lateral moraines that extend both upstream and downstream, though the eastern lateral is larger than the western. During glacial retreat, the moraines impounded a temporary lake that is now recognised by the lacustrine and alluvial sediments forming the conspicuously flat dale floor. The lake was drained when its outlet stream cut a channel through the moraine; this is on an alignment east of the preglacial thalweg, and has exposed the profile of the sub-till valley where the stream has entrenched into the limestone bedrock forming its eastern flank. Where this stream now cascades back into the preglacial valley, immediately downstream of the moraine, 50 m of headward retreat has cut back to the Thornton Force waterfall; this descends over the unconformity between the limestone and the underlying basement slates. Beside the waterfall, Britain's finest exposure of a buried valley has the downstream end of its plug of glacial till lying between limestone scars along the old valley sides.

The Raven Ray recessional moraine (forming the skyline) and the buried valley of Kingsdale seen in profile, with the grass-covered slope of till between the limestone scars (left of the Thornton Force waterfall and on the extreme left) that mark the pre-glacial valley sides. (Photo: T. Waltham).

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KIRKHILL QUARRY SSSI, Aberdeenshire, Scotland [NGR: NK 011 528]

Nominated by E.R. Connell

Kirkhill Quarry (and neighbouring Leys Quarry, NK 005 525) found ~15 km NW of Peterhead, Buchan, form a key Site Special Scientific Interest and Geological Conservation Review site for the Quaternary of the region. The complex sequence of glacial, periglacial sediments and pedogenic horizons formerly exposed represents the most complete sequence of Middle and Late Pleistocene age known on land in Scotland. The sequence is preserved within channels/basins cut into bedrock.

In the earliest of the three glaciations (MIS 8?) recorded at the site, an icesheet flowed W-E across Buchan and was succeeded by the deposits of ice penetrating westward up the Ugie valley from the coast. An interglacial podzol is developed on these sediments. During the second cold stage, periglacial sediments (OSL dated to 142 +/-19 ka BP) accumulated before an icesheet advance from the NW (probably MIS 6) left another till unit. A brown earth palaeosol developed on its surface during the last interglacial (Ipswichian, MIS 5e).

During the last glacial cycle, ice sheets advanced across the site from both the NW (redepositing Mesozoic mud rocks from the Moray Firth Basin) and the WSW to deposit a complex till succession. A single rhomb porphry erratic from the Oslo Graben has been recovered from near-surface till, likely reworked from earlier deposits.

Whilst the Kirkhill sequence is unique, with deposits in clear superposition, and forms the basis of the Pleistocene stratigraphy of north-east Scotland, many elements of this succession have been recognised recently in correlative deposits at other sites across central Buchan.

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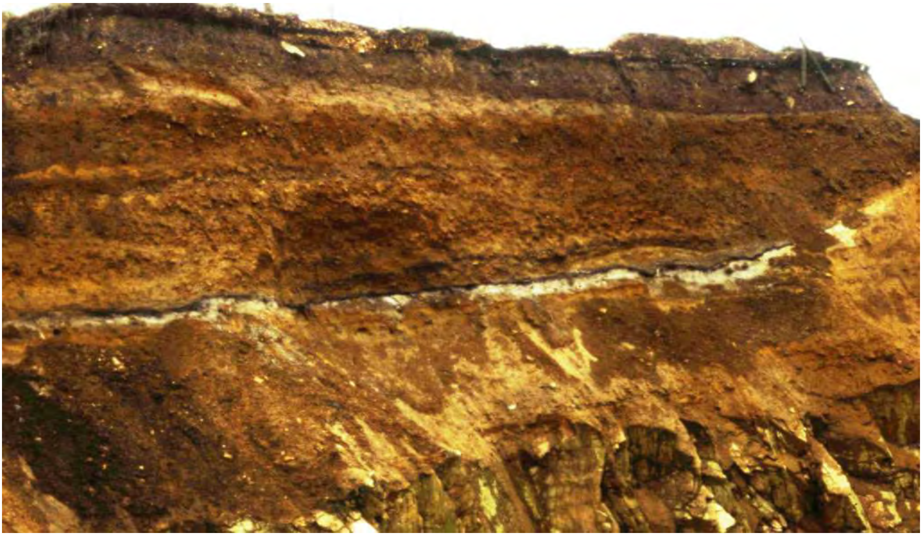

South face of Kirkhill Quarry photographed in 1979. Height of the section is ~10m. Above bedrock, the earliest glacifluvial gravels (MIS 8?) can be seen. (Till of this glaciation is only known from the nearby Leys Quarry). The white/black podzolic palaeosol horizon is developed in these sediments. Periglacial gelifluctate deposits overlie the soil and are capped by reddish brown till (MIS 6) in which the last interglacial palaeosol is formed. Pale coloured periglacial sediments can be seen below the dark brown Late Devensian till derived from the WSW (with apparent glaciotectonic structures beneath it). (Photo: E.R. Connell).

LEET HILL, Norfolk, England [NGR: TM 384 926]
Nominated by Ian Candy

The site of Leet Hill, Norfolk contains some of the most impressive exposures of Bytham river gravels and Middle Pleistocene glacial sediments that are available in Eastern England. As well as containing evidence for the progressive evolution of the Bytham system, and its interaction with an ice advance, the site has been controversial in providing evidence for a suggested MIS 16 glaciation. This suggestion has been based on the occurrence of glacial erratics and balls of reworked Corton Till within the Bytham sands and gravels at this site. The site of Leet Hill has been central to the construction of the Bytham river terrace sequence and the position of these glacial indicators has been used to suggest the existence of an ice-advance during a pre-Anglian

(MIS 12) glaciation.

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LITTLE HEATH SSSI, Hertfordshire, England [NGR: TL 017 082]
Nominated by John A. Catt & Clive R. Maton

Little Heath was designated a SSSI in 1954. It is located at 170 m OD on the Chiltern plateau, and consists of ~6 m of marine gravels overlain conformably by 2-3 m of yellowish-red intertidal sand with grey clay partings and then by an upper strongly cryoturbated gravel which is probably a Middle/Late Pleistocene solifluction deposit. The marine gravels rest unconformably at ~160 m OD on thin layers of Reading Beds sand and the Palaeocene Upnor Formation over Upper Chalk. The sequence is strongly weathered and unfossiliferous.

As part of ongoing research, the marine gravels are being dated by the cosmogenic nuclide burial method using small white quartzite pebbles. Despite this component, they are shown on BGS sheet 238 as part of the Eocene Reading Formation (55-56 Ma). The current view is that the gravels represent an uplifted beach of the Red Crag sea (Late Pliocene/Early Pleistocene, ~2.5 Ma), as originally suggested by Gilbert (1920). If so, they are part of a sequence of shallow marine deposits occurring: at OD on the Suffolk/Essex coast, extending to ~90 m OD at Stansted Mountfichet in western Essex (Mathers and Zalasiewicz, 1988); at ~130 m OD at Rothamsted, where blocks of sandy ironstone with the same heavy mineral assemblage contain a Red Crag mollusc assemblage (Dines and Chatwin, 1930); and at ~180 m OD at Lane End near High Wycombe, where gravel similar to that at Little Heath was recorded by White (1906).

These sites together suggest increasing westward uplift since 2.5 Ma (Moffat et al, 1986), which matches the uplift pattern over the same period shown by the Thames terrace sequence.

Exposure of sand and gravels at Little Heath, excavation sponsored by Natural England and National Trust 2012. (Photo: C.R. Maton).

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LLEINIOG SSSI, Anglesey, Wales [NGR: SH 619 787]

Nominated by Stewart Campbell and Jonathan Lee

Lleiniog is a reference site for understanding the dynamics and interactions of the Irish Sea Ice Stream (ISIS) of the British and Irish Ice Sheet (BIIS). Cliffs and foreshore at Lleiniog expose thick sands, gravels and till deposited by the ISIS c. 25,000 years ago during the Last Glacial Maximum. The generalised sequence comprises well-bedded subglacial and proglacial meltwater sediments overlain by Irish Sea till which was deposited as the ISIS

Irish Sea glaciofluvial sands and gravels overlain by till in cliff and foreshore exposures at Lleiniog, southeast Anglesey. (Photo: S. Campbell).

overrode and submerged Anglesey from the northeast. Diverse erratics show clearly that the ISIS had sources in Scotland, Ireland and the Lake District. These include Ailsa Craig microgranite and Shap granite (Cumbria), and red (Permo-Triassic) sandstone, coal and flint dredged from the floor of the Irish Sea. Large striated Carboniferous limestone blocks (including two of the largest erratics on the island) litter the foreshore and were derived from nearby Penmon. Rock types from Snowdonia indicate possible coalescence of the ISIS in the Menai Strait with northward-flowing Welsh ice and/or reworking of deposits from a previous Welsh glacial advance. Faults disrupt the sequence and indicate melting of buried ice masses. Nearby, periodically exposed submerged forest beds extend the palaeoenvironmental record into the Holocene. The site has featured in major regional stratigraphic syntheses and detailed sedimentological research for over 150 years. It is currently the subject of reinterpretation.

Lleiniog is unrivalled as an accessible and safe site for teaching and demonstrating the principles of glacial transport and deposition. Lleiniog's importance is recognised by its protection as a Site of Special Scientific Interest.

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LOUGH NEAGH, Northern Ireland [IGR: J 030 700]

Nominated by Rick Battarbee and Frank Oldfield

Research on Lough Neagh yielded the first, detailed and accurately dated sedimentary record of eutrophication in the UK using diatom and chironomid analysis (Carter, 1977; Battarbee, 1978). The results were critical to the future management of the lake and initiated the use of palaeolimnology as a tool in solving contemporary environmental problems. Combined analyses of magnetic properties, diatom and pollen records demonstrated, for the first time, the value of magnetic measurements in core correlation and in the reconstruction of environmental processes in lake-catchment systems (O'Sullivan et al, 1973; Thompson et al, 1975). This heralded the establishment of the new research field of environmental magnetism (Oldfield, 2012). Research on the Lough Neagh sediments thus laid the foundation for two crucial developments in Quaternary science.

Lough Neagh (source unknown)

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MALHAM COVE, Yorkshire, England [NGR: SD 897 642]
Nominated by Cynthia Burek

Malham Cove, part of a Special Site of Scientific Interest (SSSI) in the Yorkshire Dales National Park, is a superb example of an upland limestone pavement (Group 6) of the Sue Willis classification scheme (Willis, 2011; Burek and Willis, 2012). This is a high altitude, flat, open, deep grike, species-rich (Ward and Evans, 1976), classification group. Malham Cove itself has deep, narrow grikes developed on the thickly bedded limestone which allow specialist plants to grow and survive here.

The limestone pavement was formed during the last part of the Devensian Ice Age when glacial ice scraped away all the overlying material including soil and loose debris, exposing the bedding planes of the Carboniferous Great Limestone to weathering and erosion. This was then covered with till which was subsequently removed. The enlarging and widening of the grikes and the

Malham Cove (photo: C.V. Burek)

weathering of the clint surfaces with the classic karstic forms of runnels, pans and pits are easily recognisable.

Limestone pavements in England are protected nationally under the 1981 Wildlife and Countryside Act and were the first habitat to be named and protected under criminal law in this country (Burek, 2012) . They are also protected internationally under the European Habitat Directive of 1992. The iconic features of this site show the intimate relationship between the geodiversity and biodiversity. The limestone pavement forms the upper surface of the spectacular dry waterfall, an 80 metre arcuate cliff. This is a well visited site and has a geoconservation status which has been heightened by public exposure on the 2010 Harry Potter film: Harry Potter and the Deathly Hallows (Part 1). This site definitely deserves to be one of the top Quaternary sites in the UK.

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MAM TOR, Derbyshire, England [NGR: SK 132 835]
Nominated by Tony Waltham

Mam Tor is a classic, active landslide containing over 3.2 million m^3 of slipped material that has been moving for more than 3000 years. With a fall of 270 m below a head scar 70 m high, it is 1000 m long, with an upper zone of rock slices produced by rotational failure of the original slope, and a lower debris flow of broken slide material sliding over a basal shear surface. Between these, an unstable central complex of blocks and slices disintegrates into debris over the steepest part of the landslide’s basal shear. A road (closed since 1979) is broken where it crosses the head scars of these active slide blocks, while a lower road is merely deformed into waves by the plastic movement of its underlying debris flow. Mean annual movement is around 0.25 m, which occurs largely through the winter months, and is predictably increased in wet years when thresholds of rainfall and groundwater levels are exceeded, typically once in every four years. When rainfall in a winter month exceeds 210 mm after at least 750 mm of rain in the preceding six months, parts of the slide move more than 0.5 m (mostly during the wet month), but drier years have only 10% of the wet-year movement.

The road across the middle section of the Mam Tor landslide, where currently active displacements of the various fault slices are clearly shown by offsets of the road surface, which has not been maintained since its closure in 1979. (Photo: T. Waltham).

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MARKS TEY, Essex, England [TL 912 242]
Nominated by Ian Candy

The deposits of many interglacial episodes in the British Quaternary are highly fragmented, discontinuous and represent very short time intervals. In this context, Marks Tey, Essex, is relatively unusual in that it contains evidence for lacustrine sediments, and the range of palaeoecological and sedimentary proxies that these contain, that accumulated across an entire interglacial; the Hoxnian (correlated with MIS 11). As well as being the one site in Britain at which the evolution of climate and environment across an entire interglacial can be studied, Marks Tey has two major attributes that make it of singular importance. Firstly, for large parts of the record the sediments are annually laminated, or varved, allowing the climate of this interglacial to be investigated at high resolution. Secondly, the interglacial that it is correlated with, MIS 11, is widely considered to be the most appropriate Holocene analogue.

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MARSWORTH, Buckinghamshire, England [NGR: SP 933 142]
Nominated by Ian Candy and Julian Murton

The site of Marsworth, Buckinghamshire, is relatively unusual in the British Quaternary in that it contains lithological and biological evidence for two separate interglacial episodes (MIS 5e and MIS 7) plus the intervening cold stage (MIS 6). The U-series dating of this sequence has allowed direct correlation between the deposits at this site and the marine isotope record. Both temperate deposits contain an extensive assemblage of fauna and flora that have greatly enhanced our understanding of late Middle and Late Pleistocene stratigraphy and environments in southern England. It has been an important site in establishing the credibility of an interglacial between the Hoxnian and the Ipswichian. Accordingly, the site has been designated as the Pitstone Quarry Site of Special Scientific Interest (SSSI).

The site is located on a chalk platform between the Chiltern Hills scarp and the Vale of Aylesbury, a geomorphological setting that has preserved sequences of fluvial, slope and aeolian deposits. The deposits comprise clayey, silty, organic

Main stratigraphic units of the Lower ('Mammoth') Channel deposits in a controlled excavation. They comprise, from base upwards: (1) gravelly sand (grey) containing vertebrate bones beneath (2) organic mud (black), both of which are thought to have accumulated towards the end of MIS 7. These river channel deposits underlie (3) interbedded fine chalk gravel (white) and chalky mud (grey) interpreted as periglacial slope deposits of MIS 6 age. (Photo: David Parish/Buckinghamshire County Museum).

and gravelly sediments, many containing locally-derived chalk and some with molluscan, ostracod and vertebrate remains and tufa fragments. Periglacial features include involutions, wedge structures, brecciated bedrock and coombe rock.

The Pleistocene history reconstructed for Marsworth identifies four key elements: (1) Anglian glaciation during Marine Isotope Stage (MIS) 12 closely approached Marsworth, introducing far-travelled pebbles such as Rhaxella chert into the area; (2) Interglacial environments inferred from fluvial sediments during MIS 7 varied from fully interglacial conditions during sub-stages 7e and 7c, cool temperate conditions during sub-stage 7b or 7a, temperate conditions similar to those today in central England towards the end of the interglacial, and cool temperate conditions during sub-stage 7a; (3) Periglacial activity during MIS 6 involved thermal contraction cracking, permafrost development, fracturing of chalk bedrock, fluvial activity, slopewash, mass movement and deposition of loess and coversand; (4) Fully interglacial conditions during sub-stage 5e led to renewed fluvial activity, soil formation and acidic weathering.

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MARYTON, Angus, NE Scotland [NGR: NO 683 565]
Nominated by Sue Dawson

The site at Maryton is an exposure within a cliff section in raised estuarine deposits on the west side of the Montrose Basin, eastern Scotland. It provides the key site for the examination in section of deposits representing a high magnitude coastal inundation. This is ascribed to tsunami sediments associated with the Storegga submarine landslide off the Norwegian continental shelf and dated here to c. 7,200 radiocarbon years BP. These cliff section deposits also demonstrate the stratigraphic relationship between the tsunami sediments and the estuarine carse sediments associated with the Main Postglacial Shoreline. The tsunami deposits are here are variable across the basin but typically 25 cm

Tsunami section, Maryton, Montrose Basin. The tsunami deposit shown here as a grey distinctive unit between peat. (Photo: S. Dawson).

in thickness and comprise a steel grey micaceous silty sand deposit with intraclasts of the underlying peat unit encased within the sand. The lower contact is typically eroded and sharp. The site at Maryton has become a key reference site for demonstrating its stratigraphic position and unique sedimentary characteristics.

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MOUNT'S BAY, Cornwall, England [NGR: SW 500 310]
Nominated by Frank Howie

The extensive 'submerged forest' and peat deposits exposed intertidally in northwest Mount's Bay are the visible evidence of a distinctive mid- to upper

The intertidal submerged forest in Mount's Bay, Cornwall, exposed after the first winter storm of 2014, with St Michael's Mount in the background. (Photo: F. Howie).

Holocene sequence of intercalated organic-rich sediments and marine sands typically associated with many embayed sites on the Cornish coast.

The relative sea level curve for West Cornwall, determined by Healy (1995), and his palaeoenvironmental studies at Penzance, Hayle and Marazion Marsh, just inland from St Michael's Mount, indicate that before 4,500 BP the accumulation of organic-rich sediments occurred at lower altitudes than seen in more easterly coastal forests and wetlands. Around 4,300 BP, as relative sea-levels rose, the forests were inundated and rooted stumps, fallen trees and peat deposits were preserved by the landward migration of protective coastal barrier structures in Mount's Bay.

The submerged forest and palaeosols periodically well-exposed along the foreshore to the east and west of Penzance are readily accessible and contain impressive and well-preserved remains of oaks, yew and hazel. Samples of wood have been radiocarbon dated to between 3,900-4,300 BP. The Mount's Bay submerged forest deposit was first described as such by Borlase (1758) but has fueled local mythology for centuries, giving rise to tales of lost lands (Lyonesse), the Cornish name for nearby St Michael's Mount (Karrek Loes y'n Koes meaning "grey rock in the woods") and influenced some of Sir Humphrey Davy's poetry.

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NELLY’S COVE, Porthallow, Cornwall, England
[NGR: SW 797 235]
Nominated by Peter Ealey

Nelly’s Cove is historically an important site in the South-West as it was here that De La Beche (1839) illustrated his concept of ‘head’, overlying raised beach deposits and burying older fossil cliffs in a Quaternary section north of Porthallow, South Cornwall, SW England. As De La Beche noted, a head of angular fragments is common to all the raised beaches of the coasts of the SW England. This deposit was postulated to comprise degradation products of the cliffs themselves, mingled with weathered rock fragments washed down from the higher ground behind.

Nelly’s Cove lies at the southern end of a Quaternary section, extending one kilometre northwards (Flett and Hill, 1912; Flett, 1946). The section in Nelly’s Cove is perpendicular to the coastline, i.e. a relatively rare dip section. It shows a contemporary wave cut platform below a relatively high level former platform with a notch (8.5 m OD) at base of the former cliffs at its landward end. This platform is overlain by indurated red (iron) stained raised beach deposits. The basal ‘head’ section comprises strongly seaward dipping stratified gravels, overlain by more typical diamict, the upper metre of which appears to be paler and probably loessic.

Older shore platform, overlain by raised beach with former cliff line and basal notch, buried by ‘head’ in Nelly’s Cove, Porthallow. (Photo: P. Ealey).

The site, essentially the type section of South-West ‘head’, can be seen both from the coastal footpath above the cliffs, from where De La Beche drew it, or better from the foreshore (attached photo and Plate XIV in Flett and Hill, 1912). The latter involves some rock scrambling at low tide.

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THE NEW FOREST: CRANES MOOR, Hampshire, England [NGR: SU 193 028]

Nominated by Keith Barber

The New Forest is a unique survival of the Medieval wood pasture system that was regulated by Norman law after the Conquest and is now a National Park. It is renowned for its Ancient & Ornamental Woodlands, its heathlands and its mires, known locally as valley bogs or moors. Three key sites are described here: Cranes Moor, the largest and deepest site, displays unrivalled detail of early Holocene vegetational change but is truncated by peat cutting; Church Moor contains Lateglacial deposits as well as demonstrating woodland dynamics though the early to mid-Holocene, and the record is completed by; Barrow Moor with a high-resolution pollen diagram from around 4,000 cal. BP to the present.

The Cranes Moor mire complex is the largest and arguably the most scientifically valuable early to mid-Holocene site in the New Forest and indeed in south-central England. There are 500 cm of mainly organic peats, with an area shielded from water inflow being dominated by *Sphagnum*, suggesting that the bog acted ombrotrophically throughout the early Holocene. The age of the earliest deposits, at 11,600 cal BP, demonstrates that accumulation began at the very start of the Holocene and the thickness of the Boreal peats is probably unique in Britain with 2.5 m of accumulation before the alder rise denotes the opening of the Atlantic period dated to 8,150 cal BP. The order of immigration of the forest taxa is conventional with an early birch peak around 11,600 cal BP succeeded by over a millennium of pine dominance from 10,900 to 9,610 cal BP, after which the usual broadleaved mixed forest of oak, alder, hazel and elm become established. The record is truncated by peat cutting c. 5700 cal BP with its legacy of large pools, most of which look natural today. Causeways of drier peat, often with intercalated sand lenses, also testify to human activity

Panorama of the Cranes Moor mire complex. (Photo: K. Barber).

over this large site. Macrofossil and charcoal analyses have recently shown that the site was climatically sensitive and that periods of warmer / drier summers were coincidental with burning episodes which affected the natural woodland dynamics of the early Holocene, the first time that this has been demonstrated in Britain. The plant macrofossil record is important for understanding the palaeoclimate of the early to middle Holocene in southern Britain, as there are few other records. Increased fire incidence coincides with drier periods at 10,000 – 9,500, 8,700 – 7,500 and 7,000 – 6,000 cal BP, with wetter episodes at 9,400, 7,400 and 6,600 cal BP.

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THE NEW FOREST: CHURCH MOOR, Hampshire, England [NGR: SU 248068]

Nominated by Keith Barber

Church Moor is a valley bog that lies in the heart of the Ancient & Ornamental Woodlands of the New Forest, an internationally recognised area of surviving medieval pasture woodland and heath. At the southern end of the bog, basal deposits date from the Windermere Interstadial (14,700 cal BP) when the local vegetation was dominated by tall sedge and dwarf birch, with some tree birch, and a notable moss groundlayer including *Calliergon cuspidata*, *Campylium stellatum* and *Homalothecium nitens*, all typical of Lateglacial floras. The Loch Lomond Stadial seems to have had a seasonally dry climate giving rise

Church Moor south – area containing Lateglacial deposits. (Photo: K. Barber).

to a dark silty peat with fine sand and evidence of burning in the form of charcoal. At the northern end of the site the basal sediments are dated around 10,350 cal. BP and the bog was surrounded by a woodland of hazel and oak, with pine and elm present. At 8,820 cal BP recent pollen analyses show beech, lime and ash immigrating into the area, confirming earlier less detailed counts, and confirming that beech is a native part of the British flora although its expansion in the New Forest and elsewhere in Britain owes much to human disturbance of the forest. At 8,100 cal BP there is a major burning event, associated with macroscopic charcoal, causing falls in alder, hazel and to a lesser extent oak, after which alder carr re-establishes quickly. There is a stratigraphic break in the record at 105 cm, above which the peats are recent, from about 700 BP.

Nevertheless, Church Moor is important for its Lateglacial flora and early Holocene vegetation dynamics, allied to its fire history. Linked to Barrow Moor, only 600 m away in Mark Ash Wood, the Church Moor record supports the view that woodland cover in this area has been continuous throughout the Holocene.

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THE NEW FOREST: BARROW MOOR, Hampshire, England [NGR: SU 247 072]

Nominated by Keith Barber

Barrow Moor is a companion site to Church Moor in Mark Ash Wood, one of the 4,000 ha of pasture woodlands that represent the largest remaining area of its type in Western Europe. Peat accumulation has been continuous since c. 4,000 cal BP and recent high resolution pollen and charcoal analyses have yielded a unique insight into late-Holocene woodland dynamics. The oldest pollen spectra are very similar to those immediately before the stratigraphic break in the Church Moor sequence, being dominated by oak and hazel with abundant alder from the local alder carr and significant amounts of lime. Beech is also present at low values. Lime declined at this site over some 200 years beginning in the early Bronze Age c. 3,500 cal BP, finally disappearing during Romano-British times. It was an important part of the natural woodland of northwest Europe and various factors contributed to its decline, including clearance for farming, animal browsing, soil deterioration, climatic change and paludification. Whilst the woodland cover of the area around Barrow Moor continued at a high level through until Medieval times there is evidence of woodland management in the form of charcoal and reciprocal changes in

Barrow Moor alder carr. (Photo: K. Barber).

oak and hazel pollen – the area has evidence of pottery kilns and charcoal pits. From c. 1250 cal AD there are substantial changes with the decline of hazel and later oak and birch, and the expansion of beech and grasses, with large increases in charcoal and pine around 1850 AD. Alder was coppiced to be used in local gunpowder factories until Victorian times and hazel became extinct locally due to a switch from coppicing to timber production as well as heavy browsing pressure. Despite these pressures, the area remained wooded up to the present – with the evidence from Church Moor this is rare if not unique in Britain.

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NIGG BAY, Aberdeen, Scotland [NGR: NJ 965 045]
Nominated by E.R. Connell

The Pleistocene sediments (tills, gravels and sands) exposed in the south cliffs of Nigg Bay, Aberdeen, are a classic site researched by many emminent geologists since Thomas Jamieson first drew attention to them in 1882. Their importance to the glacial history of Aberdeen, and more widely to NE Scotland, is reflected in their status as a key SSSI and GCR site. The deposits have been used to reconstruct the timing and ice-flow directions during glaciation, including the possible “Aberdeen Readvance”. The exposed sequence (~20 m) in the cliff is the uppermost part of a 60 m thick succession filling a buried valley (former course of the River Dee or an ice-directed meltwater channel?). The oldest unit exposed in the cliff, fining-upwards gravels and sands, though derived from the west contain a significant number of Scandinavian erratics and has recently given an OSL age estimate of 63 +/-5 ka BP. This unit may represent deglaciation from an MIS 4 glaciation reaching the east coast of NE Scotland. Uncomformably above these deposits are grey and red coloured tills reflecting ice advances from the Dee valley and Strathmore to the south respectively. Both tills are believed to date from the last glaciation. Coarse gravels in the south cliff indicate deglaciation of the later advance. Recently studied sections in the north cliffs of the bay have revealed a third thin till possibly deposited during a readvance of Dee valley

Nigg Bay, Aberdeen, south cliff section, 2001. Section is ~15m in height. The gravels and sands (OSL age estimate 63 +/-5 ka) are seen immediately above the excavated debris overlain by grey till deposited by ice flowing eastward down the Dee valley. The red till, deposited by ice flowing north from Strathmore, is not seen in the photograph but its deglacial outwash is the coarse gravel deposit at the top of the face. (Photo: E.R. Connell).

ice. Though having been studied for more than 130 years, the site still offers significant research opportunities.

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NORBER erratic boulders, North Yorkshire, England [NGR: SD 765 697]

Nominated by Tony Waltham

On the southeastern flank of Ingleborough, the Norber erratic boulders, each about 1 m to 5 m across, consist of Silurian greywacke derived from a rocky spur in the western slope of Crummack Dale. This source lies at the head of a well-defined train of erratics extending for about 1500 m. Though they now lie on younger Carboniferous Limestone, the erratics were not transported uphill by any significant amount; their train extends almost horizontally from the exposed basement ridge onto the gently down-folded limestone. They were emplaced by a tongue of ice that overflowed from Ribblesdale, crossed the limestone benches and deepened Crummack Dale before merging with ice

The central zone of the Norber glacial erratic boulders, looking north with Ingleborough up to the left and the source of the erratics over the brow at the right edge of the image. (Photo: T. Waltham).

flowing southeastwards along the Craven Lowlands; this was at around 17 or 18 ka BP, during retreat of the Late Devensian ice sheet. Many of Norber's erratics are perched on low pedestals of the limestone bedrock, but the heights of individual pedestals are greatly influenced by the immediate bedrock structure, and are only partly a consequence of dissolutional lowering of the adjacent surfaces.

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OVERSTRAND, North Norfolk, England [NGR: TG 256 405]
Nominated by Emrys Phillips

Overstrand is truly one of the classic sites in the UK for glacitectonic deformation within the Middle Pleistocene glacial sequence exposed on the north Norfolk coast, eastern England. Glacial rafts or 'megablocks' are dislocated slabs of bedrock and/or unconsolidated sedimentary strata that have been transported from their original position by glacial action. Such rafts are typically composed of relatively thin slabs of material that may have

Rafting of chalk bedrock at Overstrand on the North Norfolk coast. (Photo: E. Phillips).

been transported over distances ranging from tens of metres to hundreds of kilometres. They generally occur as single, horizontal slab-like features, but may be stacked within conspicuous ice-pushed hills of various types. The section at Overstrand is dominated by a large raft comprising Cretaceous chalk bedrock overlain by pre-glacial marine sands and gravels of the Wroxham Crag. The raft is approximately 20-25 m thick and 100 m in length, and was detached, transported and finally emplaced by a major ice sheet flowing from the north, down the North Sea. The chalk and Wroxham Crag within the raft are deformed by a southerly verging anticline which occurs within the hanging-wall of a thrust forming the prominent detachment at the base of the raft. This southerly direct thrust and the deformation associated with the emplacement of the raft are well exposed at the base of the cliff section.

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PAKEFIELD, Suffolk, England [TM 537 884]
Nominator: Ian Candy

Deposits exposed in the cliffs at the site of Pakefield, Suffolk, contain detailed evidence of episodic sedimentation during the Middle Pleistocene. The Cromer Forest Bed (CFB) deposit exposed there, the 'rootlet' bed, contains a thick sequence of temperate floodplain and channel fill deposits which contain, through the fossil floral and faunal assemblages, important evidence for the climate and stratigraphy of this interglacial interval. The overlying marine/fluvial/glaciogenic deposits have been at the centre of a controversial discussion over the British stratigraphic record of the Middle Pleistocene. Most importantly the CFB deposits exposed at this site contain some of the oldest Palaeolithic artefacts in northern Europe, indicating that one of the first episodes of human colonisation of Britain occurred ca 700,000-780,000 yrs BP under a "Mediterranean" style climate.

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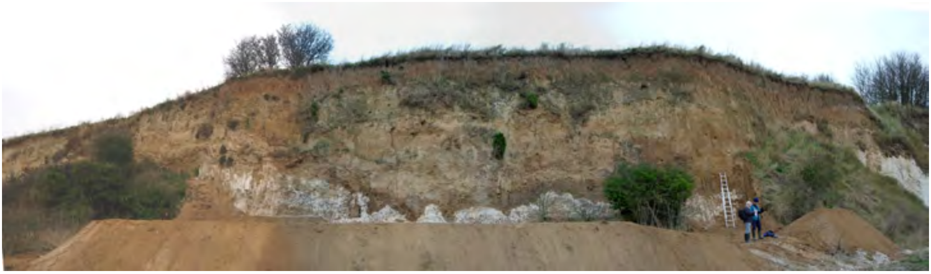
PEGWELL BAY, Kent, England [NGR: TR 635 164]
Nominated by Julian Murton and John Catt

Pegwell Bay contains a rich variety of periglacial sediments and structures that provide important insights about Devensian cold-climate processes and environments. The site is part of the Sandwich Bay to Hacklinge Marshes SSSI and the infilled dry valley is a RIGS site.

Loess deposits overlie a widespread involuted layer and cap an infilled dry valley. The loess, best exposed behind the former Hoverport, is up to 3 m thick and attributed to deposition of windblown silt on a partially vegetated land surface between about 18,000 and 15,000 years ago, near the end of the last ice age. The involuted layer, widespread in the chalklands of lowland Britain, represents a cryostratigraphic marker horizon that formed by freezing and thawing processes during the Late Devensian, when permafrost developed beneath Kent. The infilled dry valley provides the thickest sequence of



Northward view of vertical cross section through the infilled dry valley at Pegwell Bay. The stratigraphy comprises, from base upwards: (1) disturbed chalk bedrock (white), (2) brown flinty diamicton (1-2 m thick), (3) pebbly silty loam (5 m thick), (4) flinty gravel (0.5 m thick), (5) silty loam (loess; 2 m thick) and, in the eastern part (6) silty slopewash deposits that contain a buried mid-Holocene palaeosol. The brown ridge in the foreground is spoil excavated from the lower part of the section during English Nature's Facelift programme in February 2005. The sides of the excavation are marked by abrupt boundaries through the vegetated talus (green) on the left and right. Persons for scale. (Photo: J. Murton).

Quaternary sediments at Pegwell Bay and is thought to have infilled through fluvio-colluvial and slopewash processes. Analysis of the valley infill has extended the record of known periglacial activity on Thanet from about 18,000 years BP to about 88,000 years BP, and the excavation in February 2005 (see photo above) indicates that the infill contains still older sediments which may provide an important record of environmental change in a period of time that is poorly known in Britain.

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PENNINIS HEAD, Isles of Scilly, England [NGR: SV 911 095]
Nominated by Pat Sargeant

The origin and morphology of granite tors has long been the subject of extensive study and debate. Linton's (1955) seminal paper on the granite tors on Dartmoor proposed a twofold phase of formation with Tertiary weathering being followed by later Pleistocene periglacial processes. More recently Scourse (1986, 1987) has carried out a comprehensive review of the granite tors found on the Isles of Scilly.

Four different types of tor, including one type restricted to the previously glaciated northern parts of the archipelago, have been identified. However Penninis Head on the south side of St Mary's contains the most concentrated suite of granite tors to be found on the islands, if not in Britain. The headland exhibits examples of 'vertical or castellated', 'hillslope' and 'horizontal' tors. Pulpit Rock is a classic and most spectacular example of the horizontal tors and special enough to be selected for the front cover of the GCR Volume 'Quaternary of south-west England' (Campbell *et al*., 1998).

Fortunately, organic sediments within the nearby Porthloo Breccia have provided radiometric dates that suggest that the tors were subject to periglacial weathering during the Middle and Late Devensian (Scourse, 1998) but no evidence of earlier Tertiary chemical weathering on any of the tors on Scilly

Pulpit Rock , Penninis Head, St Mary's, Isles of Scilly. (Photo: P. Sargeant).

has been found.

Penninis Head is also one of the favourite locations of visitors to the islands and is a 'must see' site especially at sunset or with storm waves etching out the joints and crevasses of such a spectacular and complex granite tor landscape.

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PILTDOWN Skull Site, Sussex, England [NGR: TQ 439 217]
Nominated by Colin Prosser

The Piltdown hoax, the elaborate falsification of fossil material and associated artefacts in order to make them appear to represent the evolutionary 'missing link' between man and apes, is internationally renowned as one of the most notorious cases of scientific forgery in history and has been the subject of hundreds of papers, books, articles, press reports and web-pages. As such, the site of these 'finds' is arguably the most famous, or infamous, Quaternary site in the UK. Although now known to be little more than a gravel deposit representing a terrace of the River Ouse, it was once a focus of scientific excavation and research throwing light on the evolution of man and was regarded being of such importance that it became the GB's first geological

Piltdown Skull Site showing the memorial to Charles Dawson marking the location of the Piltdown 'finds' and the brick-built entrance to the 'witness section' that once exposed the gravels. (Photo: C. Prosser).

National Nature Reserve (NNR) in 1952. The uncovering of the forgery during 1953/4 led to international embarrassment for Britain and British science and started a ‘who done it’ still discussed today. Although only a small site with little or no exposure, and stripped of its NNR status, the Piltdown Skull Site still has a strong sense of history. The site of original 1913 excavations, the memorial to Dawson who ‘discovered’ Piltdown Man, and the remains of a brick-built ‘witness section’ constructed when the site was made an NNR, are still visible and remind us of the importance of taking a rigorous approach to all science.

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PORTH NANVEN, West Cornwall, England [NGR: SW 355 310]
Nominated by Pat Sargeant

Porth Nanven exhibits one of the largest and most spectacular raised beach deposits in Britain. It was also one of the earliest raised beaches to be described, first noted by Borlase (1758). Later Reid and Flett (1907) interpreted the site as an ancient Pleistocene cliff line. A comprehensive review of the sites history and interpretation is given by Scourse in Campbell (1998).

The 16m thick deposits rest on a wave cut platform cut across the local granite

Upper section of the Raised Beach sequence at Porth Nanven, Cot Valley, West Cornwall. (Photo: P. Sargeant).

bedrock. The lower 8 m comprise of a mixture of well-rounded granitic cobbles and boulders. Surprisingly this horizon becomes coarser towards the top of the sequence where boulders up to 0.6 m can be seen. The upper 4 m of the cliff is composed of coarse angular granitic breccia or head. Fragments of greenstone and killas, both of local provenance also occur here (Scourse, 1985).

Recent studies of other Quaternary deposits and features in West Penwith by Scourse (1996) have attempted to shed some light on the possible age of the deposits at Porth Nanven. One suggestion is that the Porth Nanven raised beach deposits accumulated during a massive high energy pre-Ipswichian storm event and that the overlying head deposits are of Late Devensian age (Scourse, 1985).

Whenever the deposits were laid down, Porth Nanven with its exposed location in the far west of the Land's End peninsula, will have been subject to extreme high energy storm events both in the past as it is at present. Such storms frequently release fresh supplies of beautiful rounded granite boulders onto the beach. In the past they have attracted the attention of tourist 'collectors'. This is now controlled by National Trust who encourages visitors to leave this spectacular site for others to enjoy and contemplate the how, when and why.

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PRAWLE POINT TO START POINT, Devon, England
[NGR: SX 830 370 to SX 773 350]
Nominated by Jenny Bennett

The coast between Prawle Point and Start Point shows 'some of the finest sections through periglacial slope ('head') deposits anywhere in Britain' (Keen, 1995). These deposits sit on a raised shore platform and abut and surround an abandoned cliff line of probable Ipswichian age. They are up to 33 m thick and show layering within the solifluction deposits. There are

Periglacial slope deposits, abandoned clifflines and shore platforms From Prawle Point looking westwards. (Photo: J. Bennett).

further higher marine platforms representing sea levels in earlier warm stages also present. The precise ages of the deposits are unknown but the combination of raised shore platforms, abandoned cliff lines and extensive head deposits gives a good record of types of Quaternary climate change.

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PURFLEET Chalk Pits SSSI, Essex, England [NGR: TQ 513 737]
Nominated by Danielle Schreve

Purfleet is a key site for study of MIS 9 sediments as represented within the Lower Thames sequence, within the Lynch Hill (Corbets Tey) terrace (Bridgland, 1994; Schreve, 2001). This is without doubt the least well known of the late Middle Pleistocene interglacials, this site having been of great importance in establishing it as part of the terrestrial record (Schreve *et al.,* 2002), the mammalian signature from this and correlative sites having been a critical factor (Schreve, 2001). The complex of quarries here was notified as an SSSI for the richly fossiliferous and artefact-bearing sediments exposed above the Chalk of the Purfleet Anticline, which was once quarried here for

QRA–Essex Field Club excursion visit to the Purfleet conservation site (Greenlands Quarry) on October 5th, 2014. The inset shows detail of the Greenlands Shell Bed, the most richly fossiliferous of the MIS 9 interglacial deposits at the site. (Photos: D. Bridgland).

cement making. Added to the coverage as a result of the GCR (Bridgland, 1994, 2013), the site is an analogue for the erstwhile Grays brickpit, once a rich source of fossils from equivalent deposits, but long disused.

The Purfleet sediments are also notable for the tripartite sequence of Palaeolithic industries they contain, as has been confirmed recently by research in connection with construction (through part of the SSSI) of 'HS1', the Channel Tunnel rail link (Wymer, 1968, 1999; Schreve *et al.,* 2002; Bridgland *et al.,* 2013). The basal gravel contains Clactonian artefacts, whereas handaxes occur higher in the sequence and Levallois technology appears for the first time in the Thames record in the uppermost gravel.

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RIBBLEHEAD drumlins, North Yorkshire, England [NGR: SD 775 790]

Nominated by Tony Waltham

The drumlin field at Ribblehead is probably the finest in Britain, with more than 300 individual drumlins lying within an area of about 25 square kilometres. They were formed beneath the Devensian ice sheet that was moving southwards to flow largely but not entirely down Ribblesdale. Individual drumlins are typically a few hundred metres long, somewhat

View across the northern end of the Ribblehead drumlins, where Devensian ice flowed straight towards the camera and then off to the right. (Photo: T. Waltham).

narrower, up to about 30 metres high, with little or no regular pattern of asymmetry and lie not only across the dale floor but also up onto the flanking limestone benches. Some have been breached or dissected by postglacial streams, and exposed faces reveal only poorly sorted glacial till. They appear to have been formed beneath an area of slowly moving ice; this was certainly not static but was not moving as steadfastly as the ice streams that occupied and enlarged the main dales, which are glaciated troughs largely free of drumlins.

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RIMSMOOR, Dorset, England [NGR: SY 814 922]
Nominated by Keith Barber

Rimsmoor is an exceptional site, unique in Britain. It is only 35 m in diameter, but has 18 metres of Holocene peats. The chalk of the Dorset Downs outcrops within a kilometre to the north, and the bog has developed in a doline, a form of depression in the landscape caused by the slow solution of the chalk underlying the Tertiary strata that feather out over the chalk. These dolines are very common in the area, but whilst most are dry, Rimsmoor has a clay base which has subsided and infilled with peat at a rate of around 1 cm every 4 years for the last 8,000 years. The peats are herbaceous with much *Phragmites* up to 1300 cm depth, after which they are dominated by *Sphagnum*.

High resolution pollen analysis has revealed an interesting vegetational history with Boreal period woodland of pine and hazel being replaced by closed oak – elm – lime woodland after the Boreal – Atlantic transition. The Elm Decline is dated at 5670 cal BP and there are signs of farming, with herbs and two occurrences of cereal grains, some 400 years prior to this. Contiguous 1 cm counts across the Elm Decline horizon show that this event took only between 4 and 7 years.

Lime declines to virtual extinction during small scale clearances in the Early Bronze Age before major extensive clearances during the later Bronze Age, around 3000 BP, and the Iron Age at about 2450 cal BP. There are large increases in both grass pollen and heathland taxa, before a period of subdued impact during Roman / Dark Age times, followed by the maximum expansion of agriculture around 1340 cal AD, and the expansion of heathland for which this part of Dorset is famous today.

Rimsmoor bog and pond from the north. (Photo: K. Barber).

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ROUND LOCH OF GLENHEAD, Galloway, Scotland [NGR: NX 450 804]
Nominated by John Birks and Rick Battarbee

The Round Loch of Glenhead was the first UK site where diatom-based palaeolimnological techniques showed that sensitive upland lakes were suffering from "acid rain" and where natural acidification during the Holocene was shown not to be a contributory cause of recent acidification. It was also the first site in the world where weighted averaging regression and calibration transfer functions were used to reconstruct pH. More recently, diatom analysis of sediment samples has shown that recovery from acidification is beginning as UK emissions of sulphur dioxide from fossil fuel combustion have decreased.

It is a classic site for Quaternary science as analysis of its sediments demonstrates the value of palaeoecology in helping to resolve one of the world's most controversial environmental issues. It lies within the Merrick Kells Site of Special Scientific Interest and Special Area of Conservation and it has generated over 100 publications.

The Round Loch of Glenhead (photo: Ewan Shilland)

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SEWERBY RAISED BEACH, Yorkshire, England [NGR: TA 198 685]

Nominated by Mark Bateman

The Sewerby site encompasses so many aspects of Quaternary science and in essence represents a complete interglacial-glacial cycle. Its lower facies are interpreted as a raised beach banked against a palaeocliff-line which show sea-levels were higher during MIS 5e. Overlying this are what were coastal dunes formed as sea-levels regressed which have been luminescence dated to 120ka (Bateman and Catt, 1996). From this unit, diverse mammalian fauna (including elephant, hippopotamuis and rhinocerous) have been found indicating what roamed the landscape at this time. Colder glacial facies indicative of climatic cooling are represented at first by periglacial colluvium and then the Skipsea till reflecting the extension to this part of Yorkshire of the Last British Icesheet at the Last Glacial Maximum around 22-16 ka (Bateman *et al.,* 2011).

Finally, post glaciation climatic amelioration is reflected in the Sewerby sands and gravels with striking periglacial ice-wedge features and the Holocene soil. Two final reasons why Sewerby is a top site. Firstly, it has year round public access and with only limited digging all the units can be seen. Secondly, it is still not fully understood, with the controversy of the Basement Till rumbling on.

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

SIMON’S COVE, County Cork, southern Ireland [IGR:W 423 381]
Nominated by A. M. McCabe MRIA

Explanation and dating of the classic shore platform (~4 m OD) along the south coast of Ireland has still not been resolved following Wright and Muff’s basic descriptions in 1904. None of the overlying deposits have been dated with any certainty but it is likely that they were formed during the last cold stage and record an important range of glacial and sedimentary processes

Undoubtedly the platform is marine simply because of its lateral extent and the fact that it is cut across diverse geologic structures. Hundreds of closely spaced (<m scale), subparallel north to south subglacial meltwater furrows at right angles to the rock strike may well be related to a major deglaciation or meltwater event when the seals around subglacial meltwater reservoirs were broken. The ice limit associated with this deglaciation of the inner Celtic sea

North to south subglacial erosional furrows cut into the surface of the shore platform at Simon’s Cove, east County Cork. The subparallel furrows eroded by meltwater cut directly across the east-west strike of the local rocks, are closely spaced, up to a few metres deep and can be incised into topographic highs on the platform. Note the potholes along the axes of the furrows. (Photo: A.M.McCabe).

is unknown.

The overlying beach facies infill unweathered furrows, though occasionally shallow water wave-influenced hummocky and swaley cross-stratified sand and pebbly beds directly overlie the furrows. No fossils have ever been recovered from these facies. Angular joint blocks up to 2 m across form prominent boulder lines one clast thick at intervals in the beach gravels. Complexity occurs because much of the beach debris seems to be associated with a local subglacial efflux. Together, the facies records submergence with delivery of angular clast from adjacent fossil cliffs. Finally thick breccias record emergence at the site with little evidence for renewed ice overriding. These sequences are therefore part of an event stratigraphy rather than type sites for Irish Sea Stratigraphies.

Raised beach facies directly overlying the subglacial furrows. Sequence dominated by diffuse lamination in the granule to gravelly facies with horizontal beds and shallow scours infilled with well-rounded and and sorted pebbles and cobbles. Note the presence of angular rock slabs which can be several metres long and shore parallel. Collectively these facies are typical of shallow marine settings subject to mass flow off local slopes, sorting and sediment downdraw by return marine currents. Rule is 0.6 m long. (Photo: A.M.McCabe).

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STANTON HARCOURT, Oxfordshire, England [NGR: SP 413 051]
Nominated by Katharine Scott

Excavations were directed by Drs Katharine Scott and Christine Buckingham at Stanton Harcourt, Oxfordshire between 1989 and 1999. These produced an extraordinarily rich assemblage of bones, teeth and tusks, molluscs, insects, wood and other vegetation attributed to MIS 7. The exceptional preservation of the fauna and flora from Stanton Harcourt is making it possible to describe in unprecedented detail, the environment of southern Britain during this warm climatic period around 200,000 years ago.

The large vertebrate remains include forest elephant, bear and wolf, large forms of bison and horse, and a huge lion. By far the most numerous bones (including more than 100 tusks) are those belonging to a small mammoth. At first thought to be an early form of woolly mammoth *Mammuthus primigenius* it is now described as a small 'steppe mammoth' *Mammuthus trogontherii*, an animal adapted to a warm climate and partly forested habitat. Stanton Harcourt now comprises the largest collection of this small mammoth in north-west Europe.

At the outset of the excavations, it was a widely held opinion among Palaeolithic archaeologists that hominins were absent from Britain around 200,000 years ago. However, although no human bones were found in the excavations, more than 30 stone tools (some in almost mint condition) were recovered in the MIS 7 horizons.

It is rare to have access over 10 years to several acres of undisturbed late Middle Pleistocene deposit. As a consequence, the stratigraphy across the site was recorded at metre intervals in extraordinary detail identifying the exact location of all the processed remains. Large sediment samples have been stored for future research and there is an extensive photographic archive. The preparation of so much material for final publication has been a slow process but is almost complete.

Late Middle Pleistocene deposits at the base of Dix Pit quarry, Stanton Harcourt in 1995. (Photo: K. Scott).

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SWANSCOMBE Heritage Park (SSSI & NNR), Kent, England [NGR: TQ 599 745]

Nominated by David Bridgland

Given that it includes Britain's only geological National Nature Reserve (NNR) designated for Quaternary interests, this site, comprising the Swanscombe Skull Site NNR and the satellite Alkerden Lane Allotments SSSI (Bridgland, 1994, 2013; Conway *et al.,* 1996; Wymer, 1999; *http://www.*

Giant facsimile handaxe (left) erected at the entrance to the Swanscombe Heritage Park in 2005 (opened by Phil Harding of Channel 4's 'Time Team) and new plinth (right), of the same vintage, marking the location where the first skull fragment was found by the London dentist, Alvin T.Marston, in 1935. Photos: Natural England. Part of Figure 1 in Bridgland (2013).

swanscombeheritagepark.co.uk/; Fig. 1) is arguably our most illustrious Quaternary site.

It was already well known as a rich source of Palaeolithic artefacts and fossils before the discovery there of three separate pieces of a human skull in 1935, 1936 and 1955; they fit together and their find-spots are marked at the NNR by separate plinths. The Swanscome sediments belong to the highest and oldest terrace of the Lower Thames, representing the first Croll–Milankovitch climate cycle following diversion of the river (by Anglian ice) into its modern valley through London. Swanscombe provides a record of the Thames valley as it was from latest MIS 12 (Anglian) through MIS 11, the Hoxnian interglacial. In addition to the large subspecies of fallow deer (*Dama dama clactoniana*) that characterized that interglacial (Schreve, 2001) there was also a pigmy mole and a giant beaver. The lengthy but cool MIS 11 interglacial is an important analogue for the Holocene, so a sedimentary record of such value for its study is of clear significance, notwithstanding the archaeological and anthropological importance of the Swanscombe site. Until discovery of the

Boxgrove tibia and tooth, the Swanscombe skull was Britain's oldest hominin fossil; it remains one of a handful of Middle Pleistocene human fossils from these islands.

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THE COBBLER, SW Highlands, Scotland [NGR: NN 260 058]
Nominated by David Jarman

Paraglacial Rock Slope Failures (RSFs) are the 'elephants' in the Quaternary room, poorly understood and little researched. There are around 1000 in the British mountains, with 200 exceeding 0.25 km^2. There are some spectacular, but relatively small, rock avalanches; arrested translated slides which can be massive; and extensive slope deformations. All these are exemplified on The Cobbler, one of the most recognisable and popular mountains in Britain, with triple fangs around a small cirque.

It owes its extraordinary shape not to glacial erosion, but to RSFs on its external faces. The largest (0.62 km^2) slices across the cirque rim to isolate the 884 m summit, one of a handful in Britain only attainable by courageous scramblers, and the 858 m South Peak, a classic rock-climbing challenge on rugged schists. The first panel has only moved a few metres, but is riddled with cavities and fissures. The second panel has descended ~50 m, marked by antiscarped slices and powerful basal springs.

The Cobbler was recorded as a 'Landslip' by the first geologist to systematically map montane RSFs, the legendary C.T. Clough. It is within the largest cluster of RSFs in upland Britain, the Arrochar Alps, which is also one of the most heavily dissected by glacial breaching. The main RSF on

A large landslip complex on the flank of The Cobbler above Glen Croe, Argyll, has pulled away from the summit ridge to expose horn-like peaks. (Photo: David Jarman, taken from The Brack opposite).

its SW flank is above Glen Croe, a deeply eroded trough which descends from the Rest-and-be-Thankful breach to the sea.

The Cobbler is within Loch Lomond National Park and lends itself to geo-interpretation. It is a Geological Conservation Review site.

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THREE COUNTIES CAVE SYSTEM, North Yorkshire, England [NGR: SD 675 770]
Nominated by Tony Waltham

At the western end of the Yorkshire Dales glaciokarst, the limestone benches that wrap around Gragareth hill are largely covered by glacial till that is pitted by hundreds of subsidence dolines and a handful of small stream sinks. Beneath the benches, the Three Counties Cave System has more than 120 km of known passages, and these extend into Lancashire and Cumbria to give the cave its name. The active stream caves and sub-water-table conduits carry all the drainage to the resurgences of Leck Beck Head and Keld Head on opposite sides of Gragareth. Multiple levels of largely abandoned passages were formed by successive generations of drainage during the Quaternary interglacials. They too have multiple tributaries to ancient, phreatic, tubular trunk passages that are 5–10 m in diameter; these drained to resurgences that were on the contemporary valley floors but the truncated passages are now buried by till higher in the hillsides. A chronology based on stalagmite age determinations extends back only about 300 ka, but this combines with features of the cave morphology to indicate progressive decline of past water tables at contemporary resurgence levels. These imply a mean rate of about 0.15 m/ka for erosional lowering of the valley floors by Quaternary glaciations and intervening phases of fluvial excavation.

An abandoned passage in the Pippikin Pot section of the Three Counties Cave System, with stalagmites that have been dated to the Ipswichian interglacial. (Photo: T. Waltham).

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TRAETH Y MWNT, Ceredigion, Wales [NGR: SN 194 519]
Nominated by Andrew Crossley

Mwnt Beach is a spectacular Quaternary site, coming about as the combinations of: i) Irish Sea ice sheets depositing a volume of till, as it decayed/retreated along with; ii) movement and settlement due to fluvioglacial processes.

The till was dumped between the Ordovician outcrops of the then northern shore of the mainland and the southern shore facing an outlying island. This gave us the raw material for the beach as the rising sea level eroded the till to produce this coastal landform we now see. A predominantly constructive wave pattern has retained much of the material locally.

There is considerable discussion as to the processes which caused the movement and slumping of the till, shown by recumbent folds, especially towards the southern end of the deposits. The till contains a wide range of materials, as indicated by particle size, overlain by glaciofluvial sand and gravel deposits. The warming of the environment towards the end of the last glacial cycle is a factor in the pattern of the landform found. The references below give a useful summary of discussion of the site, which I would only be repeating and would not be as eloquent in explaining it. I just love the site!

Mwnt Beach in winter showing Irish Sea deposits and overlying sand deposits. (Photo: A. Crossley).

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VICTORIA CAVE, Yorkshire, England [NGR: SD 838 650]
Nominated by Tom Lord and Phil Murphy

A spectacular cave site with the longest sequence of Quaternary sediments of any British cave, and the scene of important nineteenth century investigations. Victoria Cave is a pivotal site for our understanding of Pleistocene history in the north of England.

The site was originally an archaeological site famed for Romano-British metal work but a major British Association funded excavation in the 1870s encountered a bone bed accumulated by spotted hyaenas sealed beneath glacial sediments, crucial evidence of antiquity before the development of a Quaternary time scale. The dig was pivotal in showing the warm and cold faunas were separate supporting the cyclic model of glaciation, as opposed to the migratory model. Hopes of finding skeletal evidence for a Darwinian "missing link" failed to materialise, and fierce arguments between the main investigators meant the site was "lost" to science for over a hundred years.

The cave is unique for its remarkable sequence of laminated clays inter-

Excavations at Victoria Cave in 1874-75. (Photo: Tom Lord).

bedded between TIMS U-Th dated calcite flowstones. The laminated clays are interpreted as glacial sediments formed underneath warm based ice during MIS 12, MIS 10, MIS 6 and MIS 2 . The hyaena bone bed has evidence of hippopotamus and mammoth during MIS 5e. Late Glacial sediments document large mammal colonisation after the LGM, and provide the earliest dated evidence for modern humans in northern England.

The site had been neglected for many years but a re-evaluation of the site has shown it to contain the most complete middle and late Pleistocene sequence in the north of England and has revealed new details of Pleistocene ice cover and climate history of the region.

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WARREN HOUSE GILL, County Durham, England [NGR: NZ 446 423]
Nominated by Bethan Davies

Warren House Gill, in Co. Durham, northern England, contains a unique sequence of glacial and interglacial sediments dating from the Mid- to Late-Pleistocene. They were first described in 1915, when they were interpreted as representing an incursion of the Fennoscandian Ice Sheet onto NE England. Colliery waste on the beach precluded further scientific study until recently. In 2006 and 2013 the QRA granted funds for a JCB to excavate these rare

Warren House Gill. A JCB, funded by the QRA, is being used to excavate glacial sediments from beneath the colliery waste, which is visible in the foreground. (Photo: B. Davies).

sediments. New analyses revealed that the deepest sediments derived from Scotland, the North Sea and Scandinavia, and were deposited in a glaciomarine environment. They are overlain by warmer-climate pink estuarine silts.

The younger sediments above these were deposited during the LGM and record complex ice-sheet dynamics. The area was overrun by ice streams originating from the Pennines and southern Scotland.

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WAST WATER SCREES SSSI, Cumbria, England
[NGR: NY 155 045]
Nominated by Peter Wilson

The Wast Water screes, developed in rocks of the Borrowdale Volcanic Series, extend for 2.5 km along the south shore of Wast Water in the English Lake District. They have been referred to in numerous text books and other (non-academic) literature and, for many years, were regarded as the classic example of mountain scree formation in Britain. For geomorphological and botanical reasons they are designated as a Site of Special Scientific Interest.

Close inspection of the screes indicates that they are not the product of freeze-thaw and rockfall processes alone. The screes form a series of coalescing cones that taper up to prominent gullies in the cliffs. The cones indicate that water has been responsible, in part, for their development.

The main body of bare scree extends downslope from a broad amphitheatre of shattered crag directly below the crest of the hillside (see photo). The rock outcrops of the amphitheatre carry considerably less vegetation than the flanking buttresses. The limited extent of vegetation cover in the amphitheatre suggests recent rockfall activity and here freeze-thaw and rockfall could have been important in scree accumulation.

However, the ridge crest above the amphitheatre comprises a series of low grassy ridges with intervening depressions running parallel to the cliff edge. The depressions represent tension fissure and are testimony to large-scale movement of the rock mass. It is proposed that scree formation below the amphitheatre has resulted from large-scale rock-slope failure rather than intermittent rockfalls. The limited vegetation cover in the amphitheatre suggests the process remains active.

The traditional model of scree development by freeze-thaw action alone is no longer tenable. The Wast Water screes are a product of rock-slope failure, freeze-thaw action and fluvial transport that have acted in combination since removal of LGM ice cover.

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Wast Water screes seen from the north side of Wast Water. (Photo: P. Wilson).

WELTON-LE-WOLD, Lincolnshire, England
[NGR: TF 278 883 and TF 284 882]
Nominated by Allan Straw

Welton-le-Wold is arguably the most important inland Quaternary site in Lincolnshire. Working of the quarry ceased in 1973. Much had been backfilled as work proceeded, but two sections remain open, maintained by Heritage Lincolnshire, and the site retains both SSSI and RIGS status. Forty three annotated photographs, taken between 1954 and 1973 have been lodged with 'The Collection' (Lincoln County Council Museum) together with the recovered artefacts and fossils.

The West Section reveals Calcethorpe Till, a highly chalky deformation till, but not now the underlying contemporary Welton Till, or basal Welton Gravels the reason for exploitation. The East Section shows the unique Lincolnshire circumstance of a Devensian till sharply overlying Welton Till and Gravels along a west-rising planar unconformity. The ice which emplaced the Devensian till (Marsh Till), probably earlier than the Late Glacial Maximum, entered the area from the East, but the older tills were laid down by south-flowing ice that had moved over east Lincolnshire and the Wolds during, it is argued, MIS 8.

The Welton Gravels averaged some 10-12 m in thickness spread across the chalk floor of a palaeovalley. Deposition of the Lower Gravel had commenced when the Lower Cretaceous inliers became exposed in the head of the palaeovalley, and progressed under subarctic nival regime. The Upper Gravel bears witness to full arctic periglacial conditions until the arrival of Welton Till ice, but they incorporated derived fossils of temperate animals, and four humanly-fashioned artefacts were recovered between 1969 and 1973.

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Welton-Le-Wold, west section – Calcethorpe Till over Welton Till (behind talus). Slab of Corallian Grit from North Yorkshire Moors, set up on back fill [TF 278 883]. (Photo: A. Straw).

WEST RUNTON TO SHERINGHAM, coastal cliff sections, North Norfolk, England [NGR: TG 181 432 to TG 165 433]

Nominated by Emrys Phillips and Jane Hart

West Runton on the North Norfolk coast is a classical site within the British Quaternary, not only for being the stratotype for the early Middle Pleistocene 'Cromerian' interglacial stage (West Runton has the Cromerian West Runton Freshwater Bed and the West Runton elephant), but also for the spectacular array of highly-deformed preglacial and glacial sediments - some of the best examples of lowland glaciation in Britain. Deformation between West Runton and Sherringham has resulted in the modification and locally intense reworking of the succession to the extent that many of the primary sedimentological characteristics and stratigraphic relationships of the succession have been overprinted. Whilst there is no doubt over the highly deformed nature of the sequence, controversy exists over the mechanism of its deformation. Some considering the deformation to be induced by subaqueous slides and debris flows, whereas others consider it to be diagnostic of subglacial deformation.

A recent study interpreted the highly deformed sequence between West Runton and Sherringham as recording a single progressive proglacial to subglacial glacitectonic deformation event associated with ice advancing from the west.

Four key lithological units can be recognised in the section: (i) at the base of the glacigenic succession, the grey, massive to moderately foliated Happisburgh Till Member variably exposed at the base of the cliff; (ii) this is overlain by the highly folded and foliated, brown, Bacton Green Till; (iii) at the top of the succession are the outwash sands and gravels; and (iv) a glacitectonic mélange derived from both the Bacton Green Till and outwash sands and gravels. Structurally below this glacitectonised sequence are the essentially undeformed, preglacial shallow marine sediments of the Wroxham Crag Formation, exposed towards the eastern end of the section, and underlying chalk bedrock that crops out along the foreshore. The Bacton Green Till and mélange also contain thrust-bound, locally stacked slices or rafts of chalk and Wroxham Crag, as well as Marl Bed and chalky Walcott Till which, in their original stratigraphical position, occur between the Happisburgh Till and Bacton Green Till.

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Deformed sand intraclasts within the Bacton Green Till exposed between West Runton and Sherringham on the North Norfolk coast. (Photo: Emrys Phillips).

WHITTLESEY, Peterborough, England [NGR: TL 238 979]
Nominated by Harry E Langford

The Pleistocene to Holocene fluvial succession at Whittlesey has: 1) a minimum maximum age of MIS 8; 2) a MIS 7 fully temperate fossil assemblage that includes the only so far known occurrence of Theodoxus danubiana of this age in the UK; 3) a MIS 5e fully temperate fossil assemblage that is the only so far known fully fluvial record of this age within the Nene catchment; 4) an extensive Holocene record including the infill of a rodden and complete buried Bronze Age boats, among other archaeological artefacts; 5) a record of the last three glacial stages that places important constraints on regional palaeogeographical reconstructions, and finally; 6) a record of two possible North Sea storm surge events.

WICKEN FEN, Cambridgeshire, England [NGR: TL 555 700]
Nominated by Zoë Hazell

Wicken Fen is a sedge- and reed-fen wetland of national and international importance, claimed to be Britain's 'first nature reserve'. It is protected for its high biodiversity, its educational and research values, its association with the development of British Natural History and for its traditional and historical

View across Sedge Fen (part of Wicken Fen NNR, SSSI and Ramsar). The windmill pumps water up onto it from Monk's Lode in order to maintain water levels at the site. (Photo: Z. Hazell).

land management regimes. Wicken Fen contains up to 4m of Holocene peats that began forming c 5000 years ago (Godwin and Willis, 1961; Peglar, 1994) and the palaeoenvironmental potential of which has been demonstrated by the palaeoecological studies of Godwin (1940) and Peglar (1994). By inference, the potential for containing waterlogged organic archaeological remains is also high. It is a rare remaining example (being a least-altered fragment) of wetland habitats that were once extensive across the Fens region, and now sits isolated within a landscape of degrading and eroding peaty soils.

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Lough Neagh	59	Lake	Holocene palaeoecology
Malham Cove	60	Landform	Glacial geology and geoconservation
Mam Tor landslide	61	Geomorphology	Active processes
Marks Tey	62	Lake sediments	MIS 11 deposits
Marsworth	63	Quarry deposits	Middle to Late Pleistocene palaeoenvironments
Maryton	64	Cliff section	Holocene tsunami deposits
Mount's Bay	65	Coastal peat deposits	Mid- to Late Holocene
Nelly's Cove	67	Coastal exposures	Pleistocene deposits
New Forest: Cranes Moor	68	Peat bog	Early to Mid Holocene palaeoenvironmental record
New Forest: Church Moor	69	Peat bog	Lateglacial to Early Holocene palaeoenvironmental record
New Forest: Barrow Moor	71	Peat bog	Late Holocene palaeoenvironmental record
Nigg Bay	72	Coastal exposure	Glacial geology
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Overstrand	74	Coastal exposure	Glacial geology
Pakefield	75	Coastal exposure	Middle Pleistocene palaeoenvironments and archaeology
Pegwell Bay	76	Coastal exposure	Glacial and periglacial deposits
Penninis Head	78	Geomorphology	Periglacial processes
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Stanton Harcourt	91	Channel deposits	Late Middle Pleistocene palaeoenvironments and archaeology
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Three Counties Cave System	96	Cave deposits	Late Quaternary processes
Traeth y Mwnt	97	Coastal exposures	Glacial geology
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Warren House Gill	99	Coastal exposures	Glacial geology
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Welton-le-Wold	102	Disused quarry	Middle to Late Pleistocene deposits, palaeoecology and archaeology

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Whittlesey	105	Fluvial deposits	Late Pleistocene palaeoenvironments and archaeology
Wicken Fen	105	Peat bog	Mid- to Late Holocene palaeoenvironments