
NUMBER 101

OCTOBER 2003

QN

Quaternary Newsletter



A publication of the
Quaternary Research Association

QUATERNARY NEWSLETTER

EDITOR:

Dr Julian Murton

Department of Geography

University of Sussex, Brighton BN1 9QJ

Tel: 01273 678293 Fax: 01273 677196 e-mail: j.b.murton@sussex.ac.uk

Instructions to authors

Quaternary Newsletter is issued in February, June and October. Articles, reviews, notices of forthcoming meetings, news of personal and joint research projects, etc. are invited and should be sent to the Editor. Closing dates for submission of copy (news, notices, reports etc.) for the relevant numbers are 1st January, 1st May and 1st September. These dates will be strictly adhered to in order to expedite publication. **Articles must be submitted at least 6 weeks before these dates in order to be reviewed and revised in time for the next issue of QN, otherwise they may appear in a subsequent issue.**

Suggested word limits are as follows: obituaries (2000 words); articles (3000 words); reports on meetings (2000 words); reports on QRA grants (500 words); reviews (1000 words); letters to the Editor (500 words); abstracts (500 words). Authors submitting work as Word documents that include figures must send separate copies of the figures in .eps format. Quaternary Research Fund and New Research Workers Award Scheme reports should limit themselves to describing the results and significance of the actual research funded by QRA grants. The suggested format for these reports is as follows: (1) background and rationale (including a summary of how the grant facilitated the research), (2) results, (3) significance, (4) acknowledgments (if applicable). The reports should not (1) detail the aims and objectives of affiliated and larger projects (e.g. PhD topics), (2) outline future research and (3) cite lengthy reference lists. No more than one figure per report is necessary. Recipients of awards who have written reports are encouraged to submit full-length articles on related or larger research projects.

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Argraff/Printed by:

Gwasg Ffroncon Press

BETHESDA

Gwynedd, North Wales

Tel: 01248 601669 Fax: 01248 602634.

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COVER PHOTOGRAPH:

The gathering clouds over Loch Coulavie, one of the sites investigated by Eileen Tisdall for Holocene lake level fluctuations and a proxy for precipitation change. See report on the Glen Affric short field meeting. Photo kindly supplied by John Cooper.

OBITUARIES

TONY CARTER

1931–2003

Anthony Henry Charles Carter died on 25th February 2003 at his home in Whittlesford, Cambs. He had superb qualities – a brilliant exponent of his subject in the lecture theatre and in the field, a fine artist, cartographer and a sparkling raconteur. For the past two decades Tony has been a member of the Dendrochronology and Dendroclimatology Group at the Godwin Institute, Cambridge University. His tremendous breadth of learning and tireless enthusiasm has enabled him to play an important part in our dating and palaeoclimate projects. His death has left an enormous gap in the lives of all his friends and colleagues.

Born on Midsummer's day 1931 in Swaffham, Norfolk, Tony was the eldest of three children of Harry and Maude Carter. His father, an art master at Hammond's Grammar School, is well known as the designer and carver of the numerous delightful village signs that can be seen throughout East Anglia. Tony's great uncle, Samuel John, was a member of the Royal Academy and painted canvases on a grand scale for the decoration of stately homes and public buildings; another great uncle was Howard, the artist and discoverer of the tomb of Tutankhamen in 1922. Tony inherited many of the family artistic skills and traits.

His early education was at the convent of the Sacred Heart followed by Hammond's School. Between 1949 and 1953 he read for the Honours Geography Degree at University College, London, under Professor Darby. This was followed by a Diploma in Education at Aberystwyth and a teaching appointment at the experimental residential Wymondham College in Norfolk. Here it was that he met and married the history teacher Patricia Neeves in 1958. In those days, however, the college regulations required that housemasters and mistresses had to live in the same accommodation as their students and there were no married quarters. Tony sought a new appointment.

This appeared in 1959 when he became lecturer in the Geography Department at the Cambridgeshire College of Arts and Technology (CCAT), the forerunner of Anglia Polytechnic University. He was not content with teaching solely in any one branch of science, so here he taught geography, geology, meteorology and chemistry at 'O' and 'A' levels, as well as City and Guilds and some at Degree level. He co-authored several school text books on geography with his colleague Peter Speak, including the best seller *Map Reading and Interpretation* in 1964. He organized many field excursions in East Anglia, Dorset, Yorkshire,

Brecon Beacons and even Czechoslovakia, which were hugely appreciated by his many students.

He was granted a sabbatical in the academic year 1980–81, which he used to read for his Master of Philosophy Degree in Quaternary Sciences at Cambridge University, where he specialized in dendrochronology. I was privileged to supervise his work for a research project on a study of the oak trees at Emily's Wood, near Brandon. Up to this point, Tony's career had been entirely in teaching but this academic research kindled a new interest in him. He decided to take early retirement from teaching at CCAT in order to spend more time in pursuing 'dendro'.

This led to an association with my Dendrochronology and Dendroclimatology Group at the Godwin Institute that lasted for the remainder of his life. He joined us towards the completion of a lengthy project based on sampling cross sections of numerous 'bog oaks' and other species from the nearby Fens from which was eventually derived a master Fenland dendrochronology ranging from 3196 BC to 1681 BC. The Fenland chronology (a section of the longer Irish Oaks chronology) was instrumental to English Heritage for dating the timber circle found in the intertidal zone near Holme-next-to-sea in 1998. The felling date of the oaks in this monument was found to be the early Spring of 2049 BC. Another project in which Tony joined with me was in dating the President's Lodge at Queens College. The felling dates of the studding running vertically through the building, 1604 AD, showed that this construction was likely to be some fifty years later than previously believed. We also dated the oldest timber framed building belonging St. Catharine's College (now a wine lodge on King's Parade). Since 1982 Tony and I have jointly presented public lectures and practical courses to various archaeological and architectural societies in East Anglia, including Cambridge, Huntingdon, Ipswich, Kimbolton and Stevenage on topics showing how tree ring science may be used, not only for dating, but for studies in geomorphology, river flow and climatology.

Tony has always taken great interest in the work of my graduate students and he befriended several generations of them. They benefited from his encyclopaedic knowledge of so many subjects from his early teaching career and he was always helpful in offering assistance and guidance on lecturing and tutorials. We particularly valued his advice in meteorology, which is basic to our research programme for the calibration of the reconstruction of past climate on a year-on-year basis from the stable isotopic composition. This is one of the most powerful methods available at the present time in environmental and climatic research and it utilises the stable isotopes of hydrogen, carbon and oxygen contained in the cellulose of the individual growth rings. In return for his advice we taught Tony about physics and isotopes. Whenever he was able to do so, he joyfully joined in with field work in the UK and in Finland, surveying the sites and obtaining the dendrochronological samples. It is certain

that his tuition increased the standard of the student presentational skills in many areas. With Tony's aid and characteristic attention to detail, the members of the Group have been able to date a series of government listed buildings as well as hall houses, vernacular and ecclesiastical structures and even windmills. He loved delving into the background history and building styles of these ancient structures. Of note is the dating, with the aid of funding from English Heritage, of the roof of St. Botolph's Church, which is believed to be one of the oldest extant in Cambridge.

Tony was fascinated by the complexity of the world around him and how the different elements interact. He could effortlessly integrate physical geography with human perspectives and could easily link social trends with climatic and environmental events. His interests encompassed many aspects of the Quaternary and he frequently attended the Discussion Group lectures at Clare College and Clare Hall, and was a member of the QRA. Though his work in dendrochronology was only part time, Tony played his full part in the social life of the Group and his well appreciated acerbic comments and dry humour during coffee breaks will be long remembered.

Tony Carter was laid to rest in the churchyard of the Norman church of St. Mary and St. Andrew, Whittlesford, on 8th March 2003. A commemoration '*Quercus robur*' (English oak) has been planted in the centre of the Green of the Swallow Croft community, to which Tony had given many years of dedication.

Roy Switsur
Dendrochronology and Dendroclimatology Group
Godwin Institute for Quaternary Research
Cambridge University

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D. S. PEAKE

1915–2002

Dorothy Sarah Peake, nee Coates, known as Sally, died at a hospice near her home in Whyteleafe, Surrey on 29th October 2002 after a long struggle with cancer.

Quaternary geology was a lifelong enthusiasm, and Sally was a founder member, in 1963, of the Quaternary Field Studies Group, later the Quaternary Research Association. Her two areas of study were the North Wales border country, the home of her youth, and the North Downs near Croydon, where she spent her later years.



Sally's interest in the Quaternary began during her undergraduate days at Birmingham University, between 1933–36, under the inspired direction of Professor L.J. Wills. After graduating with First Class Honours, Sally remained at Birmingham to work on the Quaternary history of the Welsh Border area near her home in Bronington, Flintshire, under the guidance of Professor Wills. She was awarded a M.Sc. for this work in 1937.

Following in the footsteps of her father and grandfather, who were both headmasters of the village school at her home in Bronington, Sally secured a teaching post, in 1938, at Bromsgrove County High School. She remained there for three years. With her focus on teaching, and later her family, she was not to return to research for some twenty years. At university, Sally met a civil engineering student, Frederick Gervase Peake, known as Peter, on a geology field meeting. They were married in Birmingham during October 1940, and she vividly recalled the enemy bombing of the city on her wedding day, severely curtailing their celebrations.

In 1957, with the reducing pressures of family life, Sally returned to her research in North Wales and the work on the Quaternary history of the Alyn valley north of Wrexham was published some four years later in the *Quarterly Journal of the Geological Society*.

In 1973 the substantial progress that had been achieved in Quaternary stratigraphy was consolidated in the seminal Geological Society publication *A Correlation of Quaternary Deposits in the British Isles*. Sally chaired the Welsh sub-

committee. Professor David Bowen recalls the need for her firm control of "the younger bloods", including himself, and the great care with which this section of the report was put together.

By now Sally had turned her attention to her local area around Croydon, Surrey and its small, somewhat neglected river, the Wandie. Her original research formed the basis of a talk, in 1975, to the Croydon Natural History and Scientific Society and was finally published in the Proceedings of the Society for 1982. For some years Sally had suffered from arthritis and she was to have a number of major hip operations in the 70s and 80s which restricted her ability

to undertake fieldwork. Nevertheless she continued to contribute short notes to the Quaternary Newsletter on matters relating to the Wandie and was thrilled that her work was consolidated into the wider studies of Dr. David Bridgeland on *Wealden Rivers north of the Thames*.

Sally had the knack of sustaining friendships over long periods and it gave her deep pleasure to learn, some months before she died, that the Geological Society had awarded the Wollaston Medal to Dr. Harry Whittington, a lifelong friend from undergraduate days in Birmingham.

Sally bore her illnesses with great fortitude and the subject rarely arose in the numerous conversations we had over twenty years. Rather it was with her family, her friendships, her abiding interest in nature and, in particular, in Quaternary geology that we passed these hours.

Ron Williams
182 Old Lodge Lane
Purley
Surrey CR8 4AL

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ARTICLES

100 ISSUES OF *QUATERNARY NEWSLETTER* – AN OVERVIEW

Allan Straw

The 100th issue of *Quaternary Newsletter* (*QN*) appeared in June 2003, and the editor has deemed it appropriate for someone to take stock – perhaps a member who can not only recall the circumstances that led to formation of the QRA but indeed was a small part of them.

QN – this bold logo heads a magazine which has become a vital part of QRA activity. From the outset it was "...to provide members of the Quaternary Research Association with miscellaneous information relating to the Quaternary, including brief notes on the scientific results of the work of the Association." So wrote founder Graham Jardine in September, 1970.

No. 1 (six A4 pages produced as a supplement to the Circular) reported the aims and activities of INQUA and the composition of the INQUA Sub-Committee of the British National Committee for Geology, accompanied by a list of overseas journals dedicated to the Quaternary and some notices including a Calendar of Meetings. It also had short sections for correspondence and discussion, thereby providing the means of communication.

No. 100 (eighty A5 pages bound in an attractive cover) contains three articles, a Comment on an article and a Reply, reports of three meetings (IGCP, QRA, JAQR/BGRG0), reports of work supported by the Quaternary Research Fund and the New Research Workers Award Scheme, a PhD thesis abstract, a Review of new geological maps, and notices regarding Conferences and the *Journal of Quaternary Science*.

Such features have now been standard for many years, but *QN* was not born fully-fledged – it had to be nurtured and trained, and distinct stages in its history may be identified because innovation has accompanied growth. The obvious increase in the range of items published reflects not only editorial policy, supply of material, and membership demand, but also a willingness generally to allow *QN* to expand – more material requires more pages and vice versa.

The average length of the first 12 issues was 6.5 pages and of the next 12, 14.5 pages. No. 69 comprised 110 pages, and since then the average has approached 65 pages. Simple but revealing facts.

Graham Jardine was editor for four years. The QRA Constitution was set out in No. 3 (the annual subscription being 50p) which also introduced a Conference report. No. 4 had a long supplement detailing a Field Study course in the Netherlands. Such conference and field study reports, frequently with abstracts of papers or substantial notes, have continued to the present as invaluable summaries of ongoing research by QRA and other research group members.

A short paper in No. 7 by Eric Robinson on Ostracods collected in East Yorkshire and North Lincolnshire during the QRA Annual Field Meeting of 1972 might be claimed as the first original article. Articles became a regular component from No. 14 under John Catt's editorship, and *QN* has long demonstrated its function as a means of providing rapid publication and opportunity for discussion. No. 7 also carried the first book review, and book and map reviews have been forthcoming in almost every issue from No. 25, when Jim Rose became editor. John Catt's first issue, No. 13, included a long account of a QRA Study Course of the North Foreland of the Alps, and similar accounts followed on the Hebrides (No. 20) and south Norway (No. 21). He introduced a series of descriptions, from No. 18, of Quaternary research at various academic institutions.

Jim Rose promoted greater use of illustrations. Photographs began to appear with articles from No. 26 and detailed maps with Francis Synge's contribution in No. 28 on Quaternary Glaciation in Ireland. He doubled the size of *QN* to over forty pages from No. 28 onwards and earned the gratitude of all readers by introducing a Contents page in No. 32.

David Keen, from 1981, followed the by-now established pattern increasing the number of articles for several issues but, with No. 39, he widened *QN*'s scope seminally by directly involving that proliferating group of members pursuing postgraduate research. Since February 1983 almost every issue has carried abstracts of PhD theses – an initiative of great value, not least to the graduates.

No. 43 appeared with a report of the 20th Anniversary Meeting of the QFSG/QRA, in which Richard Hey gave an illuminating personal account of QRA origins, and Fred Shotton an assessment of the progress of Quaternary Science since 1964. "Multidisciplinary" was the latter's keynote, and "co-operation and exchange of ideas between exponents of so many disciplines" were his perceived achievements of the QRA, by then (1984) with over 800 members.

David Holyoak entered the editorship in 1985. No. 46 advertized the launch of *QN*'s sister publication, the *Journal of Quaternary Science*, and included correspondence debating 'palaeosol and rubification', topics considered in No. 44. 'Magnetostratigraphy' was discussed in No. 48 and Comment and Reply concerned several items in No. 49, resplendent in a proper blue coat. In No. 53

Jim Rose posed the question of the status of the Wolstonian Glaciation in Britain, which drew responses in No. 54. Surprisingly, however, this issue included a plea from the editor for more material.

1989 was the 25th Anniversary Year of the QRA, and three issues of *QN* emerged in grey suits. In No. 57, Jim Rose's Presidential Address and Peter Worsley's personal account of the origin of the QRA and its forerunner took pride of place and, perhaps through a technical mishap, were presented in part in duplicate (at least in the writer's copy) as were other items in the issue (26 pages became 39) – a curious but ingenious way of responding to the editor's plea.

From No. 58, somewhat light-hearted editorials by Brian Taylor became a feature that, in No. 62, included a restatement of the aims and objectives of *QN* – it “aims to provide a relatively quick means of communicating articles, reviews, notices and news on all matters related to the Quaternary both in the UK and overseas” – in a nutshell, as Brian might have said. During his editorship QRA awards to Young Research Workers were advertised, grants being conditional on reports being made in *QN*. The first report appeared in No. 66, and from No. 68 regular reports have revealed, through the range and quality of the research done, the success of the scheme. Complementing these reports, those of occasional Postgraduate Workshops, and the Ph.D abstracts, summaries of the Annual Postgraduate Symposia feature from No. 82 onward.

With No. 64 an enlarged role for the QRA as the Royal Society's representative to INQUA was mooted. Inclusion of INQUA material had been and indeed remains a regular feature in *QN* and, in No. 89, a clear statement on QRA/INQUA relationships was set out. Also in the international field *QN* has reported faithfully on various IGCP Projects, particularly meetings and progress.

No. 68 came out in a new jacket with a mid-riff photograph (a style destined to last at least to No. 100), and James Scourse produced a bumper 110-page No. 69, the bulk comprising abstracts and reports of conferences and meetings.

James Scourse, Stuart Campbell and Julian Murton have consolidated the format and firmly established the character of *QN*, with members producing a rich and varied Quaternary content. A particularly controversial topic has been the Quaternary succession in East Anglia, still seemingly far from resolution. A paper in No. 77 on ‘Kesgrave and Bytham Sands and Gravels in Eastern Suffolk’ triggered Comments and Replies in Nos. 78 and 79. After a breathing space, a Report on a Field Meeting in East Anglia (No. 91) and an article in No. 92 prompted Comment in No. 93 and a Reply in No. 94, the cover of which, as if to emphasize the topic, figured a map of East Anglia. This should be the stuff of *QN* – serious, almost emotive certainly committed, multidisciplinary debate on which indeed reputations may be tested.

In Nos. 88 and 90, Rhaxella chert was discussed. In between, No. 89 was dominated by reports from grantees of the Research Fund and the New Research Workers Award Scheme.

QRA members come (now over 1000) but sadly also go. *QN* has kept faith with former friends and colleagues by publishing obituaries, fortunately not too many being required, reminding us of services rendered, reputations earned and friendships treasured.

Clearly *QN* has evolved over time and has been fortunate in its editors, for all have been innovative as well as consolidating past achievements. Content has certainly increased in range and volume – some lines have faded out, others have blended in. In this writer's opinion the aims and objectives of *QN* have been and are being maintained by successive editors and it is through them that much of its success stems. However, responses to demands and preferences of the membership over the years are also evident and, surely, the burgeoning and maturing of *QN* reflects expansion of Quaternary science itself?

What of the future? Although the current format of *QN* is attractive and convenient, and the spread of material is commendably broad and interdisciplinary, there will undoubtedly be innovations in presentation by future editors. The sheer volume of research, underpinned now by so many ingenious analytical techniques, will inevitably generate results eminently suitable for publication. But it is the pace of research and discovery that requires a rapid outlet such as *QN*.

This writer has been privileged to receive *QN* over all these years, has admired the altruism and competence of the editors and has always looked forward to the next issue. Because Quaternary scientists can expect great revelations in coming years and have reason to assume that *QN* will continue to play its particular role he is confident that his overview of the next 100 issues will be equally positive and commending.

Allan Straw
37 Rosebarn Lane
Exeter EX4 5EQ
Emeritus Professor of Geography
University of Exeter

A FORMER ICE-DAMMED LAKE IN GLEN LUIBEG, CAIRNGORM MOUNTAINS, SCOTLAND

Nick Gолledge

Introduction

The Cairngorm Mountains (Figure 1), part of the Central Highlands of Scotland, consist of an area of ~ 800 km². They represent the largest coherent upland area above 1000 m O.D. in Britain, and reach a maximum elevation of 1309 m O.D. on the rounded summit of Beinn Macduibh [NN988 989]. The majority of the massif is composed of Late Silurian to Early Devonian age granite, which is intruded into Neoproterozoic metasedimentary rocks.

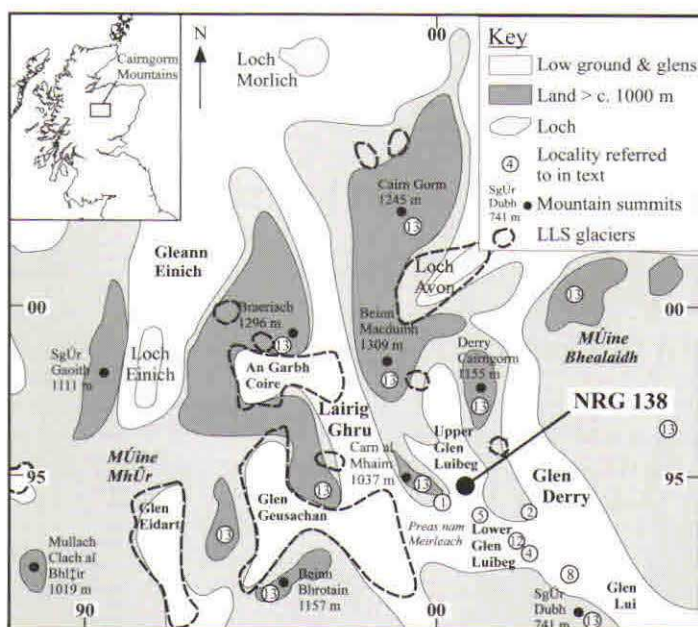


Figure 1. Location map of the field area. NRG 138 is the locality where the laminated sediments are exposed. Loch Lomond Stadial (LLS) glaciers (shown schematically) are taken from Sissons, (1979).

Officers of the Geological Survey of Scotland identified and recorded numerous glacial features throughout the Cairngorms and attributed many of them to a period of valley glaciation following the last glacial maximum (LGM), when

ice retreated actively into the glens and corries (Barrow *et al.*, 1912, 1913; Hinxman and Anderson, 1915). Many of the ice-directed ridges, however, were subsequently reinterpreted as sub-glacial deposits formed during *in situ* mass-wasting of the Main Late Devensian (MLD) ice sheet (Sugden, 1970; Young, 1974, 1975a, 1975b). Recent research now supports a return to the earlier models, suggesting that deglaciation of the Cairngorms was most likely characterised by numerous actively retreating valley glaciers sourced from plateau icefields (Brazier *et al.*, 1996, 1998). That these valley glaciers were dynamic and supported oscillating ice margins has been demonstrated in Gleann Einich (Golledge, 2002), and north of the Spey at Raitts Burn (Phillips and Auton, 2000).

The Geological Survey also recorded corrie moraines in the Cairngorms, and suggested that these formed during a later and more restricted phase. These renewed glacial conditions, now recognised as the Loch Lomond Stadial (LLS), led to regrowth of glaciers in many of the high corries, and most probably the rejuvenation of ice that had survived the preceding Windermere Interstadial (Bennett and Glasser, 1991). Sissons (1979) mapped 17 LLS glaciers in the Cairngorms, and identified 'hummocky moraine' as a landform assemblage diagnostic of their final *in situ* stagnation. Subsequently, hummocky moraine has been shown to consist of lineated ridges typically formed at active ice margins (Hambrey *et al.*, 1997), which suggests that organised and coherent glacier recession, rather than mass wasting, characterised the end of the LLS (Bennett and Glasser, 1991).

The former existence of glacial lakes in the Cairngorm Mountains has been reported by many authors, including Barrow *et al.* (1913), Charlesworth (1956), Sugden (1970), Bennett and Glasser, (1991), and Brazier *et al.* (1996, 1998), and from the wider region by Aitken (1990), Brown (1994), Phillips and Auton (2000) and Lukas (2002). Ice-marginal ponding during both the Late Devensian and the LLS therefore appears to have been a relatively common phenomenon in the Central Highlands of Scotland. The precise timing of lake formation is still uncertain, although a relative chronology constrained by radiocarbon (Sissons and Walker, 1974), cosmogenic (Everest *et al.*, 2001), and preliminary luminescence dates (Golledge *et al.*, 2002) is emerging.

Field area

The field area is covered by Ordnance Survey 1:10 000 scale sheets NO09NW and NO09SW. Glen Luibeg is situated south of the Beinn Macduibh – Carn Etchachan watershed, and initially runs from north to south (upper Glen Luibeg) before turning east (lower Glen Luibeg), where it joins Glen Derry (Figure 1). The area is one of high relief, ranging from ~ 460 m O.D. in the middle reaches of Glen Luibeg to around 1000 m O.D. at the eastern end of the Carn a' Mhaim summit ridge.

Method

Geological mapping of the field area at 1:10 000 scale was carried out during 2001/2. This consisted of a detailed walkover survey, including logging of natural sections, and the interpretation of 1:24 000 scale black-and-white stereo aerial photographs. Figures 1 and 2 show the locations of the numbered geomorphological features described below.

Landforms and sediments

In this, and the surrounding, area the higher slopes are characterised by blockfields [13] and by sheets of gravelly and bouldery head deposits (e.g. [14]), such as solifluction lobes, that grade downhill into till-covered slopes (e.g. [15]). Some valley-sides are stripped of all drift cover and expose glacially-smoothed bedrock surfaces [1]. An incipient *roche moutonnée* [2]

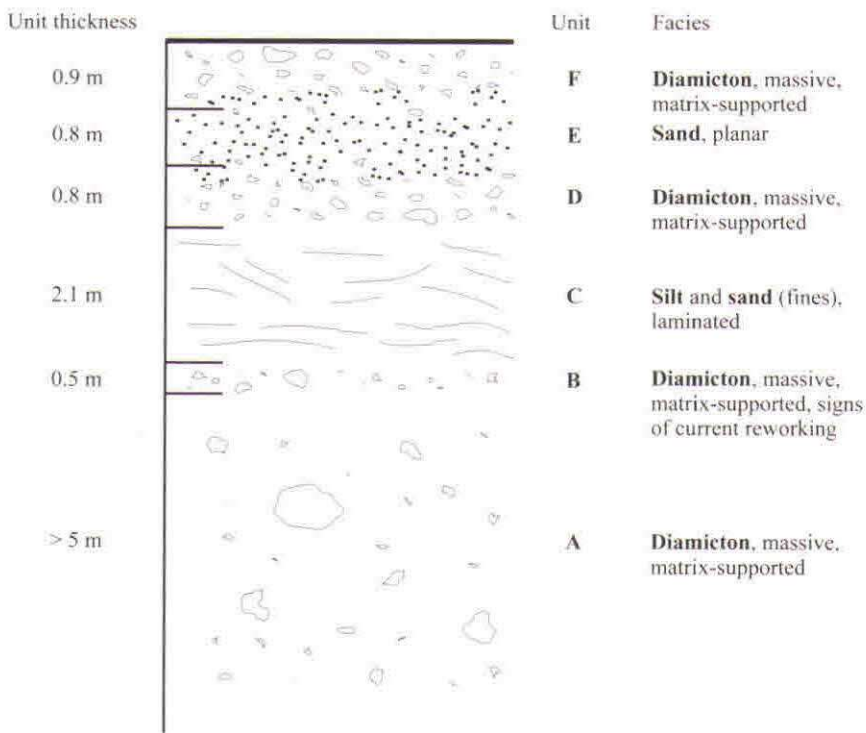


Figure 3. Lithological log of the sedimentary sequence at locality NRG 138, upper Glen Luibeg.

can also be seen below the smoothed bedrock crags. Depositional landforms can be divided into glacial features such as arcuate moraines (commonly associated with meltwater channels), (e.g. [3] and [4]); Holocene deposits of alluvial sand and gravel [5]; and accumulations of peat [6]. A number of well-defined valley-floor ridges, [7] and [8], are interpreted as eskers. A small rock-cut gorge [9] is found directly below and immediately downstream of the large moraine [10] and delta [11] complex, and is spanned by the Luibeg Bridge. Bedrock is also exposed farther downstream [12], although less deeply incised. Several debris cones and alluvial fans are also evident.

Although several natural Quaternary sections are present within the field area, the one described here is that which is of most relevance to conditions within upper Glen Luibeg during Late Devensian deglaciation (Figure 3).

Section NRG 138 is located at [NO01239 94822] at ~ 530 m O.D. and has a westerly aspect (Figure 4). The section is in a fragment of the former delta [11] and is ~ 8–10 m in total height, although only the uppermost 5 m was exposed.



Figure 4. The laminated sediments of Unit C, NRG 138. BGS registered photo P513540.

The sediment sequence at NRG 138 is described in Table 1.

Table 1. Description and interpretation of the sedimentary sequence at NRG 138.

Unit	Thickness (m)	Description	Miall Facies code	Interpretation
F	0.9	Firm, friable dark yellowish brown, (10YR 4/6*), clast-rich sandy diamicton. Matrix is coarse sand, although laterally and vertically variable. Iron staining present in the upper 0.3 m of the unit. All clasts are unweathered granite, mostly SA / SR in shape, and up to 0.3 m diameter. Some clasts coated with a thin silt layer.	Dmm	This is interpreted as a debris flow, based on silt drapes over the granite clasts that suggest deposition of the diamicton unit in a water-rich environment.
E	0.8	Hard, bedded, sand and silt unit, clasts < 0.5 cm diameter.	Sp	The transitional nature of the lower contact reflects partial reworking of Unit D and incorporation into Unit E.
D	0.8	Unweathered yellowish-brown, (10YR 5/4*) gravelly diamicton with a matrix that varies in its content of silt and fine sand both laterally and vertically. Appears to grade into Unit E above.	Dmm	The variable composition of the matrix can most reasonably be explained as a debris flow deposit, perhaps from an ice margin or from paraglacial slope adjustment.

C	2.1	Laminated fine sand and silt with rare thin clay laminae. Lower 1 m exhibits locally disturbed bedding and a detached rectangular block of laminated silt and sand within a bed of coarse-medium grained sand. Sediments in the upper 1 m more highly disrupted. Open folds and faults are abundant, boudins can be seen, and many laminae are □streaked-out□. Small granite clasts, < 30 mm in diameter also present.	Fl	Reflects quiet water settling (no ripples seen) of suspended fine-grained material. Cyclic alternation of silt and sand laminae, with some thin clay laminae, indicate sediment was deposited in a lake. Bedding slightly disturbed in the lower 1 m of the deposit, possibly attributable to syn- or post-depositional slumping. Deformed bedding in the upper 1 m of the sediment sequence more pronounced and the presence of boudins and □streaked-out□ laminae suggest this material has been moved laterally under a confining pressure.
B	0.5	Clast-rich firm yellowish-brown diamicton, (10YR 5/4*) conformably overlying Unit A. Has a siltier matrix than Unit A and contains SR cobbles and boulders of coarse-grained granite < 0.5 m diameter. Lenses and thin discontinuous beds of coarse sand also present.	Dmm(c)	The firm, silty matrix and more rounded clasts than Unit A suggest that this may be sub-glacial till similar to that described by Bennett and Glasser (1991) in Glen Geusachan. The lenses and discontinuous beds of coarse sand are the result of sediment reworking by water.
A	> 5	Hard, reddish-brown diamicton, (5YR 4/4*), matrix of coarse to medium sand and silt supporting sub-rounded (SR) to sub-angular (SA) clasts of reddened granite.	Dmm	Similar in colour, texture and composition to the stratigraphically lowest till recorded in Gleann Einich, preservation of this sub-glacial till may be limited to only a few sites. Granitic composition indicates derivation from the local bedrock, transported and emplaced by locally-sourced ice.

* Munsell Soil Colour

Interpretation

In upper Glen Luibeg, immediately north of the Luibeg Bridge, a large mounded sediment accumulation almost completely blocks the valley (Figure 5). This composite feature comprises a moraine [10] and contiguous fan or delta [11], augmented by later valley-side debris falls. The moraine has a steep southern face, interpreted here as the contact slope with ice flowing eastward across the Preas nam Meirleach col. This ice descended steeply into lower Glen Luibeg and became partially embayed in the mouth of the upper glen (Figure 2). Contiguous with, and immediately north of the moraine are two fragments of a former delta. A narrow channel has subsequently been cut through both the morainic and deltaic sediments and into the underlying granite bedrock [9].



Figure 5. The moraine and delta landform in upper Glen Luibeg, ~ 500 m total width. BGS registered photos P513555/6/7.

North of this position, smaller arcuate moraines [3] with ice-contact faces on their northern sides relate to frontal positions of a smaller, retreating, valley glacier, flowing south down Glen Luibeg. Construction of these moraines was accompanied by erosion of the meltwater channels. The sinuous esker ridge [7] reflects sub-glacial drainage and sediment deposition that took place when this glacier occupied the upper glen. The esker ridge is ~ 250 m long and terminates sharply between two moraines. The esker marks the route of sub-glacial drainage towards the snout of the Luibeg glacier during construction of these moraines. It is not known whether this ice margin was contemporaneous with the southern ice margin, and hence if its meltwater contributed to the lake.

Relative chronology of events in Glen Luibeg

Growth of valley glaciers in the Cairngorms at some time before the Late Devensian led to the excavation of the local, red granite bedrock, already weakened by prior weathering. Redeposition of this material from the ice

produced the diamicton that forms the lowest unit in the sediment sequence at NRG 138 (Table 1). Continued build up of ice resulted in coalescent glaciers that deposited the yellow-brown till, most likely during a period of maximum ice extent.

Subsequent recession of the smaller valley glaciers in the Cairngorms, in particular the Luibeg Glacier, led to some valleys becoming at least partially ice free. Small moraine ridges, such as those at [3], reflect dynamic oscillations of the Luibeg glacier during this retreat phase. This recession is predicated by evidence of ice flowing over the col from the Lairig Ghru and pushing northward into upper Glen Luibeg.

The ice then blocking the southern end of upper Glen Luibeg dammed its own meltwater and formed a marginal glacial lake and associated delta (Figure 6). The exact northern extent of the lake is uncertain as no other exposures of lake sediments have been found, but the upper surface of the fan / delta can be used as a constraint on the surface of the lake (~ 545 m O.D.), from which an estimate of extent can be made (Figure 2). With the lake surface at ~ 545 m O.D., and the base of the laminated sediments at ~ 530 m O.D., a depth of ~ 15 m can be estimated for the lake. The lake must have been sufficiently deep to allow deposition of the fine grained, normally-graded laminae of Unit C, which reflect gradual settling and minimal sediment mixing.

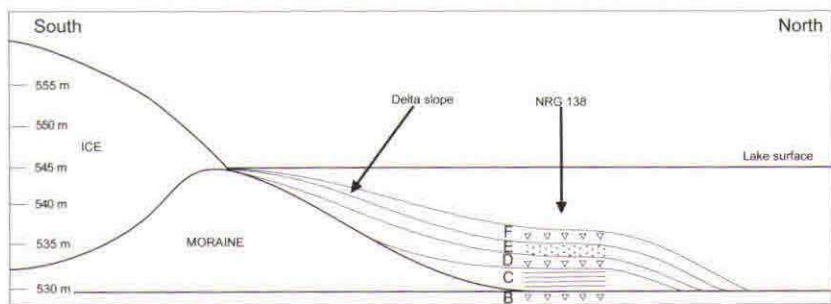


Figure 6. Schematic profile illustrating landforms and stratigraphic relationships in upper Glen Luibeg. Letters refer to lithological units described in Table 1. Not to scale.

Deformation of the upper laminae of Unit C appears to have resulted from disturbance by an external force, producing streaked-out and boudinaged sediments. Initial assessments suggest that either an oscillating southern ice margin or debris-flow input may be the cause, although post-depositional slumping must also be considered. Further investigation is currently underway to further clarify the origin of this deformation.

The overlying diamicton (Unit D) is likely to be a sub-aqueous debris flow released from the ice margin, but could also be interpreted as a paraglacial debris flow derived sub-aerially, (perhaps from a valley-side debris avalanche). Similar sequences have been reported from Alaska and Canada (Eyles, 1987), where diamictons were interpreted as debris flow deposits deposited sub-aqueously, in part because of their intercalation with laminated sediments. The upper surface of Unit D was then partially eroded, either prior to, or during, deposition of Unit E. The sand of this latter unit may have been deposited from a turbidity current flowing down the delta slope from the southern ice margin. The uppermost diamicton is interpreted as a debris flow deposit probably from similar sources as Unit D.

The southern ice margin, forming the dam, could only have existed for as long as ice in the Lairig Ghru was thick enough to overflow the 570–580 m high Preas nam Meirleach col. Once the Lairig Ghru glacier had thinned below this point, the col would cut off further ice flow to the east and therefore meltwater supply to the lake. The timing of lake drainage is unknown, and the possibility that the lake drained catastrophically cannot be ruled out.

Conclusions

Detailed mapping of landforms and sediments in the central Cairngorms has identified a former ice-dammed lake, which existed during the latter stages of the last glacial cycle. The landform-sediment assemblage in Glen Luibeg suggests that the upper and lower glens were initially occupied by two separate ice masses. After the Luibeg Glacier had retreated northward, ice descending the Preas nam Meirleach col advanced into the vacated glen and ponded its own meltwater. The resultant lake enabled deposition of the laminated silt and sand and the formation of a fan or delta.

That the lake sediments themselves are overlain by two diamicton units and a sand unit indicates that glacial ponding was accompanied by northward progradation of the delta and significant debris flow activity from the southern ice margin. Deformation within the laminated sediments may be glaci-tectonic in origin, indicating a dynamically oscillating ice front. Similar scenarios have been reported from elsewhere in the Central Highlands (Brown, 1994; Brazier *et al.*, 1996; Phillips and Auton, 2000; Golledge, 2002), suggesting that this phenomenon may have been widespread and indeed characteristic of Late Devensian deglaciation. To test this hypothesis, thin sections of sediments from Unit C are currently being prepared in order to determine the nature, provenance and direction of movement of their deforming agent.

A further implication is that recession of Cairngorm-sourced valley glaciers must have begun sooner than formerly thought, a notion supported by luminescence ages of glaciolacustrine sediments in Gleann Einich and the

Lairig Ghru of ~23–17 ka (Golledge *et al.*, 2002). It is likely that precipitation-starvation in the Cairngorms resulted in negative mass balance of many of the icefield outlet lobes, particularly where accumulation areas are small, such as Glen Luibeg.

Acknowledgements

This paper has been greatly improved by lengthy discussions with, and review by, BGS colleagues, in particular Tom Bradwell and Jon Merritt. Neil Glasser and an anonymous referee are also acknowledged for their constructive comments. Alister Clunas and Mar Lodge Estate are thanked for allowing access to the field area. The paper is published with the permission of the Director of the British Geological Survey, NERC.

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TRACE FOSSILS OF TALITRID SANDHOPPERS IN MID-HOLOCENE REGRESSIVE BEACH-RIDGES, MURLOUGH, CO. DOWN, NORTHERN IRELAND

Joanne Murdy

Introduction

The objective of this article is to report the presence of trace fossils of the ichnogenus *Skolithos*, most likely attributed to sandhoppers, located within a series of mid to late-Holocene regressive beach-ridges, Murlough, Northern Ireland. The presence of these small (<6cm), isolated cylindrical shafts observed within a series of mid-Holocene beach-ridges is the first instance in which these features have been reported in unconsolidated sediment of mid-Holocene age. Similar features have previously been reported by Scourse (1996), who described their presence within carbonate-cemented cross-bedded interglacial littoral sands in Cornwall.

The contemporary population of Talitrid sandhoppers are primarily located and restricted along the strandline of beaches, where decomposing seaweed, driftwood and other debris provide a complex and special habitat (Connor *et al.*, 1997). Sandhoppers tend not to range beyond this zone either up or down shore, due to the risk of desiccation and exposure to predators. In other words, they tend to restrict themselves along the narrow elevational range of the back-beach. It is proposed that the varying position of the *Skolithos* observed within the relict beach-ridges at Murlough, has provided a useful biotic indicator that is of palaeoenvironmental significance, particularly with respect to supporting the back-beach facies status of the relict, sub-dune beach-ridges. Since the strandline of most beaches accumulates along the high-water position, the presence of *Skolithos* preserved within the beach-ridge stratigraphy provides a strong indication of the varying position of the shoreline profile, particularly the back-beach since the mid-late Holocene, hence providing in itself strong evidence of shoreline progradation and a regressive relative sea-level tendency since the mid Holocene.

Geographical Setting

Murlough is the largest coastal dune site located along the western seaboard of the Irish Sea. It is fronted by a wide beach, dominated with ridge and runnel morphology which aligns sub-parallel to the high water line and merges into an ebb-tide orientated delta. The term ridge and runnel describes the morphological highs (ridges) and intervening lows (runnels) that are present across the intertidal zone of the low-gradient sandy foreshore. Behind the beach a series of dunes are present. This dunefield has been described as linear in form,

stretching southwest to northeast for ~ 10 km, with a limited inland extent that is ~ 1 km at its maximum (Figure 1). The morphology of the coastal dunes at Murlough generally consists of a chaotic range of dunes. Due to the reworking of the original landscape it is difficult to clearly distinguish the dune types; however, the dunes originally appeared to have been linear dunes that have developed parallel to the coast. Other dune types associated with Murlough are parabolic dunes. Parabolic dunes developed as a response to the reworking of initial linear dunes (Orford, *pers. comm.* 2000). A mixture of erosional and depositional coastal dune morphologies can be associated with the Murlough dune-field. This array of erosional and depositional morphologies is not unusual, since most contemporary Irish dunescapes tend to be indicative of a negative sediment budget (Carter *et al.*, 1990).

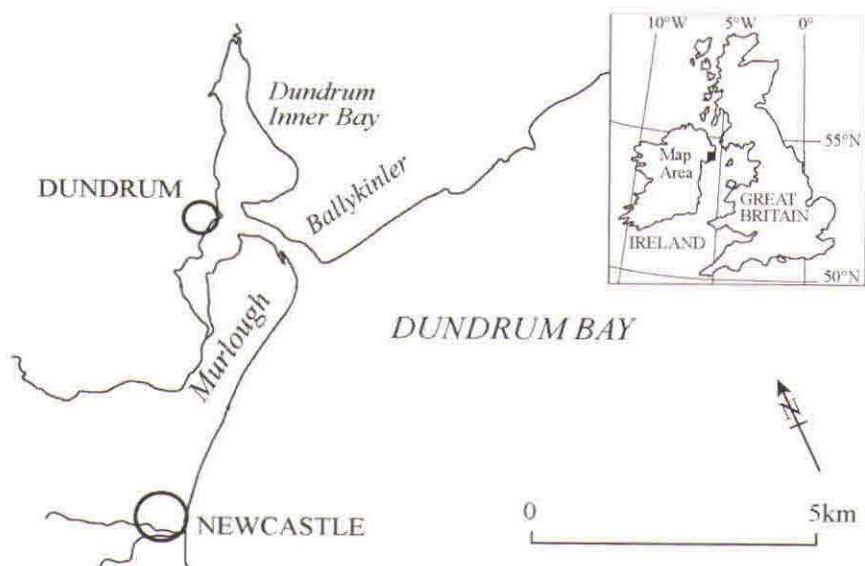


Figure 1. Location Map of Murlough, County Down, Northern Ireland

The Murlough Sub-Dune Beach-Ridges

As evident from dune blow-outs at Murlough, there appears to be a total of 18 former beach-ridges and swales trending in a SW–NE direction, roughly parallel to the contemporary coastline. Due to a thick cover of dune sand and vegetation, it is difficult to trace the spatial extent of these features across the whole of Murlough. Despite this problem of recognition, evidence from limited borehole and morphological evidence has led Orford (1982a, b, 1985) to suggest that these features probably do not cover the entire width of Murlough, but rather that they finish midway across. In investigating the heights of these

beach-ridges, initial studies carried out by Mitchell and Stephens (1974) identified the cross shore profile of the beach-ridges as having an overall reduction in ridge height, in a seawards direction. They measured the most landward beach-ridge at ~8 m OD (Belfast) while their most seaward ridge was ~4 m OD. They used this seaward reduction in beach-ridge height as evidence of mid-Holocene regressive sea-level behaviour.

Furthermore, Mitchell and Stephens (1974), thought that the beach-ridges were composed entirely of gravel, forming part of a gravel basement which migrated onshore as the result of transgressive sea-level behaviour after 10 000 yrs BP. They believed that this mechanism by which gravel moved inland and emplaced as a complete set would have terminated following the Holocene maximum relative sea-level (Flandrian Transgression) occurring 6000 yrs BP, reaching 2 to 3 m OD (Belfast). Following this transgressive peak, this gravel mass differentiated into the ridge forms during storms. This type of beach-ridge model presented by (Mitchell and Stephens, 1974) implied a mechanism of macroscale sediment source decoupling or sequential sediment sourcing (SSS). However, in light of new evidence resulting from an investigation of the internal beach-ridge stratigraphy at Murlough, Orford *et al.* (2003) reviewed the mechanisms and timescales of beach-ridge formation and favoured a model of alternating sediment decoupling (ASD) rather than (SSS) as the mechanism for beach-ridge formation at Murlough. The ADS model specified that storm or fair-weather sand beach-ridges formed at high-tide positions, subsequently this sediment acted as a source for foredune development. The Murlough beach-ridges only survived when capped by storm-generated gravels that were deposited at a frequency of 50–130 years. Finally, Orford *et al.* (2003) have suggested that the sediment volume entering the beach is thought to have fluctuated as a function of a forced regression associated with the falling sea level from the mid-Holocene highstand (~6000 cal. yr BP) identified in north-east Ireland.

Stratigraphy of the Sub-Dune Beach-ridges and *Skolithos* Occurrence

Three trenches (<5 m deep maximum with a cumulative length ~100 m) were excavated using a mechanical digger, in order to investigate the beach-ridge stratigraphy. The geographical position of the excavated trenches are illustrated in Figure 2. These trenches cut across 11 beach-ridges, to reveal a cross-profile of the internal beach-ridge stratigraphy. The geomorphology and stratigraphy of Murlough has previously been reviewed (Murdy, 2000; Orford and Murdy, 2002). It was the initial aim of the original project (Murdy, 2000) to investigate the morphosedimentology of these relict beach-ridges and extract some understanding of the mechanisms responsible for their formation. In addition, Orford *et al.* (2003) have already provided an extensive review of the mechanisms and timescales of beach-ridge formation.



Figure 2. Vertical air-photograph of Murlough illustrating the position of the excavated sub-dune beach-ridges at Murlough, County Down, Northern Ireland. The site is located in the southwest section (bottom left hand corner) of Murlough in Fig. 1 (after Orford *et al.* 2003).

Describing the internal stratigraphy of the Murlough beach-ridges Murdy (2000) reported a substantial volume of sand and gravel exhibiting a general overall seaward dip (Figure 3). The majority of sand units displayed a parallel stratification associated with swash-backwash activity. Small tube-like shafts were observed within these sand units (Figure 4). These tubes originated at the base of individual foreset laminae and bisected the underlying laminae perpendicular to the horizontal. These features were most distinguishable when they were filled by darker or lighter mineral sand than the surrounding

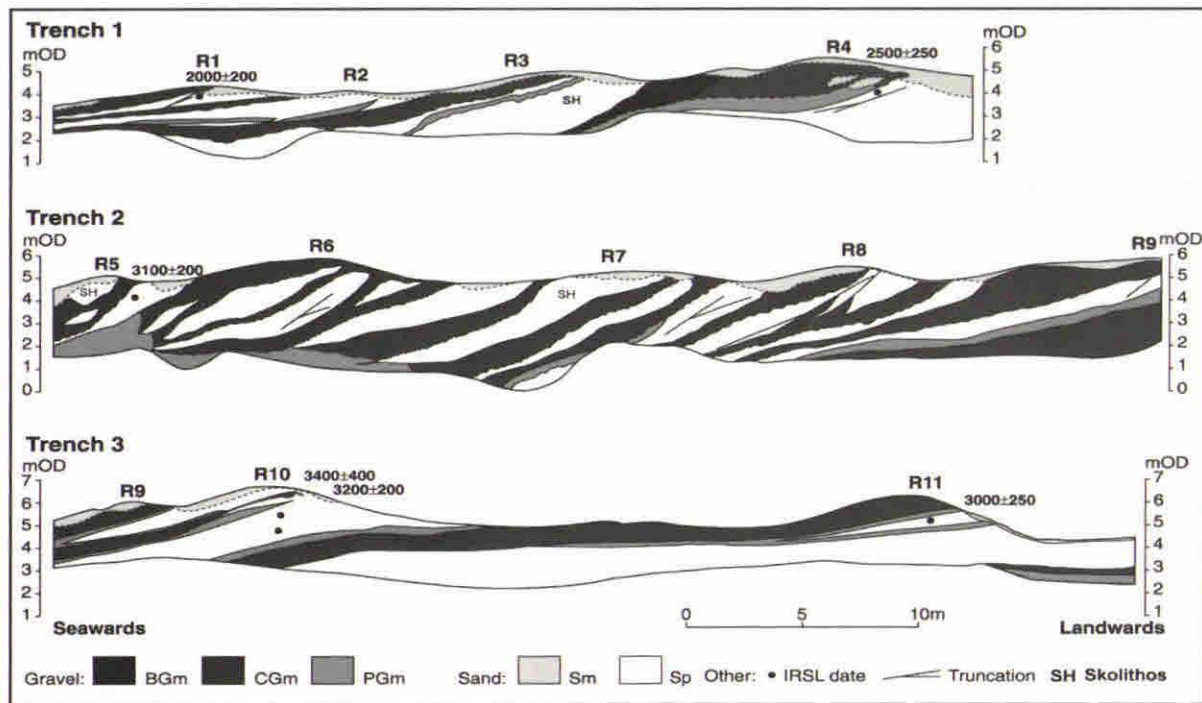


Figure 3. Stratigraphic sections through the relict Beach-ridges at Murlough. All heights relate to Belfast OD, where zero OD is approximately present-day mean sea-level. SH refers to the position of the trace fossils of ichnogenus *Skolithos*. Key to lithofacies: BGM: boulder-gravel matrix; CGM: cobble-gravel matrix; PGm: pebble-gravel matrix; Sm: massive sand; Sp: planar sand. (After Orford *et al.* 2003).

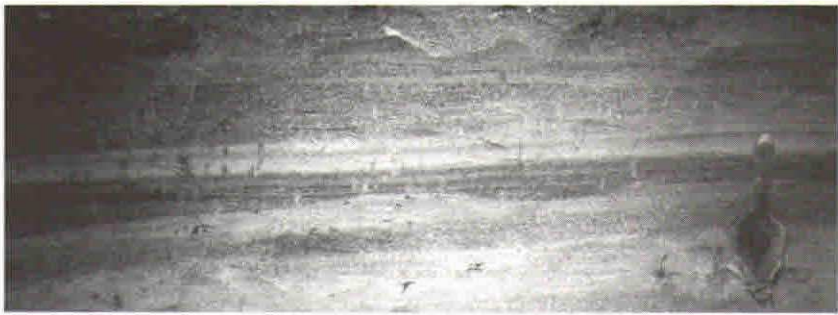


Figure 4. Small tube-like shafts observed within Murlough Gravel dominated beach-ridges, probably attributed as the result of talitrid Amphipoda (sandhopper) activity.

sediment. Tube diameter ranged between 2 and 6 mm. Along the beach-ridge sections, these tube-like shafts were located at ridges 3 (R3), 5 (R5) and 7 (R7). These features were not located beyond ridge 9 (R9).

In order to place the beach-ridges into a chronological context, infrared stimulated luminescence (IRSL) methodology, using the signal from 180–212 μm potassium-rich feldspar grains (Wintle *et al.*, 1998) was utilised, producing several dates varying between 2000 and 3400 years BP (Murdy, 2000; Orford and Murdy, 2002) and setting the formation of these beach-ridges and trace fossils into a late-Holocene context (Table 1).

Table 1. Infrared-stimulated luminescence age determinations of sand inclusions in Murlough beach-ridges

Sample	Age (a)
R1/1	2000 \pm 250
R4/1	2500 \pm 250
R5/1	3100 \pm 200
R10/1	3400 \pm 400
R10/2	3200 \pm 250
R11/1	3000 \pm 250

Behaviour of Contemporary Sandhopper Populations at Murlough

Scourse (1996) has already reviewed sandhopper burrowing behaviour and habitat. In order to understand more about sandhoppers and their burrowing behaviour at Murlough, the contemporary population was examined. It was observed that the present population of sandhoppers showed a general tendency to re-burrow landward across the beach in response to the daily and seasonal tides. Their burrows were located nearest to the dune-line (the most seaward position of the beach and the most seaward position of the coastal dunefield); at the uppermost level of the present beach-ridge during the highest tides of the year (the autumn-winter months), where they made shallow burrows in

between gravel clasts at the strandline. During observations of the relict beach-ridge sections, no *Skolithos* were observed within the gravel units. It is likely that these shallow burrows had a low preservation rate due to the open-work nature of the gravel and the reworking of gravel following winter storms. During the spring-summer months the sandhoppers were found at the foot of the current beach-ridge, where they made deep burrows in the sand. The pitted appearance of the beach surface indicated their presence. On closer examination, the oval holes measured approximately 4 mm in diameter and consisted of a shaft that measured up to 6 cm deep; the depth of the shaft was often determined by the presence of gravel clasts at the base. These excavated burrows displayed similar dimensions as those identified within the relict beach-ridge. It was also observed that the pitted sand and hence the presence of sandhoppers never ranged beyond the most landward ridge of the ridge and runnel features and beyond the foot of the most seaward sand dune.

Conclusion

Small (<6 cm) isolated cylindrical shafts located within a series of relict beach-ridges are attributed to the presence of talitrid Amphipoda (sandhopper) activity. This conclusion is supported by comparison with similar features previously identified by Scourse (1996), within carbonate-cemented cross-bedded interglacial littoral sands in Cornwall and with contemporary populations at Murlough.

The presence of ichnogenus *Skolithos*, associated with *Talitrus saltator* (sandhoppers) within the relict beach-ridges at Murlough, has provided a useful palaeoenvironmental indicator since its presence is the result of a combination of different factors that occurred over the course of the mid to late Holocene. In a coastal environment, these burrows are readily destroyed immediately or seasonally by wave activity, and consequently stand a low chance of preservation. Ironically, the examples present within the Murlough beach-ridges are mainly due to the occurrence of the gravel capping of the beach-ridges following a storm. Under the influence of storm conditions, gravels probably moved onshore as the result of higher energy waves and were subsequently deposited at the limit of wave run-up. In order to survive storm and high wave conditions, it is proposed that the presence of ichnogenus *Skolithos*, associated with *Talitrus saltator* (sandhoppers) within the relict beach-ridges at Murlough also illustrates evidence of rapid sand accretion. Bromley (1990) noted that in environments of rapidly accreting sands, such as foresets of migrating sandwaves, there may be little or no loss of upper tiers. The association of these burrows with well-developed laminae cosets at Murlough indicates that their preservation may be associated with rapid accretion. It is proposed that rapid accretion, where sediment volume entering the beach may have fluctuated as a function of a forced regression associated with the falling sea level from mid-Holocene highstand (~ 6000 cal. yr BP) identified in north-east Ireland.

The identification of sandhopper activity within a series of relict beach-ridges at Murlough has provided a useful palaeoenvironmental indicator. Since sandhoppers occupy a narrow elevational range in the backshore zone of temperate beaches (cf. Scourse, 1996), the presence of these features has confirmed the varying backshore-frontal dune environment of the relict beach-ridges, hence confirming the prograded nature of this coastline since the mid-late Holocene as the result of forced regression associated with the falling sea level from the mid-Holocene highstand (ca. 6000 cal. yr BP) identified in north-east Ireland.

Acknowledgements

This work formed part of a Ph.D project funded by a postgraduate research grant from the Department of Education (NI) and a CAST award from the Environment and Heritage Agency, co-ordinated by Mr Ian Enlander, which is gratefully acknowledged. I appreciate the critical comments made by Professor Julian Orford and Dr James Scourse on the original draft. I would also like to acknowledge my husband Colin Murdy for all his love and encouragement.

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Dr Joanne Murdy
School of Geography
Queens University
Belfast, BT7 1NN
e-mail: j.murdy@qub.ac.uk

STAC POLLAIDH - A LATE DEVENSIAN NUNATAK? A COMMENT ON BRADWELL AND KRABBENDAM (2003)

Colin K. Ballantyne

Bradwell and Krabbendam (2003) have suggested that an apparent weathering limit at an altitude of c. 500 m on the flanks of Stac Pollaidh (613 m; NC107106) in the NW Highlands of Scotland represents a periglacial trimline cut by the last (Late Devensian) ice sheet at its maximum thickness. They point out that if this interpretation is valid, it implies that Stac Pollaidh may have remained above the ice sheet as a nunatak, and that the maximum altitude of the former ice sheet may have been about 200 m lower than the reconstructed ice-surface altitude proposed by Ballantyne *et al.* (1998) on the basis of the altitudes of inferred periglacial trimlines and over-ridden summits elsewhere in the area. They note that this revised ice altitude may have profound implications for the proposed lateral (offshore) extent of the ice sheet.

The above reinterpretation is based exclusively on morphological evidence, and the absence of evidence for former ice cover (erratics, ice-moulded bedrock and striae) on the narrow summit arête. The latter comprises tor-like outcrops of Torridon Sandstone flanked to the south by some spectacular rock pinnacles. Although Stac Pollaidh was not included in our survey of high-level weathering limits in NW Scotland (McCarroll *et al.*, 1995; Ballantyne *et al.*, 1998), my own earlier observations on the mountain confirm a lack of evidence for glacial erosion on the summit ridge.

Consideration of the wider evidence for the maximum altitude of the last ice sheet in this area, however, suggests that Stac Pollaidh was indeed over-ridden by Late Devensian ice. Three points are relevant. First, on the opposite side of the Loch Lurgainn trough and 4 km south of Stac Pollaidh is a mountain of similar altitude, Beinn an Eoin (618 m; NC106064). The summit of Beinn an Eoin supports ice-scoured bedrock with chattermarks and perched glacially-transported boulders, and was thus manifestly over-ridden by ice. As former ice movement was westwards through the intervening trough, the implication is that Stac Pollaidh must also have been over-ridden by ice; it is not glaciologically feasible to envisage a northwards decline of > 120 m in ice-surface altitude across the surface of a *westward*-flowing ice stream over a distance of 4 km.

A second point concerns the degree of rock weathering on the Stac Pollaidh ridge. Bradwell and Krabbendam (2003, pp. 20–21) describe the zone above the putative trimline as consisting of 'deeply weathered sandstone', 'highly-degraded *in situ* bedrock' and 'towers of decomposing rock'. This is misleading. The rounding of rock surfaces on Stac Pollaidh, as on other Torridon Sandstone mountains, is demonstrably due to postglacial microglaciation (granular

disaggregation), and is not indicative of the prolonged chemical weathering implied by their description (Ballantyne and Harris, 1994, pp. 171–2; Ballantyne, 1998). As numerous rock climbers will testify, the pinnacles of Stac Pollaidh are composed of sound, not ‘decomposing’ rock. In this context it is notable that Torridon Sandstone mountains that escaped glacial erosion by the last ice sheet commonly exhibit a 0.5–1.0 m thick cover of mountain-top detritus. On the northern plateau of An Teallach, 24 km south of Stac Pollaidh, the pre-Late Devensian age of this detritus has been confirmed by cosmogenic isotope dating (Ballantyne, 1998; Stone *et al.*, 1998). This diagnostic debris mantle is absent from the summit ridge of Stac Pollaidh, though arguably the ridge is too narrow to support a cover of frost-weathered debris. Conversely, however, edge-rounded rock outcrops with superficial pseudobedding such as those pictured in Figure 2 of Bradwell and Krabbendam (2003) *do* occur on Torridon Sandstone ridges that were certainly over-ridden by the last ice sheet. An example is the summit of Meall Garbh (610 m; NH 081869), a spur of An Teallach, where an outcrop similar to that pictured in Bradwell and Krabbendam is flanked by ice-moulded slabs that support chattermarks and numerous ice-transported boulders. Moreover, rock samples from the slabs on Meall Garbh at altitudes of 600–605 m OD yielded ^{10}Be exposure ages of 14.4 ± 1.3 ka, 14.7 ± 1.3 ka and 13.9 ± 1.3 ka (Stone *et al.*, 1998), consistent with exposure from under the downwasting ice sheet. In sum, the morphological evidence does not provide conclusive evidence that Stac Pollaidh was a Late Devensian palaeonunatak, and no weight can be placed on the associated descriptions of bedrock weathering.

The final point concerns the wisdom of interpreting former ice altitude on the basis of morphological evidence alone, particularly when the observations are restricted to a single mountain. The ice-surface reconstruction of Ballantyne *et al.* (1998) for NW Scotland is based on observations on 140 mountains, and has since been complemented by observations on mountains in adjacent areas and the Hebrides (Ballantyne, 1999a, 1999b; Ballantyne and Hallam, 2001). The mapped trimline altitudes have been validated not only by cosmogenic isotope dating (initially at An Teallach and The Storr on Skye, but also now by unpublished dates obtained above and below mapped trimlines on the Outer Hebrides) and by comparative X-ray diffraction analyses of clay-fraction mineralogy in over 160 soil samples obtained above and below periglacial trimlines on over 50 mountains. This programme has yielded a reconstruction of ice-surface altitude that is internally consistent, yields realistic values of reconstructed basal shear stresses, and indicates ice-movement directions that conform with those mapped by the Geological Survey in the early 20th Century on the basis of striae, roches moutonnées and erratic carry. The clarity of the associated morphological evidence varies greatly, however, particularly with distance from the former ice divide, topography and lithology: the clearest trimlines are often found on the most resistant rocks (notably Lewisian Gneiss);

well-jointed rocks, such as quartzite, have often broken down to form blockfields since deglaciation. There are therefore sites where shattered rock outcrops and even blockfields occur below the reconstructed ice surface altitude, reflecting rock breakdown since ice-sheet downwastage. In attempting to reconstruct the maximum altitude of the last ice sheet on a regional scale, it is necessary to synthesise mapping and other data from a large number of sites, and to evaluate the significance of apparent anomalies carefully. This cannot be achieved on the basis of morphological observations, unsupported by rock weathering data or exposure ages, from a single site.

It remains to consider why the summit ridge of Stac Pollaidh exhibits such a shattered appearance. Striae and roches moutonnées on adjacent low ground demonstrate that the Last Glacial Maximum the mountain separated two warm-based ice streams that moved westwards parallel to the alignment of the narrow summit ridge. Erosion by these ice streams presumably steepened the flanking cliffs and reduced the summit ridge to a narrow arête. There is abundant evidence that during and after ice retreat the cliffs on either side of the summit ridge have experienced widespread rock-slope failure and rockfall. Bradwell and Krabbendam (2003, p. 23) note evidence for a 'single or composite rockfall event' during ice-sheet downwastage in the form of reworked coarse debris in a lateral moraine at c. 400 m OD, and the cliffs flanking the summit ridge overlook massive rockfall talus slopes that accumulated after ice-sheet downwastage (Hinchliffe, 1998). These talus accumulations provide evidence that the present form of the arête and the cliffs on either side owe much to converging rockwall retreat on both flanks. The spectacular pinnacles on the south side of the ridge can therefore be interpreted as postglacial residuals, isolated by the retreat of the adjacent rockwall.

The case of Stac Pollaidh represents a useful reminder of the pitfalls of attempting to identify periglacial trimlines on the basis of morphological evidence alone. Whilst accepting Bradwell and Krabbendam's suggestion that the morphology of Stac Pollaidh resembles that of a Late Devensian palaeonunatak, I believe that this interpretation is contradicted by evidence of glacial over-riding at 618 m on the opposite site of the Lurgainn trough and by the wider evidence for ice-surface altitude on other mountains in the same area (McCarroll *et al.*, 1995). The interpretation is also undermined by ill-considered assertions regarding the nature of weathering on the summit ridge: widespread rounding of Torridon Sandstone outcrops on Scottish mountains is due to postglacial microgelivation and is not indicative of prolonged exposure above an ice sheet, and there is no evidence for 'deeply-weathered sandstone'. The emergence of a narrow rocky arête from under the downwasting ice sheet is by no means restricted to Stac Pollaidh: similar arêtes crowned with tor-like outcrops occur, for example, on Suilven, 9 km to the NE, and the Horns of Alligin, 55 km to the SSW. The present form of the summit arête and the cliffs

and pinnacles on either side can be adequately explained by steepening of the cliffs flanking the ridge by glacial erosion and subsequent converging rockwall retreat, for which there is abundant evidence in the talus accumulations downslope.

Bradwell and Krabbendam (2003, p. 20) assert that 'morphological evidence alone is deemed sufficient in the identification of an upper, glacial weathering limit on this lithology', and cite Ballantyne and Harris (1994) and Ballantyne *et al.* (1998) in support of this curious assertion. Quite the contrary: the work we have carried out on identifying weathering limits in NW Scotland and elsewhere has convinced us of the necessity of testing morphological evidence with quantifiable measures of rock weathering, notably XRD analysis of clay-fraction mineralogy, and surface exposure dating using cosmogenic isotopes. Without the use of such independent data, any proposed 'trimline' must be regarded as at best speculative, particularly when it is based on a single site without observations on adjacent mountains.

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Colin K. Ballantyne
School of Geography and Geosciences
University of St Andrews
Fife KY16 9AL
Scotland, UK
E-mail: ckb@St-and.ac.uk

STAC POLLAIDH – A LATE DEVENSIAN NUNATAK? A REPLY TO BALLANTYNE (2003)

Tom Bradwell and Maarten Krabbendam

We thank Professor Ballantyne for his comment (this issue) on our paper (Bradwell and Krabbendam, 2003) and are glad that it has stimulated an interesting debate. We think that there are some points that need clarification and further discussion. Firstly, we are pleased that Ballantyne (2003) has confirmed that there is no evidence for glacial erosion on the summit ridge of Stac Pollaidh. The simplest explanation for this, we believe, is because the summit ridge was ice-free during the Last (Late Devensian) ice-sheet glaciation.

We are well aware that our proposition appears difficult to reconcile with previously published ice-sheet reconstructions (e.g. McCarroll *et al.*, 1995; Ballantyne *et al.*, 1998). However, the purpose of our short article was to discuss the possibility of Stac Pollaidh being a previously undescribed ‘anomalous’ nunatak during the Late Devensian glaciation and present possible explanations for this phenomenon. We purposefully avoided critically reviewing all the pre-existing evidence to keep the article brief and relatively objective.

We address the main points raised by Ballantyne (2003).

Firstly, Ballantyne (2003) argues that Beinn an Eoin (618 m), 4 km to the south of Stac Pollaidh, was “manifestly overridden by ice” and that “it is not glaciologically feasible” to envisage an ice gradient of 3% or more between the two mountains. We have not yet surveyed Beinn an Eoin and cannot comment on Ballantyne’s field observations. However, let us assume that Ballantyne is correct and Beinn an Eoin was indeed overridden by ice; is the resulting ice slope glaciologically unfeasible? In southeast Iceland where the Vatnajökull ice-cap encounters the mountains of Esjufjöll, ice-surface gradients well in excess of 3% occur. For instance, in the 5 km-wide breach between the Vesturbjörg and Mafabyggðir nunataks, a gradient of 8.5% occurs over 4 km. Furthermore, to the NE of the Austurbjörg nunatak a west-facing ice slope, perpendicular to the regional ice-flow direction, has a surface gradient of 10% (Landmælingar Islands, 1980). Ice-surface gradients of >3% across topographically-constrained glaciers, therefore, cannot be dismissed as “not glaciologically feasible” as they are common on present-day ice-caps. On Vatnajökull the underlying bedrock topography has a major influence on the ice-surface slope – a factor that is generally not taken into account in reconstructions of the Late Devensian ice sheet in Scotland (e.g. Lambeck, 1995; Ballantyne *et al.*, 1998).

Concerning the second point, we agree with Ballantyne that the rounding and weathering of the sandstone on the summit ridge of Stac Pollaidh are due to

granular disintegration (microgelivation). However, we do not accept that all of this weathering is "demonstrably" postglacial. The degree of weathering (microgelivation and otherwise) seems remarkably high, with abundant open joints more than 0.5 m deep, when compared with other large sandstone exposures of similar altitude in the area (cf. Meall Dearg, An Laogh, Beinn Tarsuinn). This evidence alone suggests that Stac Pollaidh has been exposed for considerably longer than these other summits. We agree with Ballantyne that the term 'decomposing rock' could be misleading; however, we meant decomposing in a physical sense (i.e. to break down into its component elements), rather than in an organic sense (i.e. rotting). The use of the term "highly degraded *in situ* bedrock" (p. 22) is justified as the word *degrade* means to "wear down and cause to disintegrate" (Oxford Dictionary of English, 1998). The term "deeply weathered" is also appropriate as the originally intact bedrock must have been deeply weathered in the past to open joints to depths of >0.5 m, leaving tor-like outcrops and isolated rock pinnacles (Bradwell and Krabbendam, 2003, figures 2 and 3). It is difficult to imagine how these features could have resulted from anything other than a period of intense prolonged weathering.

We also agree with Ballantyne that most of the rock pinnacles are made of sound rock. Most of the loose weathering products have since been removed by wind and rain erosion. But sound rock is not necessarily an indication of recent exposure. As numerous Peak District rock climbers will testify, the gritstone towers of the Froggatt and Stanage Edges in Derbyshire are just as sound as those on Stac Pollaidh yet have been exposed for considerably more than the last 10,000 years.

A third point is how our observations on Stac Pollaidh 'fit' with the wider evidence made on other mountains, by Ballantyne and co-workers (e.g. McCarroll *et al.*, 1995; Ballantyne *et al.* 1998). Ballantyne (2003) claims that the existing ice-sheet reconstruction and data set are "internally consistent". But does this consistency hold for the Coigach mountains? On Cul Beag, McCarroll *et al.* (1995) reported ice-scoured bedrock to summit level (769 m OD) and gibbsite was absent from soil on the summit. BGS mapping in 2003 found no unequivocally ice-scoured bedrock above 620 m OD. A distinct decrease in the number of quartzite erratics was observed between 650 and 700 m OD, with only 4 quartzite cobbles found on the eastern flank of the mountain above 700 m. The highest quartzite erratic was found at 715 m (2220 ft) OD [2139 9086R]. Interestingly, during the original BGS survey (1886) L W Hinxman recorded "Quartzite and Moine schist fragments up to 2300 feet" on Cul Beag (BGS field map). It is therefore possible that the last ice sheet reached only as high as ~650–720 m OD on Cul Beag and did not overtop the summit. On neighbouring Cul Mor, McCarroll *et al.* (1995) place the weathering limit at 670–840 m OD. Their bedrock joint depths, Schmidt hammer measurements

and clay-fraction mineralogy all suggest that the uppermost portion of Cul Mor was ice-free during the last ice-sheet glaciation. BGS mapping has confirmed the highest occurrence of clearly ice-scoured bedrock at 640–660 m OD [2165 9117]. Periglacial features above ~700 m OD are consistent with a long history of exposure. Therefore a maximum ice-sheet altitude of ~660–700 m is quite probable for the east face of Cul Mor. On Ben More Coigach, 6 km south of Stac Pollaidh, McCarroll *et al.* (1995) place the upper limit of glacially moulded bedrock at >680 m OD and consequently infer a weathering limit altitude of 680–700 m OD. However, this figure is adjusted to >600 m OD in Lawson and Ballantyne (1995, Table 3.1) and also in Ballantyne *et al.* (1998, Table 1). It has been suggested that the “highest parts of the plateaux remained above the upper surface of the last ice sheet, as these support tors...whilst the surrounding ground is ice-scoured” (Ballantyne, 1995, p. 56). The location of a tor at ~580 m OD (Ballantyne 1995, fig. 5.4) would suggest that a figure of 600 m OD is a *maximum* height for the last ice-sheet which probably sloped from east to west on Ben More Coigach, and may have been as low as ~550 m in places. Evidence from early BGS mapping supports this notion (BGS field maps). H M Cadell found “no evidence of drift, perched blocks or ice action above 1500 feet” (480 m) around the western flank of Ben More Coigach. It would appear on closer scrutiny that the existing trimline evidence for the Coigach mountains is not as convincing or internally consistent as Ballantyne (2003) suggests.

Ballantyne (2003) proposes a model of rockwall retreat to account for the shattered appearance of the summit ridge of Stac Pollaidh. We believe it would be difficult to generate isolated rock pinnacles 12–15 m high (Bradwell and Krabbendam, 2003, figure 3) by simple rockwall retreat, particularly in the limited time since deglaciation. However, if Ballantyne is right, features of this size would be expected to occur on other glacially-overridden sandstone ridges in the area. Our mapping has found that they do not. By way of example, Cioch Beinn an Eoinn (380 m OD), a conspicuous, narrow, sandstone ridge on the south side of the Loch Lurgainn trough shows clear evidence of glacial overriding. In stark contrast to Stac Pollaidh, this ridge has a rounded, streamlined, morphology with an ice-smoothed, not shattered or castellated, crest. No rock pinnacles or large tor-like forms occur on the Cioch Beinn an Eoinn ridge even though it too has been exposed to rockwall retreat and weathering processes since deglaciation. We believe that the difference in exposure history of these two summits is the simplest and most likely explanation for their marked difference in appearance.

Finally, we must stress that the purpose of our original article was not to review the evidence for glaciation in the area as a whole but merely to address the unusual geomorphology of Stac Pollaidh in a glacial context. The simple question remains: why does a mountain, supposedly over-ridden by the last ice-sheet, so strongly resemble a late Devensian nunatak? We agree with Ballantyne’s

assertion that morphological evidence of weathering limits should be tested using a range of quantitative techniques. However, we aimed to show that the identification of palaeo-nunataks in certain cases is possible using morphological evidence alone. It has already been pointed out that Neoproterozoic sandstones of the NW Highlands have been "little affected by macrogelivation [frost shattering] since ice-sheet downwastage" (Ballantyne and Harris, 1994, p. 185) and consequently, "detection of a weathering limit...is often relatively straightforward on these lithologies" (Ballantyne *et al.*, 1998, p. 1162). We believe that the morphological evidence on Stac Pollaidh is particularly clear, and we will be using clay-fraction mineralogy and cosmogenic techniques on Stac Pollaidh and neighbouring mountains in the near future to test our hypothesis.

In conclusion, the comments of Ballantyne (2003) are interesting and pertinent but do not discount the possibility that the summit ridge of Stac Pollaidh was a nunatak during the Late Devensian ice-sheet glaciation.

Acknowledgement

This article is published with the permission of the Director of the British Geological Survey.

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Tom Bradwell and Maarten Krabbendam
British Geological Survey
Murchison House
West Mains Road
Edinburgh EH9 3LA, UK
E-mail (Bradwell): tbrad@bgs.ac.uk

REPORTS

THE QUATERNARY OF GLEN AFFRIC AND KINTAIL, NORTHERN HIGHLANDS OF SCOTLAND

QRA Short Field Meeting, 8–12th May 2003

The meeting to Glen Affric and Kintail provided an excellent opportunity to visit some of the most spectacular scenery of the Northern Highlands. One of the principle aims of the meeting was to present new and largely unpublished work on the Holocene evolution of a typical Highland landscape. Glen Affric is a large, predominantly upland valley extending from the east near Beaully to the west coast at Loch Duich in Kintail. The area is the focus of research on Holocene climate change, peat formation and spread, vegetation history and human activity, slope and fluvial geomorphic evolution, sea-level change, palaeo-seismicity and nature conservation.

Richard Tipping (Stirling), the meeting organiser, welcomed the QRA members to Cannich and gave an introductory talk and slide show to illustrate the areas we planned to visit. **David Jarman** (Mountain Landform Research) then introduced us to his particular area of interest, rock slope failures, and showed us some splendid photographs of them.

Day 1: Upper Glen Affric

The day started at Loch Coulavie, a small bedrock basin at the head of Loch Affric. **Eileen Tisdall** (Stirling) described her investigation of lake-level fluctuations as a proxy for precipitation change during the Holocene. A rock bar ensures that the height of the outflow has not altered over time but that the lake level can fluctuate below this outlet level. Eileen interpreted the sediment record in terms of changes in both lake-levels and precipitation during the Holocene. The discussion included the problem of determining catchment area and how this might change over time.

We then moved a short distance to **Althea Davies'** (Stirling) site – Torran Beithe. This area of West Affric is characterised by a treeless landscape covered by blanket peat. This contrasts with the ancient pinewoods found today in East Affric. Torran Beith, a relatively small peat-filled basin, was chosen to investigate the local vegetation history of the West Affric area. The pollen stratigraphic evidence for early Holocene woodland dynamics and the subsequent spread of blanket peat was outlined. Althea proposed that the area has been predominantly treeless since c.2030 BP (1970 cal. BP) with evidence for some human activity at and before this time.

Richard Tipping discussed the spread of peat in West Glen Affric. He described the results of a series of radiocarbon assays from basal peats taken from hollows in the area. As might be expected, the peat accumulated first in the wettest areas and with complete ground cover of peat by 6000 cal BP. However, from the pollen evidence, this does not seem to have affected the woodland composition and occurred long before the arrival of the earliest farmers (Althea Davies, previous site). Therefore, the native woodland co-existed with acidic and nutrient-poor peaty soils and peat initiation was not thought to be anthropogenic in origin.

During a lull in the rain, the group enjoyed lunch on a small a knoll overlooking one of **Eileen Tisdall's** sites. She described her analysis of the degree of humification at four blanket-peat sites situated on a West-East transect along Glen Affric. Although there were no clear west-east trends, Eileen identified correlations with the precipitation changes identified at Loch Coullvie and changes in temperature suggested by the humification changes in the blanket peat sites.

David Jarman pointed out the first of the proposed rock slope failures. His enthusiasm was contagious and it was not long before we all re-trained eyes to look for these features in the landscape. Their investigation requires both a head for heights and a degree of fitness. David introduced us to the evidence for the An Sornach rock slope failure. This impressive classic 'armchair failure' provoked some lively debate on neotectonics following deglaciation and factors which might trigger such mass movement.

Due to the high level of the river we were unable to visit **Althea Davies'** site at Carnach Mór, a palaeochannel sequence, so we viewed it from the track. Althea pointed out the pockets of brighter green vegetation which indicate more fertile soil and species-rich vegetation. Evidence for human settlement included a stone-built ruin adjacent to the pollen site. The local vegetation was described and reference was made to human impact during the late Bronze Age and early Iron Age. The present wilderness landscape is thought to be a relatively recent phenomenon since there is evidence for agricultural on the valley floor which reached a peak during the medieval period. Discussion included the problems of incorporation of re-worked peat into the sediment, as several large blocks could be seen near the river.

Day 2: East Glen Affric, Strathglass and Strathfarrar

Richard Tipping started the day by outlining the Holocene palaeoecology of the local area and the problems of conservation versus longer term presence of the pinewoods in East Glen Affric.

The scale of ecological reconstruction possible using pollen analysis is largely determined by basin size and pollen source area. The site of Allt Garbh, a peat-

filled bedrock basin was chosen to investigate the recent woodland history in this part of East Glen Affric. The pollen evidence shows that between 800 and 900 years ago pine almost disappeared and was replaced by heather, thus raising questions on the longevity of pine in Glen Affric. Richard proposed that heather reaches a mature 'leggy' form at about 70–80 years, falls over and pine seedlings invade the gaps. However, due to the large surface area of the site, it has a fairly large pollen source area. Therefore, the pollen signal may not reflect the change in vegetation immediately around the site. Most of the discussion was about the effects of local deer on pine regeneration.

Richard Tipping took the group to a small woodland hollow at Allt an Laghair. He described the work in progress of Helen Shaw (Stirling), who was unable to attend the meeting. Small woodland hollows should have a relatively local pollen signal and so allow the investigation of changes at the spatial scale of woodland stands (*c.* 50–70 m maximum pollen source distance). What appears to be a fairly stable woodland, however, supports evidence from elsewhere in Glen Affric for high dynamism and disturbance in the woodland prior to *c.* 200 years ago. The question of water movement and hence transport of pollen through the small hollow was raised, but Richard believes that the site has a very small catchment area.

The next stop was to view Plodda Falls, where theories for the geological origin of these falls were discussed.

After lunch, the group moved on to a very different landscape, that of the Strathglass Valley. **Justine Kemp** (Northumbria) described the results from two of her sites. She outlined the history of severe flooding in the valley for the past 200 years. Justine described the floodplain dynamics and in particular the sediments preserved in the meander cut-offs. These can provide evidence for palaeohydrological reconstruction, including the date of abandonment.

Next we moved to the other side of the river, where Justine told us about some very recent work, not included in the guide. One of the palaeochannels investigated proved to be surprisingly deep and a relatively old sequence was retrieved. The basal AMS radiocarbon dates range from 7560–8130 ¹⁴C BP, demonstrating that some of these channels are relatively stable, with very little geomorphological activity over the past 8000 years. Discussion included whether the provenance of the sediment was upstream or from bank erosion.

The weather improved as we headed into the spectacular Glen Strathfarrar. This was an opportunity for **David Jarman** to describe both his and **Elspeth Reid's** (Inverness College) geomorphological research. Elspeth was tragically killed in a road accident in March 2003; the guide is dedicated to her. David showed us three postglacial rock slope failures, each at a progressively higher altitude and over even more difficult terrain. The first was Carn Ban, which is an unusual gravitational spreading feature. The second, Sgurr na Ruaidhe, is a

classic example of 'armchair' failure, with distinctive head and flank scarps. The third, Creag a' Bhruic, is a miniature armchair failure. Rock slope failures are not usually found on the steepest slopes and David suggested that they may have been stressed and hardened by repeated glaciations. The gentler slopes therefore weaken and fail first following deglaciation. Discussion focussed on whether they could perhaps be rock glaciers and whether the debris flow could be described as sub-cataclastic.

Day Three: Glen Shiel and Kintail

The third and final day of the meeting started with a drive over to the west coast. **Callum Firth** (Brighton) pointed out some possible faulting (The Strath Croe Fault) and Loch Lomond Stadial moraine features. **Ian Shennan** (Durham) introduced the evidence for Holocene sea-level changes in the region and showed us two of his research sites. Raised tidal marshes and isolation basins provide records of changes in the relative sea level. This region is within the Loch Lomond Stadial limits, but the radiocarbon assays of the basal sediments suggest that deglaciation appears to be much later than previously thought. The group visited Loch nan Corr, which is an isolation basin at the eastern end of Loch Duich. The group had an opportunity to participate in the coring of the basin and to take a closer look at the sediments which Ian Shennan described in terms of changes in relative sea level.

The relatively late deglaciation following the LLS in the region corresponds with the evidence for delayed deglaciation proposed in the guide by Richard Tipping, Eileen Tisdall and Althea Davies. AMS ^{14}C dating evidence from five localities in Glen Affric show that organic matter accumulation was delayed by 500 or more ^{14}C years after initial deglaciation.

The next site was a road cutting section presented by Callum Firth. Callum talked about the Kintail Seismic Zone and showed us the Strathconon Fault in the Invershiel road cutting. This fault continues to be active, and recently 4.8 was recorded on the Richter scale. Callum showed us the fault gouge, a green rock running through the fault. He proposed ages of the faulting and highlighted the difficulties of determining the conditions of formation.

The group then headed inland again, stopping at an idyllic lunch stop at the side of the river on the way before continuing towards the head of Gleann Lichd. Richard Tipping described the work that Elspeth Reid undertook on interpreting fluvial activity of two alluvial fans in the Gleann. The stratigraphy was described, which included some sub-fossil wood not previously found at one of the sites. Hypotheses were proposed for fan propagation, development and chronology. Discussion focussed mainly on chronology and dating of the sediments and the sort of triggers, natural or anthropogenic, which caused the marked geomorphic changes.

David Jarman showed the group a rock slope failure on the SW slopes of Beinn Fhada, the largest such failure in mainland Scotland. The formation and initiation of this impressive feature was discussed.

On the way out of the Gleann we visited the lowland pollen site of Althea Davies at Morvich and Strath Croe. This site was chosen as a contrast with the upland sites in Glen Affric described on Day 1. There is little doubt that deforestation occurred here due to human activities, and the lowlands were the main areas for farming. Althea proposed that the uplands were only used for farming during periods of duress. The late and short-lived expansion of oak was discussed and whether it was deliberately planted.

On the way back to Cannich Callum Firth showed us the Sgurr na Ciste Dhuibe (Five Sisters of Kintail) fault, a prominent feature highlighted by a skyline notch.. An interesting discussion ensued regarding mechanisms for faulting.

We stopped to look at the Glen Shiel rock slope failure cluster, which David Jarman suggested might be a response to Lateglacial major breaching of the main watershed of Scotland. This is the highest density of paraglacial rock slope failures in Scotland and well worth seeing. Thin snow on the peaks picked out some stripes just below the false crested skyline – these had not been seen before and a lively discussion ensued; a fitting end to a great meeting.

This was an extremely enjoyable field meeting, despite the rather cruel weather; Richard Tipping's ability to maintain his enthusiasm over the three days through heavy downpours is quite remarkable. The meeting had exactly the right balance of site types and range of geomorphology. I am sure it will be long remembered as the meeting where some of us were first introduced to rock slope failures. Richard Tipping and his colleagues are thanked for organising such a varied meeting and producing a comprehensive, useful and superb field guide – I recommend it wholeheartedly as both a reference text and for use in the field.

Acknowledgements

John Cooper is thanked for providing a valuable photographic record of the meeting and comments on the text.

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Heather Binney
Environmental Change Research Centre
Department of Geography
University College London
26 Bedford Way
London WC1H 0AP

IGCP 437 UK WORKING GROUP SOLENT FIELD MEETING

Southampton University, 8th–10th July 2003

The final IGCP 437 UK field meeting was hosted by the University of Southampton at the Southampton Oceanography Centre on the 8th–10th of July. It consisted of a paper session and conference dinner on the 8th, followed by two splendid days of field excursions to a number of sites of research importance around the Solent area. The meeting was effectively organised by **Dr Robin Edwards** (Trinity College Dublin) and **Dr Justin Dix** (Southampton Oceanography Centre), who assembled a stimulating and informative conference itinerary on the general theme of sea-level change in Southern England, with specific reference to coastal evolution in the Solent region and associated coastal management concerns.

Introduction and paper session

The meeting was opened under the chairmanship of Dr Dix. The first paper of the afternoon, by **Wil Marshall** (Plymouth), proposed that geochemical and magnetic chronologies could be used as possible alternatives to the direct ¹⁴C dating of minerogenic saltmarsh sediments. A late Holocene chronology, obtained using palaeomagnetism, was presented from the Taf Estuary in Wales. Next, **Simon Jennings** (London Metropolitan) argued the importance of a full understanding of coastal sediment transport systems and past drift cell activity when attempting sustainable coastal management interventions. This was skilfully illustrated with reference to periods of activation and subsequent breakdown of the Selsey–Dungeness drift cell and the influence of these events on the gravel beaches of the East Sussex coast.

Mike Hardbottle (Durham) shifted the focus to Australia, and presented preliminary foraminiferal evidence of sea-level change on the Great Barrier Reef coastline during the Holocene. This was followed by an enlightening talk by **Ben Horton** (Durham) on the use of foraminifera-based transfer functions to reconstruct sea-level histories. The relative merits and predictive powers of local and regional transfer functions were demonstrated using data from Holkham, North Norfolk. Then, in contrast to the earlier research-related papers, **Peter Murphy** (English Heritage) presented some of the complex issues related to the coastal Historic Environment and the practical protection of archaeological sites from marine inundation, especially under Managed Realignment scenarios. This interesting presentation revealed some of the difficulties that can arise when attempting to attach monetary value to coastal archaeology.

Following a short refreshment break the session resumed with a number of talks designed as introductions to the field excursions. **Robin Edwards** (Dublin) gave an informative overview of sea-level investigation in the Solent region, and then outlined the problems that can occur when trying to establish Holocene sea-level index points that are closely constrained in both age and altitude. **Antony Long** (Durham) continued the theme of coastal evolution during the late Holocene with an examination of estuary development using the 'transgressive' model of the landward translation of estuarine facies infilling accommodation space. It was suggested that this approach could be expanded to regional patterns of estuary development in southern England.

Andy Bradbury (Channel Coastal Observatory) spoke on the on-going management of Hurst Spit and how this landform had evolved during the Holocene. Then **David Bridgland** (Durham) described how past marine high-stands in this part of England could be elucidated by the study of the fluvial record of the Solent region where rivers had responded to past changes in base-level. This topic of high-stands was carried on by **Martin Bates** (Lampeter) who introduced the raised beaches of the Sussex and the Solent. Finally **Alex Bastos** (Southampton Oceanography Centre) presented some of the findings of his and Dr Dix's ongoing work on the Solent palaeoriver system using offshore geophysics surveys.

Field Excursion One

The first stop on day two was at a saltmarsh in the RSPB reserve on the Arne Peninsula. In a marsh near Long Island, Robin Edwards and Antony Long described some of the sea-level research that had been undertaken in Poole Harbour. They outlined how it had been possible to use foraminifera-derived tidal palaeoheights and pollen chronohorizons to supplement data from basal peats to develop a very plausible model of late Holocene sea-level change. A sediment core was examined and a lively discussion ensued. The party then travelled north to Hurst Spit, where Andy Bradbury explained the complexity of the ongoing management of the spit and the issues surrounding the protection of the hinterland and Hurst Castle. The effectiveness of beach re-profiling and other protective interventions were discussed. It was evident that there was the need for a holistic and unified approach to the long-term management of this part of the coast for it to be sustainable. The day ended at Bury Farm, Southampton Water, where Antony Long and Robin Edwards expanded on the theme of sea-level histories for this area, and highlighted the similarities in change that were apparent between sites on the Solent and the sedimentary record from Poole Harbour.

Field Excursion Two

The third day focused on sea-level change and coastal evolution of the Solent region during the latter part of the Pleistocene. The first stop was at the internationally renowned Boxgrove site in West Sussex where Dr Martin Bates and Dr Matt Pope expertly guided the group around the extensive marginal marine deposits and raised beach sequences dated to Oxygen Isotope Stage 11. This quarry site has been recently purchased by English Heritage and has thick sequences exposed that contain Lower Palaeolithic flint scatters. Articulated horse remains have been found with butchery evidence suggesting hominoids may have been in place as top predator at this time. We then travelled forward in geological time with a short stop at the site of younger deposits at Norton Farm. After lunch we travelled down to the coast and viewed marine sequences and raised beach deposits exposed at Selsey Bill, and Dr Bates explained his current thinking on Pleistocene coastal evolution up to a marine sequence proposed to be from Oxygen Isotope Substage 5e. This provided the stimulus for further discussion regarding the extent and chronology of sea-level movements during the late Pleistocene.

Conclusion

This was an excellent meeting that successfully combined issues relating to events that had occurred over differing time scales with topics that spanned diverse sea-level research interests. The organisers had not only produced a varied itinerary that was both interesting and stimulating, but they had done it in ideal surroundings and had somehow ensured perfect weather for the field excursions.

Wil Marshall
Department of Geography
University of Plymouth

DRIFT DEPOSITS AT THE 'RED LION', STIFFKEY, NORTH NORFOLK

Background and rationale

When an ice sheet entered north Norfolk during the Late Devensian (Dimlington Stadial) interval, the region already possessed a cover of glacial deposits. The drift that is exposed in the ~50 m-long, west-east oriented face behind the 'Red Lion' public house, Stiffkey (TF 96844394; ~14 m O.D.), consists of interstratified reddish brown diamicton (cf. the Devensian Hunstanton Till = Holkham Member, Hunstanton Formation [Bowen, 1999]) and light-coloured highly calcareous diamictons (cf. the 'Anglian' Marly Drift = Weybourne Town Member, Lowestoft Formation [Bowen, 1999]). It was felt that by unravelling this unusual Quaternary sequence light might subsequently be thrown on the dynamics and extent of the Devensian ice in the district.

The Quaternary Research Fund grant allowed the recipients to spend two days at the section, during which time the exposure was cleaned, surveyed, logged and sampled.

Results

The 'Red Lion' succession is made up of banded or laminated diamictons (and other minor elements) with a maximum thickness >4 m; these rest on an easterly-inclined Upper Chalk bedrock surface. Three principal diamictons are immediately recognisable on the basis of field-state Munsell colour: (a) a 5YR 4/4 (reddish brown) facies, a colour that has been regarded as diagnostic of the Hunstanton Till; (b) a 10YR 5.5/6 (yellowish brown-brownish yellow) facies; and (c) a 2.5Y 6/4 (light yellowish brown) facies.

Bedrock and drift show signs of glacial disturbance. The Chalk has been disrupted to a depth of several decimetres, and clasts have been forced up to ~0.08 m into the broken material. (Shearing of a thin surface layer of bedrock was noted when the site was exposed briefly in 1990.) The diamicton sequence is folded and has become partially repeated. Mesofabrics (declination only) measured on oriented blocks of the 5YR and 10YR facies suggest that the material was deposited by ice advancing from the north-northeast and northeast.

The calcium carbonate-equivalent content of the matrix (<2.00 mm fraction) of the 5YR facies (~15%) is somewhat high for the Hunstanton Till (Gale and Hoare, unpublished data). This deposit almost invariably occupies a near-

surface position within northwest Norfolk and is consequently frequently strongly weathered; but it has been protected by superjacent, highly calcareous, diamictons at the 'Red Lion'. The carbonate content of the 10YR facies matrix (~32%) far exceeds that of the Hunstanton Till, but lies at the lower end of the range recorded for the Marly Drift (Banham *et al.*, 1975). The 5.60–8.00 mm fraction of the 5YR facies consists of ~51% chalk clasts; ~40% of the gravels in the same fraction of the 10YR facies are of chalk. Small, far-travelled erratics may be found with considerable ease in both facies.

Non-opaque heavy mineral data from the fine sand (63 μm –0.250 mm) fractions of two samples of the 5YR facies and one of the 2.5Y facies, when expressed as epidote/zircon and amphibole/pyroxene ratios, and plotted one against the other, lie within the field occupied by the Hunstanton Till and the Skipsea Till of Holderness (Madgett, 1975). The heavy mineralogy of these samples is similar in some respects to the Withernsea Till of Holderness and the North Sea Drift (Banham's [1970a, b, c] First, Second and Third Cromer Tills), but significant differences preclude any suggestion of a correlation.

Significance of the work

The intimate relationship of the three 'Red Lion' diamictons suggests that they were deposited at the same time as each other. Their position immediately above a heavily glaciated Chalk surface is regarded as evidence of accumulation as tills beneath a land-based ice sheet. All the glacial events identified at the site probably occurred during a single episode.

The 10YR till facies, notwithstanding its Marly Drift-like colour, possesses a heavy mineral signature indistinguishable from that of the Hunstanton and Skipsea Tills. It is interpreted as a fresh deposit, rather than one reworked from older glacial material. The Hunstanton ice sheet appears to have been responsible for a number of till facies, not only the 'characteristic' reddish brown deposit. The extent of the Hunstanton Glaciation may be underestimated if reliance is placed on Straw's (1960) strategy of mapping reddish brown till and related 'drift soils'.

In north Norfolk, as elsewhere, many Quaternary problems can be solved only by a multidisciplinary approach. A sound knowledge of the stratigraphy, matrix colour, clast lithological content, sand and clay mineralogy of the 'Red Lion' deposits is required if work such as that based on mineral magnetic data (Andrews *et al.*, 2002) and on isolated borehole sequences (Brand *et al.*, 2002) is to have real meaning.

Acknowledgements

The authors are indebted to Mr Matthew Rees of the 'Red Lion' for his tolerance and interest in the work; to Dr Paul Madgett for undertaking the heavy mineral analyses; and to the QRA for the award from their Quaternary Research Fund.

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Peter G. Hoare
26 Victoria Street
Ely
Cambridgeshire CB7 4BL
E-mail: P.G.Hoare@tesco.net

E. Rodger Connell
Department of Geography and Environment
University of Aberdeen
Elphinstone Road
Aberdeen AB24 3UF

RELATIVE SEA-LEVEL CHANGES AND NEOTECTONICS SINCE THE LAST GLACIAL MAXIMUM AROUND THE BERING GLACIER, ALASKA

Field campaign 2002

The objective was to conduct preliminary field surveys and collect sediments that would potentially enable reconstruction of relative sea-level (RSL) changes since the Last Glacial Maximum, neotectonic land movements and the relationship between RSL change and changes in the Bering Glacier. The Bering Glacier area underwent differential uplift, up to ~3m, during the 1964 earthquake, which represents the co-seismic element of the present earthquake deformation cycle. Superimposed upon this and preceding earthquake deformation cycles are regional-scale variations in RSL. These are controlled by global eustatic ocean volume changes, the glacio-isostatic response to ice volume changes since the Last Glacial Maximum through to the Late Holocene, and potentially local effects from surges.

We were in the Alaska Bureau for Land Management camp August 10th – 16th but bad weather limited helicopter flights in the first three days so we had to curtail some of our objectives. Following reconnaissance flights we concentrated sampling at three sites, returning samples to Durham for diatom analysis.

Tashalich Arm of Vitus Lake – ancient forest site

We observed a main peat layer (cf. Wiles *et al.*, 1999) with tree stumps, close to lake level, but the stratigraphy indicates it was not *in situ*. The main peat lies directly upon a diamicton with other peat layers seen a few metres above in the cliff section. Samples were taken from selected horizons for laboratory analyses to establish whether the sediments formed in a glacio-marine, glacio-lacustrine or a terrestrial context. Two samples from silt horizons with rooted trees, exposed in the cliff section contained no diatoms and so we cannot offer more insight into the environmental context of the site. Numerous subtidal marine mollusc shells were found, again in sequences not *in situ*, in sediments on the top of the cliff, within a few 100 m of the ice front of the Bering Glacier Main Lobe. These indicate overrunning of older sub-tidal sediments. We aim to look for possible sources of these older sediments during our 2003 visit.

The most promising sediment sequences found are herbaceous peat layers intercalated in silt, forming “peat-silt couplets”. These are lithologically similar to those seen in the Upper Cook Inlet, Alaska (Shennan *et al.*, 1999; Zong *et al.*, 2003) and estuaries in Washington and Oregon (Shennan *et al.*, 1996, 1998), where they indicate co-seismic land- and sea-level changes. At the

ancient forest site such sediments occur only as blocks of eroded peat and silt within recent outwash or on the lake shore. None were found *in situ* but three were sampled for trial microfossil analysis. All three samples are rich in pollen (not analysed in detail to date) and have frequent fragments of diatoms, mainly *Pinnularia* spp., but only one whole frustule, a *Cymbella* species. Because of the poor preservation and low abundance no reliable environmental interpretation is possible. Both *Pinnularia* and *Cymbella* species exist in predominantly freshwater or low salinity environments.

Tashalich Arm – East shore, opposite ancient forest site

Large blocks (>5 m long, up to 1.5 m thick) of reworked peat occur in a shallow stream channel at and just above lake level. There is no clear evidence to indicate that any are *in situ*. One section shows multiple herbaceous peat layers 5-10 cm thick with intercalated grey silt layers. Some boundaries are transitional, over more than 1 cm, others are sharp. Herbaceous roots pass from the peat into the silts and organic silt horizons, indicating that the clastic layers are not later intrusions during the reworking process. The lithology is very similar to those seen from the Upper Cook Inlet and estuaries in Washington and Oregon (see above) but we did not concentrate on the site because of the lack of *in situ* deposits. A sample of an intercalated silt contains small diatom fragments. This site deserves further analysis if a section of *in situ* sediment becomes exposed.

South shore of Narrow Channel

A ~10 m high section revealed a horizontally consistent series of nine interbedded thin (2-10 mm) organic layers within clastic sediments of varying grain size, including beds with ripple marks and mud drapes. The section is clearly *in situ* and represents repeated episodes of changing water level. Sharp boundaries to the organic layers indicate probable rapid changes. In order to establish whether the sediments formed in a glacio-marine or glacio-lacustrine context we took monolith samples across the nine organic layers and adjacent clastic sediments for subsequent analysis. In more than 50 separate samples analysed only small diatom fragments were found in one sample, from the highest and youngest organic layer samples, ~3.75 m above lake level. The fragments are all of marine or brackish water *Coscinodiscus* species.

This evidence is both tantalising and inconclusive. We cannot place any reliance on just a few diatom fragments, yet the implications of the stratigraphic changes reflecting a rapid change in water level while there is tidal input, i.e. sea-level controlled, are very significant in terms of reconstructing sea-level changes and land movements from earthquakes. With the absence of diatoms from the rest of the sediments in this section we cannot see how we can resolve this further.

We plan to spend longer at camp this year in order to sample further stratigraphic sections but also to undertake a study of the distribution of diatoms in the contemporary sedimentary environments of Vitus Lake. This is essential to better understand the preservation potential of different fossil environments.

Acknowledgements

The QRA award supported fieldwork in 2002. This work was also supported by the Alaska Bureau for Land Management, the British Geomorphological Research Group and the Dudley Stamp Memorial Fund.

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Ian Shennan and Sarah Hamilton
Environmental Research Centre
Department of Geography
University of Durham
Durham DH1 3LE
United Kingdom

THE CULMINATION OF THE MAIN POSTGLACIAL TRANSGRESSION IN EAST FLANDERS MOSS, SOUTH EAST SCOTLAND

Background and Rationale

East Flanders Moss lies at the western limit of the Forth valley lowlands. This lowland peat bog overlies sequences of early Holocene estuarine sediments and estuarine sediments associated with the Main Postglacial Transgression. The Forth valley in south east Scotland has long been a focus for relative sea level (RSL) change studies, with key elements of the buried stratigraphy being investigated by J.B. Sissons and his co-workers between 1965 and 1993. Observations from the western Forth valley, in particular the RSL curves of Sissons and Brooks (1971) and Robinson (1993), are frequently used as a basis for regional scale extrapolations of Holocene RSL trends (e.g. Smith *et al.*, 2000), and to constrain rheological models of postglacial isostatic adjustment (e.g. Shennan *et al.*, 2002).

However, these existing observations have relied on utilising spatially varied sites to obtain an altitudinal range of dated points for a RSL curve. Sissons and Brooks (1971) use four different locations (over an 8 km down-valley distance), and Robinson (1993) used four sites (covering a 2 km down- valley distance). The western Forth valley lies close to the centre of glacio-isostatic uplift, and as a near-field site, the resulting Holocene RSL variation is of a high magnitude. Whilst this ensures RSL change is easily detectable from altitudinally distinct stratigraphies, RSL histories compiled from a spread of down-valley localities are likely to contain potential inaccuracies due to differential postglacial uplift. Secondly, the majority of sites previously used to establish Holocene RSL change lie close to the River Forth and it is thought that lithological transition between estuarine and terrestrial sediments may have been influenced by channel migration as well as RSL change. Thirdly, pollen analysis has traditionally been employed over lithological contacts as a check for continuity in deposition (e.g. Sissons and Brooks, 1971), and this method has inherent problems. In the case of Robinson (1993), although utilising diatoms to track changes in salinity, two of the Holocene index points for her RSL curve used did not have any microfossil support. New research at East Flanders Moss was devised to attempt to overcome these three areas of potential inaccuracy, with the aim of contributing towards the development of a more accurate Holocene RSL record for the western Forth valley.

Stratigraphic context

The interpretation of the key elements of the buried stratigraphy of the western Forth valley is summarised in Smith and Holloway (2000). At East Flanders Moss, its northern periphery has been shown to overlie the estuarine silts

('carse') associated with the Main Postglacial Transgression. Away from the edge of the Moss, buried carse sediments are absent, and deep thicknesses of peat (up to 6.5 m) have been traced directly overlying older early Holocene estuarine sediments. It has been inferred that peat accumulation rates in the mid-Holocene must have outstripped the rate of RSL rise associated with the Main Postglacial Transgression, thus ensuring that carse sediments failed to completely inundate the site.

Preliminary stratigraphical work demonstrated that the estuarine carse sediments can be shown to wedge into the peat island zone at East Flanders Moss from north to south, i.e. perpendicular to the valley axis and parallel to expected postglacial uplift patterns (Smith and Holloway, 2000). Smith and Holloway (2000) suggested that wedge features on the northern edge of the Moss appeared to be distinct from the meandering palaeochannel of the nearest water course (the Goodie Water).

In September 2002 a Quaternary Research Fund grant enabled this area to be revisited in order to investigate the assertion that the carse wedge feature at East Flanders Moss could provide a single spatially restricted area in a near-field location, from which a range of age-altitude index points spanning RSL change during the Main Postglacial Transgression could be obtained.

Results

A carse wedge feature extending for 0.45 km north-south into East Flanders Moss was identified through 11 boreholes, levelled to Ordnance Datum Newlyn. It was decided that in order to avoid the possibility of obtaining overlapping radiocarbon ages for the potential RSL index points, peat-carse contacts should be collected at points across the lower and upper surface of the carse wedge feature where altitudinal differences were greatest. The lowest part of the wedge was sampled at 9.90 m OD in order to provide an age-altitude point charting the inception of the Main Postglacial Transgression at the site. The highest part of the carse wedge was sampled (at 13.30 m OD) in order to chart the culmination of the Main Postglacial Transgression at the site. A final sample was taken at 11.4 m OD from the feather-edge of the wedge feature in order to provide an intermediary age-altitude data point. Multiple samples of contacts were taken in the field using a Stitz percussion corer. Currently these contact samples are in frozen storage prior to radiocarbon dating. High-resolution diatom biostratigraphy is planned in order to define the likely tidal context for the dating samples, in addition to providing an assessment of the continuity of sedimentation.

Significance

This work represents a first attempt to produce a refined understanding of the RSL during the Main Postglacial Transgression for the western Forth valley

following recognition that inaccuracies are likely in previous RSL curves for the area. When age-altitude reconstructions are obtained (an application to the NERC Radiocarbon Committee to date these changes is planned for the autumn of 2003) it is hoped that following the adoption of the above methodology for site selection, an attempt can now be made at producing a more refined RSL curve for the Main Postglacial Transgression in the western Forth valley. New data will then allow for previous RSL curves to be verified (or otherwise) with the overall aim that regional understanding of RSL change for this period can be improved, and that a more accurate reconstruction of RSL can be developed against which rheologically-based RSL models can be reliably compared.

Acknowledgements

The Beetons of Wards of Goodie Farm are thanked for providing access to East Flanders Moss. David Picket (Reserve Officer, Scottish Natural Heritage) is thanked for his help in the field and allowing permission to work on the SSSI East Flanders Moss site. Lewis Holloway is thanked for his assistance with this fieldwork. The Quaternary Research Association is thanked for a research grant which enabled the fieldwork to be undertaken.

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Dr. Lucy K. Holloway
30 Newcombe Road
Coventry, CV5 6NN

Dr. Sue Dawson
Honorary Research Fellow
Centre for Quaternary Science
School of Science and Environment
Coventry University, CV1 5FB
E-mail: sue_dawson55@hotmail.com

EXTENDING THE PALYNOLOGICAL RECORD IN SOUTH WEST ENGLAND: DOZMARY POOL, BODMIN MOOR, CORNWALL

Introduction

The palynological record from Dozmary Pool mire (Figure 1) has been well documented by Brown (1977) and by Conolly and Godwin (1950). Campbell (1998) states that "Organic deposits at Dozmary Pool preserve the most complete Holocene pollen sequence yet known from Bodmin Moor and provide a key record for the vegetational history of South West England for this

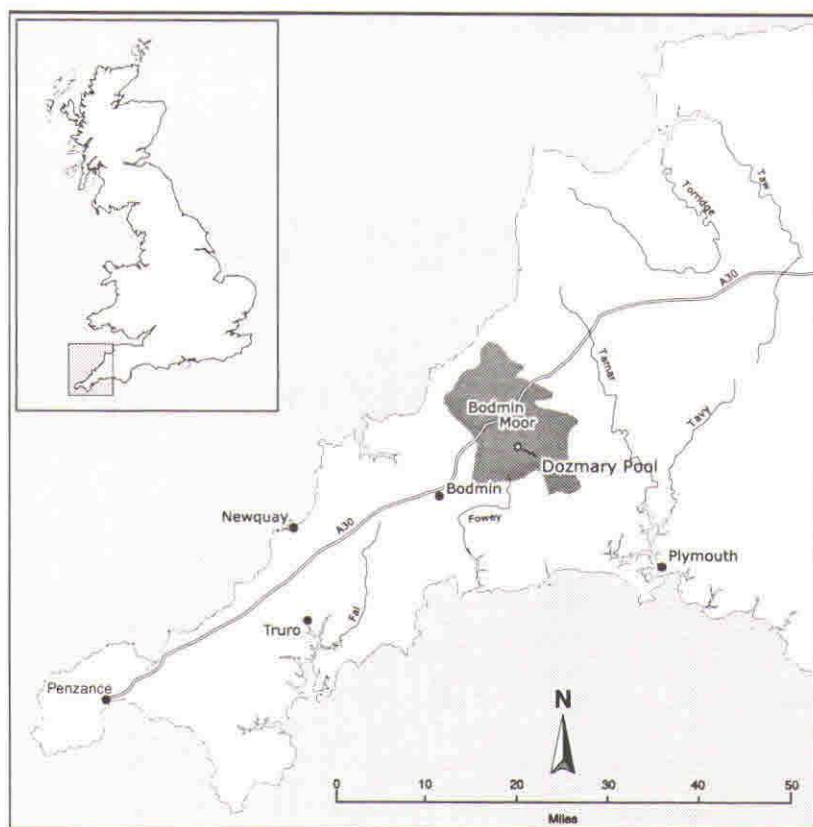


Figure 1. Location map of Dozmary Pool.

period". Since this time Gearey *et al.* (2000a, 2000b) have provided further data on Holocene vegetation history for several other areas of the moor. However, there are no organic deposits known from the region which date from the Last Glacial Maximum (LGM) to the Lateglacial (Scourse, 1998). Given the fact that the glacial limits of the LGM lie to the north, it is possible that sediments containing pollen records exist in the few natural basins in the region, such as Dozmary Pool.

Recently, deep coring using a percussion gouge auger at a central point on the mire, revealed the presence of limnic, clay-rich sediments beneath the peat. Examination of these sediments confirmed the presence of various pollen taxa that were indicative of a pre-Holocene flora. Continuity of deposition could not be assumed however, and it was necessary to support the findings of pollen analysis by dating the basal sediments. The lower section of sediment recovered (2.65 m to 6.20 m) is predominantly minerogenic in nature and contains limited amounts of organic carbon; it was therefore decided that the single grain OSL method was the most feasible means of obtaining a range finder date.

Method

A 5.85 m core was removed from the central part of the mire, in 1 m sections, during 2002. The core was removed using a percussion gouge auger, the head of which was lined with an opaque plastic tube so that the sample would not be exposed to light. The exposed ends of the core sections were each covered, upon retrieval from the ground, with triple layers of black plastic to protect the sediments from light contamination and the cores were then removed to cold storage. The lower 20 cm section of the deepest core was removed in controlled conditions, and this section was taken to the Oxford Luminescence Laboratories. A sub-sample (5.70–5.75 m) was removed from the core section in the Oxford laboratory for analysis. Processing by Drs. E. Rhodes and J-L. Schwenninger removed fine grains from the sample by sieving; silica and feldspar were removed by treatment with HF before the remaining quartz grains were analysed using the single grain OSL reader (Duller *et al.*, 1999).

Results

The calculated age for the bulk sample (5.70–5.75 m) was reported as being 23.9 ± 3.5 ka. This date confirms the pre-Holocene nature of the limnic sediments beneath the peat at Dozmary Pool mire.

The pollen diagram illustrating selected taxa suggests the existence of variable vegetation cover within the vicinity of the pool over the period between the dated horizon and the Holocene (Figure 2). The range finder date obtained suggests rapid sediment deposition and that most of the pollen record dates

Core Dz2

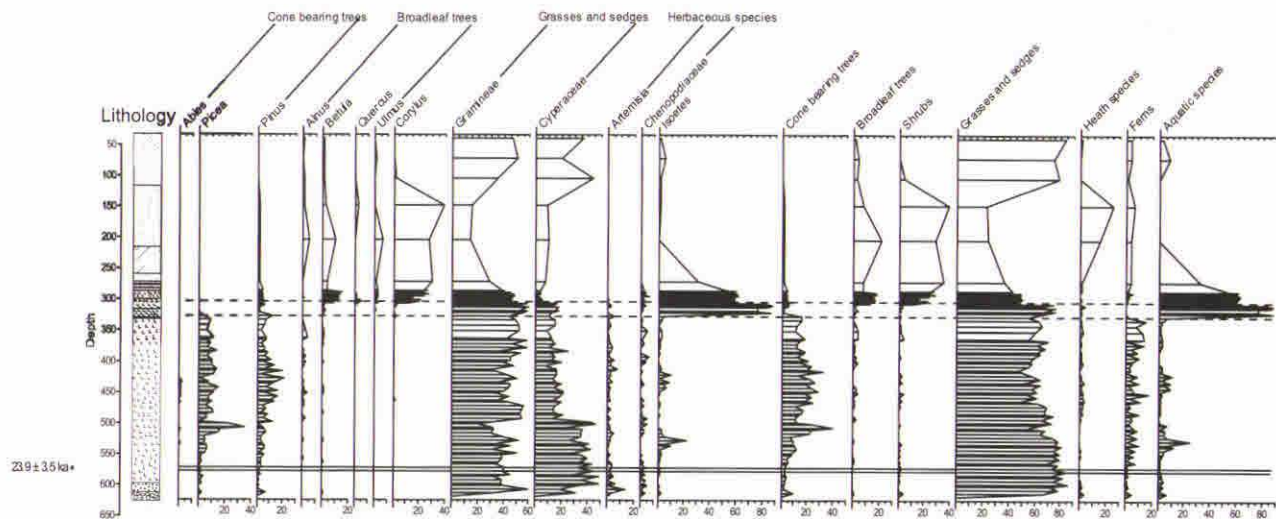


Figure 2. Pollen diagram illustrating selected taxa.

from the LGM to the Lateglacial. Some of the pollen taxa identified may represent long-distance transportation, but if the sediment age is correct, the diagram raises some interesting questions about the vegetation history of South West England during the LGM.

Conclusion

The discovery of a long palynological record at Dozmary Pool mire will add to current knowledge of a period for which there are few data within the South West of England. The OSL date provided by the QRA Quaternary Research Fund suggests that the palaeoenvironmental record at Dozmary Pool mire may extend throughout the period 24,000 to 13,000 BP, the full glacial phase of the Late Devensian.

Further work will be necessary to provide a secure chronology for the Dozmary pollen record. In particular, additional age estimates are needed throughout the profile. As the OSL range finder date provided has been shown to be within the radiocarbon range, ^{14}C AMS ages may be possible if sufficient pollen and organic fragments can be successfully removed from the sediments by density separation.

Acknowledgements

The Quaternary Research Fund award from the QRA contributed towards the cost of an OSL range finder date and is gratefully acknowledged together with an award from the School of Geography, University of Plymouth. Thanks are also extended to English Nature and the landowners for their permission to work at Dozmary Pool mire. Friends and colleagues are thanked for advice, support and their considerable contribution during coring and surveying.

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**Ann Kelly
School of Geography
University of Plymouth
Drake Circus
Plymouth PL4 8AA**

New Research Workers Award Scheme

THERMAL PROPERTIES OF SUPRAGLACIAL DEBRIS, NGOZUMPA GLACIER, NEPAL

Background

Improved estimates of ablation rates of debris-covered glaciers in the Himalayas are needed for: (1) long-term hydrological management (Nakawo and Rana, 1999) and (2) predicting the future growth of supraglacial lakes associated with debris-covered glaciers. Such lakes pose a significant threat in mountain regions where glacier lake outburst floods are becoming increasingly common (Richardson and Reynolds, 2000a).

Due to the difficulties of obtaining and extrapolating direct ablation measurements over debris-covered glaciers, mathematical modelling of melt rate from meteorological variables is commonly employed (e.g. Nakawo and Young, 1982). Such models assume that heat transfer is conductive only, and that conduction is determined by a temporally stable temperature gradient (Conway and Rasmussen, 2000), with the average heat flux, Q_c , given by:

$$Q_c = \frac{\delta q}{\delta t} = k \frac{\delta \bar{T}}{\delta z}$$

Where q is the heat flux, t , time, k is the conductivity of the medium, \bar{T} is the mean debris temperature and z is the vertical distance.

Previous work (also funded by the QRA) suggested that over short time scales and within particular debris fabrics, the effects of both convection and freeze-thaw processes may be significant (Nicholson, 2002). Furthermore, existing data of supraglacial debris temperatures in the Himalayas covers limited time periods (Conway and Rasmussen, 2000) and uncertainty remains about how the Indian monsoon affects heat flux and melt rate beneath debris covers.

Aims and methods

This research aimed to use debris temperatures and concurrent meteorological data to assess the stability of debris temperatures and potential significance of non-conductive processes over a full annual cycle.

Debris temperatures were recorded using TinyTag loggers attached to thermistors emplaced in typical supraglacial diamicton at intervals to a depth of 0.8 m. Meteorological measurements were made using a Kipp & Zonen CC48 logger.

The sampled site was at ~4,800 m.a.s.l on the Ngozumpa Glacier, in the eastern Nepalese Himalayas. Continuous debris temperatures were recorded from November 2001 to October 2002, and meteorological data spans the same period, although this record is incomplete due to power failures under cold conditions.

Results

The thermal regime of the debris responds rapidly to changes in both surface conditions and ambient meteorological conditions. Snow-covered periods, identified in Figure 1(b) where surface temperature shows no diurnal fluctuations (mid January, and 2 shorter periods in early February and March), cause rapid cooling throughout the debris, with a very short lag time.

The ablation season can be identified as the period through which daily mean vertical temperature gradient is positive. This becomes fully established in the middle of May, and continues until early October. The winter season, during

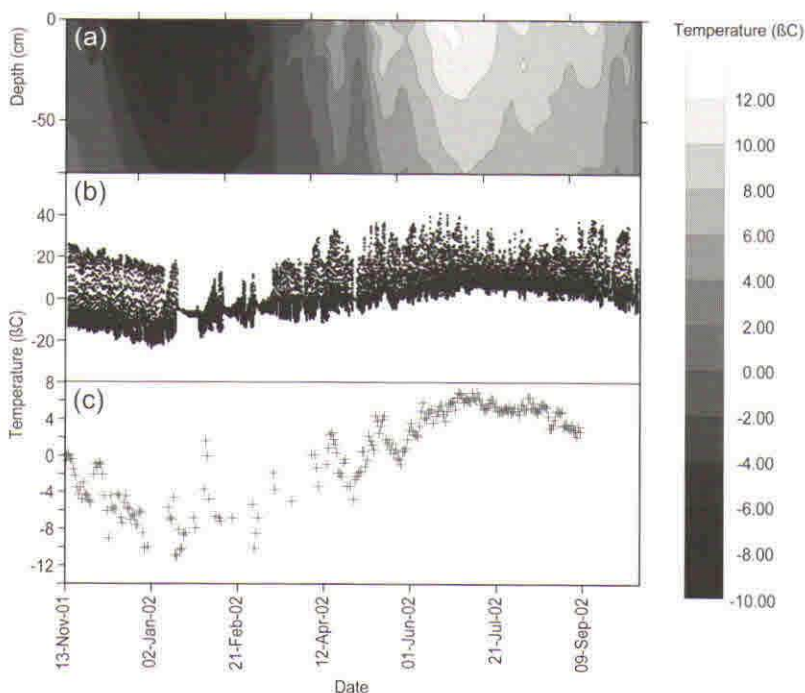


Figure 1. (a) Debris surface temperature, (b) mean daily air temperature.

which the mean vertical temperature gradient is negative, spanned a shorter period from November until early February (possibly also the missing section of late October).

Within both of these stable seasons the mean daily temperature profiles approximate linear gradients, with R^2 values >0.95 . Given that on a day-to-day basis in these established seasons the temperature of the debris can be assumed to be temporally stable, this linearity is indicative of dominant conductive heat flux.

In the seasonal transition period (mid February to mid May) the gradient of mean temperature profiles deviates from linear due to progressive warming of the debris layer. In the daily temperature profiles a zone of latent heat exchange can be identified penetrating onto the debris from the surface. During this time calculations of heat flux through the layer cannot be made on the basis of a stable conductive thermal gradient. Taking mean debris temperatures over the duration of this transitional period to be representative of overall heat flux regime at a coarse scale, the mean profile gradient is slightly positive suggesting that over this period melt may be occurring, but it is likely to be negligible.

Non-linearity of daily mean temperatures also occurs periodically through the monsoon. This may be due to advection of heat by infiltrating precipitation. However, as no precipitation data is available for the site, due to failure of the rain gauge, this interpretation is not conclusive.

The data show that the transition to an ablation gradient begins during springtime and is established by the onset of the monsoon in May, and suggest that periods of marked temperature transition in the debris layer are more complex than represented in models of conductive heat flux.

Acknowledgements

Fieldwork was funded by a QRA New Workers Award, the RSGS, The American Alpine Club and The School of Geography and Geosciences, St Andrews University. Without this support this work would not be possible. Dr Richard Bates is thanked for his assistance and good company in the field.

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Lindsey Nicholson
School of Geography and Geosciences
University of St Andrews
Fife, KY16 9AL
Email: lin@st-and.ac.uk

FIVE PEATLANDS IN SOUTHEAST ALASKA

Southeast Alaska experiences a mild, temperate climate, ameliorated by the warm North Pacific current. A mild climate with high rainfall provides ideal conditions for peat-bog growth, and bogs are a major landform throughout the region. As part of a field visit to southeast Alaska, partly funded by the QRA, five peatland sites were visited and cored (Figure 1). The sites used are briefly described in this report.

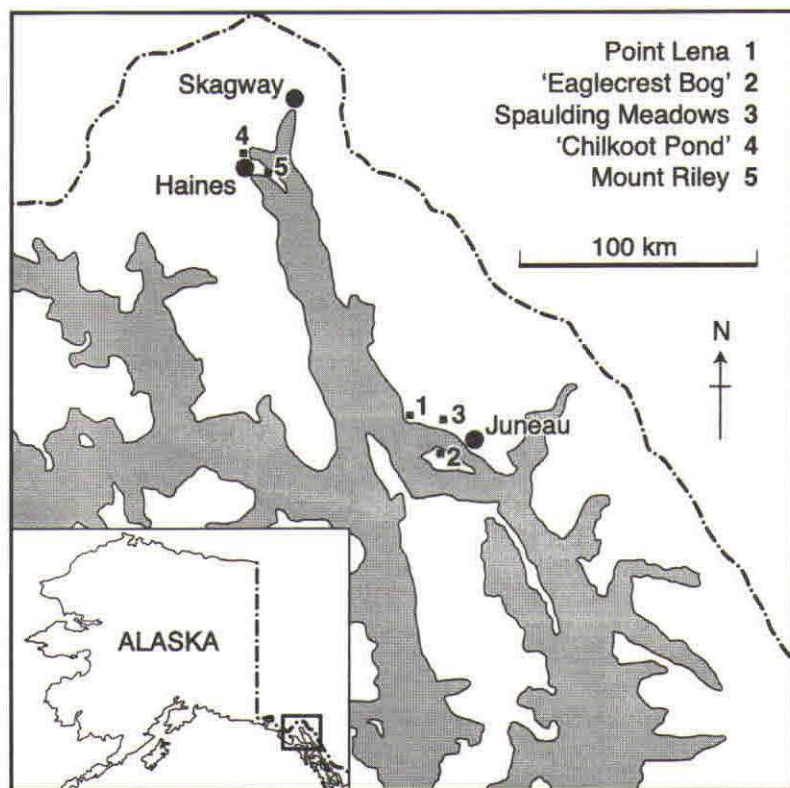


Figure 1. Location of five peatland sites in the Juneau region of Southeast Alaska.

1. Point Lena

This site has been previously described by Dachnowski-Stokes (1942, referred to as 'Lena Beach'). The site lies at $58^{\circ}23'08''\text{N}$ $134^{\circ}44'39''\text{W}$ in a small area of flatter land between the Coast Mountains and the sea (Favorite Channel) adjacent to Point Lena. Miller (1975) mapped the site as part of his more general

mapping of the surficial geology of the Juneau region. The site is a raised bog approximately 200 m wide by 300 m long, noticeably domed in profile and clearly ombrotrophic. Vegetation of the site consists of *Empetrum nigrum* with *Eriophorum* spp., *Oxycoccus microcarpus*, *Cornus Canadensis*, *Cladonia portentosa* and extensive *Sphagnum* carpets. Small *Pinus contorta* and small ponds occur in localised areas of the bog. A 530 cm long core was extracted from near the centre of the bog. Tephra ashing revealed four micro-tephra layers at 39, 100, 136 and 465 cm.

2. Eaglecrest Bog

This site lies around 58°20'00"N 134°33'36"W on the western side of the valley of Fish Creek towards the north end of Douglas Island. The site has been mapped by Miller (1975) and is approximately 700m long by 300 m at its widest. The Fish Creek road cuts across the northern end of the site. The bog has a slight slope to the north and little evidence of convexity in profile. This bog probably represents a blanket bog or 'sloping muskeg' in North American terminology (Rigg, 1937). The maximum depth of peat found at the site was 375 cm towards the Northwest of the bog and a core was extracted from this location. Tephra ashing showed three significant micro-tephra layers at 32, 100 and 162 cm.

3. Spaulding meadows

This site lies around 59°24'01"N 134°39'40"W in the valley of the Waydelich Creek above Auke Bay on the northern shore of Stephens Passage. The site is included in the map of Miller (1975) and is approximately 700 m long and up to 300 m wide. The site is at an elevation of about 250 m and is on a distinct gradient; it may not be entirely ombrotrophic. A 206 cm long core was taken from the southern end of the peatland. A single micro-tephra layer was found at 26 cm depth.

4. Chilkoot pond

This site lies at 59°19'20"N 135°33'50"W on the isthmus of land dividing Lutak Inlet from Chilkoot Lake in the Haines region. The site is a small bog (less than 100 m long) occupying a clearing in the dense coniferous woodland. A single large pond covers much of the area; the peat deposits may represent infilling of this pond. Peat is relatively shallow; a core was taken from the maximum depth at 185 cm. Two microtephra layers were found, at 33 cm and at the base of the core, 184 cm.

5. Mount Riley

This site is at 59°11'23"N 135°23'04"W very close to the top of Mt Riley (1760ft / 536m) on the Chilkat peninsula. A small muskeg occupies a shallow

basin just to the north of the summit. A 220 cm core was taken from the deepest part of the bog towards the eastern side. This site is also within 4 km of Lily Lake, from which a Late Quaternary vegetation history has been reconstructed using palynology (Cwynar, 1990). Three microtephra layers were found at 32, 146 and 190 cm.

Five peatland sites were identified by this fieldwork. All of these sites are undisturbed, *Sphagnum*-dominated peatlands and as such are suitable for palaeoecological study. From each of these sites, a complete peat core was extracted and analysis of these cores has revealed thirteen individual tephra isochrones, representing at least four different tephra. None of these tephra has been previously recorded from this area. Electron microprobe analysis will be used to determine the geochemical composition of these tephra and their source eruptions. Continuing work will examine the palaeoecological record across these tephra layers as a means of investigating the environmental impacts of these eruptions.

Acknowledgements

This work was carried out as part of a PhD studentship at Queen Mary, University of London, funded by a college studentship and supervised by Dr Jeff Blackford. Fieldwork funding was provided by grants from the Quaternary Research Association, Dudley Stamp Memorial Trust, Knowle Hill School fund and University of London Central Research Fund. Dr Cathy Connor of the University of Alaska Southeast provided valuable advice on field sites and methods.

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Richard Payne
Department of Geography
Queen Mary, University of London
Mile End Road
London E1 4NS
E-mail r.j.payne@qmul.ac.uk

A HIGH-RESOLUTION RECORD OF CLIMATE CHANGE IN ESTONIA OVER THE LAST *c.* 2000 YEARS FROM FOUR RAISED MIRES

Introduction

Ombrotrophic peat bogs provide an ideal repository for reconstructing and investigating past climate change. Owing to the nature of ombrogenous peat growth, the proxy data can be interpreted as representative of bog water-table position, which in turn is controlled by effective rates of precipitation and evapotranspiration. The influence of peat-based palaeoclimatic studies is evident from as early as 1876, when the work of Blytt and then Sernander (1908) and Weber (1910) resulted in the five-fold division of the post-glacial period. More recently, peat studies have focused on high-resolution, multi-proxy research, generally over shorter timescales and investigating possible links between decadal, centennial and millennial climate changes and possible forcing mechanisms (van Geel, 1978; Hughes *et al.*, 2000; Chambers and Blackford, 2001; Mauquoy *et al.*, 2002).

Aims

The principal aim of this project is to provide a high-resolution record of climate change in the Baltic region over the last *c.* 2000 years from four raised mires.

Methodology

The project adopts a multi-proxy approach using a range of established and relatively new palaeoecological techniques. Fieldwork was completed in Estonia at two sites, working in collaboration with Dr. Edgar Karofeld of the Tallinn Institute. High-resolution 1 cm contiguous sampling of the cores has been undertaken, with further sub-sampling for peat humification, plant macrofossil analysis and at a coarser resolution testate amoebae analysis. The top of each core will be dated using Spheroidal Carbonaceous Particle (SCP) analysis, whilst a series of closely spaced ^{14}C wiggle-matched dates will be used to determine the age of possible climate changes recorded in the peat stratigraphy.

Results

Preliminary results demonstrate a good correspondence between the proxy datasets. Furthermore, there is some evidence in the humification and testate amoebae proxy data to suggest that changes in hydrology may be synchronous between mires. However, it should be noted that without a secure chronological framework (AMS dates are awaited) it is impossible to validate the contemporaneity of inter-site proxy data. Nevertheless, at each site several marked fluctuations in humification transmission values are broadly synchronous

with changes in the plant macrofossil assemblage. Testate amoebae analysis has provided an additional independent line of supporting evidence, suggesting that the mire may be responding to regional/hemispherical climate change.

Acknowledgements

Particular thanks are due to Prof. Frank Chambers for invaluable advice and support and to Dr John Daniels for laboratory and technical help. Fieldwork assistance from Prof Atte Korhola and Dr Edgar Karofeld was much appreciated. The QRA grant contributed significantly towards travel and fieldwork expenditure.

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Garry Bosworth
Geography and Environmental Management Research Unit (GEMRU)
University of Gloucestershire
Francis Close Hall
Swindon Road
Cheltenham GL50 4AZ
E-mail: gbosworth@glos.ac.uk

OPTICALLY-STIMULATED LUMINESCENCE DATING OF PLATEAU SURFACE EROSION AND WINDBLOWN SAND RESEDIMENTATION IN THE HIGHLANDS OF SCOTLAND

Background

This research investigates the causes and timing of episodes of catastrophic erosion on plateau surfaces in the Scottish Highlands. Windblown sand deposits are common on high plateaux and valley heads on mountains in the Highlands of Scotland, particularly on lithologies that weather readily under freeze-thaw action to produce abundant sand (such as granite, Torridon Sandstone and siliceous schist) (Ballantyne and Harris, 1994; Ballantyne, 1998). On many high plateaux, however, widespread stripping of sand cover has occurred, exposing the underlying sterile regolith and redepositing sand on lee slopes. The stratigraphy of aeolian sand deposits on such lee slopes comprises two units (Figure 1): a lower weathered unit, and a fresh upper unit derived from stripping of sand deposits from plateau areas upwind (Ballantyne and Whittington, 1987). Together, the two units are up to 4 m thick. Radiocarbon dating has shown that the older unit has accumulated progressively throughout much of the Holocene, but the upper unit contains negligible concentrations of

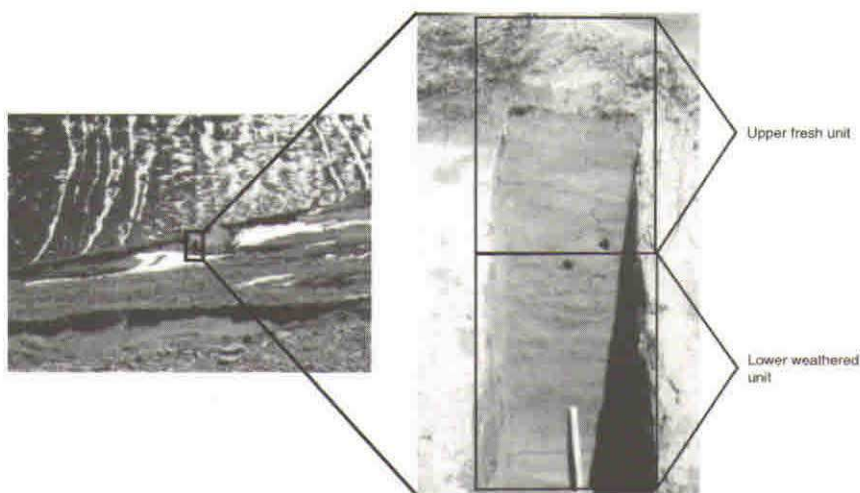


Figure 1. Aeolian sand deposit stratigraphy showing the upper fresh sand unit and the lower weathered sand unit on the lee slope of An Teallach. The holes represent the locations from which samples were taken. Section height = c.2 m.

organic sediments and cannot be dated by this method. The aim of this research is to determine the age and cause of the accelerated erosion of sand cover from plateau areas implied by the accumulation of the upper sand unit on the crests of the lee slopes. Optically stimulated luminescence (OSL) dating will provide an age bracket for the onset of sand reworking and the timing of associated plateau-surface erosion at An Teallach and Ben Mór Coigach. It is hypothesised that erosion of the plateau sands was triggered either by extreme storm events (for example during the Little Ice Age of the 16th–19th centuries AD) or by the introduction of sheep grazing on high plateaux during the period of Norse settlement in NW Scotland, or by much more recent overgrazing of plateau vegetation.

Preliminary Results

Preliminary results (based on four samples from An Teallach and four from Ben Mór Coigach) suggest that erosion of the two plateaux occurred at markedly different times, *c.* 250 yrs BP on An Teallach and *c.* 1000 yrs BP on Ben Mór Coigach. A deteriorating climate *c.* 250 yrs BP and several historical accounts of snow on the high mountains all year round in the 18th Century (Mitchell, 1998), which would have prevented grazing stock from using the montane zone, suggests that the erosion on An Teallach was the result of a more severe climate during the Little Ice Age. However, on Ben Mór Coigach erosion appears to have been much earlier and was either caused by climatic deterioration or the introduction of grazing stock by the Norse. Given the present scarcity of evidence for Norse farming practices and locations, this hypothesis cannot be ruled out as yet. However, evidence for a marked deterioration in the climate *c.* 1000 yrs BP is emerging. Barber *et al.* (2000) have replicated proxy-climate signals from two widely separated peat bogs, a lowland raised bog in Northern Ireland and a montane blanket bog in the Cairngorms. Their results show that the two bogs respond synchronously to climatic forcing with both indicating a marked deterioration in the climate *c.* 1000 yrs BP as well as at the time of the Little Ice Age. Therefore, if the climatic deterioration was widespread across Scotland *c.* 1000 yrs BP it may have initiated sand stripping on Ben Mór Coigach.

Significance and Future Work

These initial results imply that widespread erosion of plateau sands did not occur synchronously across the Scottish Highlands but affected different mountains at different times. This suggests that perhaps catastrophic erosion of the plateaux is dependent on localised antecedent conditions. However, these suppositions are only supported by dates made on eight samples from two sites. Future work will endeavour to date further samples from these two sites and from three other sites, Fhion Bheinn, Carn nan Gobhar (the Cannichs) and the

Red Hills of Skye. A greater number of dates from a wider geographical area will allow these initial suggestions to be rigorously tested.

Acknowledgements

The author gratefully acknowledges the financial support provided by the QRA New Research Workers Award, which contributed to the cost of Laboratory work. Thanks are due to Dr Joel Spencer, Angus Calder and Dr Ruth Robinson for assistance with and training in OSL dating. I am grateful to Professor Colin Ballantyne for assistance in the field and supervisory support.

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Stefan Morrocco
School of Geography and Geosciences,
University of St Andrews,
St Andrews,
Fife, KY16 9AL
E-mail: mmm15@st-andrews.ac.uk

FACIES ANALYSIS OF THE BREKKNAFJÖLL-FAGRADALLSFJALL RIDGE: AN EXAMPLE OF PLEISTOCENE BASALTIC SUBGLACIAL VOLCANISM, NEAR LANGJÖKULL, CENTRAL ICELAND

The interaction between glaciers and volcanoes has been a major influence on the Quaternary geology and geomorphology of Iceland. The Icelandic landscape is littered with hundreds of examples of subglacial volcanism, such as tindars (ridges) and tuyas (volcanic centres), many of which have been attributed to a subglacial origin. One such example, and the focus of my research is the Brekknafjöll-Fagradallsfjall ridge, which formed within an ice-sheet at least 400 m in thickness, probably during the late Pleistocene. The study area lies within the Western Rift Zone of Iceland and comprises a partially-exposed section of ridge, 7–8 km long, up to 2 km wide and of some 400 m maximum relief. It continues to the north-east as part of the Jarlhetttur ridge system and beyond for an undetermined distance beneath Eystri-Hagafellsjökull, an outlet glacier of the Langjökull Ice Sheet.

The ridge is composed of a number of volcanic, sedimentary and volcanoclastic facies associations, which change significantly in nature up through the ridge succession and are all derived from a basaltic magma. At the base of the succession and in contact with the flat-lying, pre-existing subaerial lava flows are 40–100 m of pillow, sheet and massive lavas, with minor intercalated coarse-grained, non- or low-vesicularity hyaloclastites. Above a fairly sharp, attitudinally consistent contact lies a 200–300 m thick association of yellow, hydroclastic, variably vesicular, often well sorted tuffs and breccias, which make up the bulk of the volume of the ridge. There is also considerable small to large-scale folding and faulting within this facies assemblage. The uppermost facies association is a cap of flat-lying subaerial lava. However, on Fagradallsfjall and at a few other locations, beneath the lava cap association, but closely related to it, there is a coarse-grained, highly vesicular, poorly-sorted unit. It is no more than 10 m in thickness and forms a drape over much of the yellow sand association.

Analysis of the above facies leads to the conclusion that there were four distinct phases of activity. It is envisaged that the pillow and massive lava facies formed within a vault/lake of meltwater, where pressure-depth was sufficient to inhibit the exsolution of volatiles. The 'narrow and tall' geometry of this mainly lava pile gives the impression that in these early stages the water-filled cavity was of limited lateral extent, inhibiting lateral flow of presumably low-viscosity lavas and encouraging vertical aggradation of the edifice. This supports the idea that there was relatively little heat available in the initial stages to promote thermal erosion of the ice. This was probably as a result of the low surface area

available for heat transfer between an intact lava and the ice/water body, possibly aided by the insulating effect of a chilled lava carapace. Within the lava pile itself, there is no evidence of extensional faulting or any subsequent redistribution, suggesting, initially at least, that either the surrounding ice remained in place supporting the over steepened edifice, and/or the lava was sufficiently competent to maintain its steep flank slopes.

The yellow sand facies association demonstrates the existence of a pressure-depth threshold, which was exceeded by the growing volcanic edifice, allowing exsolution of volatiles and subsequent fragmentation and phreatomagmatic activity, producing an abundance of sand sized and coarser material. This material was subject to extensive contemporaneous and subsequent reworking in a lacustrine setting, predominantly as debris and hyperconcentrated flows. The presence of tectonic structures is possibly related to the removal of ice as a lateral support as well as movement resulting from an over-steepened and unstable edifice. The aerial extent and sorting of these sediments supports the existence of a much larger water body than in the initial stages. It is likely that this is the result of two main factors; firstly, through continued eruption, the water body was enlarged by the cumulative effect of total heat released. Secondly, it has been suggested that the transition to hydroclastic, explosive volcanism provides the mechanism whereby the fragmented lava has a much greater surface area and hence facilitates more rapid heat transfer with an associated increase in the rate of melting (Allen, 1980).

The presence of a subaerial lava cap indicates that either the eruption had breached the ice or lake surface, or the lake had drained. The volume and consistent altitude of this facies along the ridge supports the existence of a fairly stable lake. This unit was not seen at all locations, probably due to the cessation of volcanic activity before breaching the water surface. This and other evidence supports the existence of distinct spreading centres along the ridge as a whole, dictating the style and pattern of both volcanism and deposition of sediments.

The final facies described here is the coarse unit beneath the subaerial lava and probably represents a hyaloclastite delta, as originally described by Jones (1969). This occurs when erupting, but largely degassed, subaerial lava flows back into the surrounding water body, partially fragmenting and being deposited as foresets on a delta front. The limited occurrence of this unit leaves a question over the relationship between the uppermost facies and is inextricably linked with the behaviour of the water body.

These facies and sequence of events are fairly consistent with that envisaged by other authors (Jones, 1969; Allen, 1980; Werner and Schmincke, 1999; Smellie, 2000; Guðmundsson *et al.*, 2002), but there are a number of anomalies between the published models and the facies and associations seen here. Questions arise regarding whether these features are mono or polygenetic, as

well as over the relationship between the deglaciation of the area and the subsequent increase in volcanism. The evolution of the water body is also of prime importance and from other evidence not presented here, which suggests more complex behaviour than the above basic model outlines. On top of this an attempt to constrain the glacial variables will be made, a matter which work on the subject-to-date has failed to address sufficiently.

Acknowledgements

I would like to thank the QRA, Dudley Stamp Memorial Fund and the International Geographical Congress Fund (Royal Society) for their support of this work. My thanks also go out to my supervisors Matthew Bennett, Stephen Edwards and Dave Huddart. I would also like to thank Gudjon Gudjonsson, David Hickey, Ulla Magnusson, Alex Tomio, Richard Waller and Craig Wright for their help and support during fieldwork.

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Martin Webb
Department of Earth and Environmental Sciences
University of Greenwich
Medway Campus
Chatham Maritime
Chatham
Kent ME4 4TB
E-mail: martinswebb@yahoo.co.uk

REVIEW

GEOLOGY OF THE COUNTRY AROUND PWLLHELI : MEMOIR (134) 151PP ¹

T.P. Young, W. Gibbons and D. McCarroll

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The excellent Pwllheli memoir covers the central southeastern portion of the Lleyn Peninsula in North Wales. It is one of the very last 1:50,000 sheets to be described in this traditional style (see *Quaternary Newsletter*, 92, 58–61) with a large format (22 by 28 cm) HMSO publication. In addition to some fascinating glacial features the memoir also describes, in just over a hundred pages, some sublime Precambrian and Lower Palaeozoic geology without ignoring the Quaternary, which in spite of this stiff competition merits a further 27 well illustrated pages. This is a welcome change from considering such Drift deposits in a rather cursory manor.

Most of the chapter on the Quaternary deals with the effects of localised glaciation originating in Snowdonia and its interaction with the Irish Sea ice

sheet followed by stagnation, retreat and localised ponding. The account focuses on the classic coastal sections at Porth Neigwl (Hell's Mouth), a sweeping 6 km wide bay, and Glanllynau, on the northeastern edge of the sheet, near Criccieth. In addition, the glacial meltwater channels through areas of more resistant bedrock are briefly outlined along with the postglacial deposits. The text mainly describes the five different glacial morphologies and sediment assemblages that are associated with these varied landforms. These assemblages were translated into the largely lithological categories traditionally used to define Drift deposits on BGS maps.

In addition to sharp black and white photographs there are a generous number of red tone figures. These includes exaggerated profiles of the coastal sections at Glanllynau (+10) and Porth Neigwl (+12.5), a good cartoon showing how the structures formed during deglaciation relate to the present exposures at Glanllynau, and seismic surveys along the sands of Porth Neigwl. The descriptive parts of the account are easier to understand because they make reference to a separate Quaternary History at the end of the chapter, which provides a coherent synthesis of these events, aided by a neat series of deglaciation maps.

While this is a good account it should be much more up-to-date than the adjacent Aberdaron memoir (Gibbons and McCarroll 1993). Unlike those in the Isle of Man research report (see *Quaternary Newsletter*, 98, 80–82) radiocarbon dates are used without qualification and the chapter does not refer to Bowen (1999), which calibrates the ~14.5 ka organic deposits at the base of the Glanllynau kettle hole to around 17.3 ka. However, apart from this annoyance this chapter shows what could be achieved if the routine production of such memoirs had been allowed to continue.

The accompanying 1:50,000 map has an innovative series of 1:250,000 inserts on seaward portion of the sheet with Sea Bed sediments, offshore geology and generalised onshore Solid and superficial Drift geology with ice flow directions. However, while it been very carefully drafted with good colour selection and balance to the usual very high standard, a northerly overlap would have greatly improved this map. The coast east of Pwllheli is especially difficult to interpret with such an arbitrary cut off: it does not allow the coastal coverage to link up with the Snowdon sheet (119). The nearby Harlech sheet (135 and part of 149) shows this can be done. It would even have been possible to produce special sheet covering the whole of the Llyn Peninsula (south of grid 40), which would then allow one future map to cover the mainland south of Caernarfon (sheet 105), including the rest of the Nefyn sheet (118) to the north of Pwllheli.

In contrast, the newly-published Cardigan and Dinas Island sheet has a small partial overlap and as this coastal map covers a small onshore area the Solid geology is repeated below the Solid and Drift map, which shows the Quaternary

Drift deposits superimposed over large portions the older bedrock geology. A schematic section illustrating the relative positions of the Drift deposits places glaciolacustrine material deposited at the western end of the glacial Lake Teifi below the rest of the late Devensian succession. This interpretation is clearly at odds with Lear (2003), who suggests that the lake's history was more complex than this supposes. The marginalia also contain gravity profiles that constrain the shape of the earlier Drift filled valleys. These profiles are well annotated with notes about how they were modelled from traverses targeting anomalies on the plotted 1:100,000 residual Bouguer gravity map with superimposed on and offshore palaeodrainage features.

The Cromer sheet explanation covers a significant portion of the North Norfolk coast and, by including nearly four pages of references, acts as a wider introduction. This small A5 (15 by 21 cm) colour booklet is presented with the folded map in a high quality clear plastic wallet. Apart from a brief outline of the underlying basement and a few isolated Chalk outcrops, the sheet explanation largely deals with the extensive Quaternary deposits. Inside the front cover is a geological succession without any indicative ages or indications of the major unconformities in this generalised sequence. However, the introduction has an excellent hill shaded relief map with the drainage patterns picked out in alluvial yellow.

As usual in East Anglia the BGS treats the marine Crag Group as Solid formations separate from mainly terrestrial Drift deposits. A detailed summary neatly bridges this technical distinction and explains that the members of Cromer Forest-bed Formation consist of non-marine equivalents to the Wroxham Crag Formation. However, this interesting account would have been aided by a schematic section to relate these members to their marine equivalents in the interdigitating Crag.

This is followed by descriptions of the varied glacial deposits and discussion of their origins and which glacial episodes they actually relate to, including rafts of Chalk incorporated into the advancing Beeston Regis Formation, illustrated by a slightly darkened photo of a large raft in the cliffs at Sidestrand to the east of Cromer. While the Blakeney Esker is discussed and clearly delineated on the accompanying 1:50,000 map, the account also includes a brief section on Kame-Lake features that are unmarked, unlike swallow holes on the Cockermouth (23) sheet. Though the age of the older glacial deposits is uncertain, the limited outcrops of the Holderness formation in the west of the district are associated with the maximum extent of the last Devensian glaciation that, relative to the present coast, did not penetrate far inland.

After this there are brief notes about interglacial deposits, which are too limited to be depicted on the map, before a detailed description of postglacial events and Flandrian deposits. Quite rightly this takes up about seven pages of the text

and is illustrated by well drafted simplified figures showing the buried palaeovalley running parallel to the coast and a section through the tidal-flat deposits. Unfortunately, they are misplaced long before they are mentioned in the text, which far more significantly refers to uncalibrated radiocarbon dates, and thus the Holocene starts around 10 ka rather than 11.5 ka. The third chapter on applied geology mainly deals with those aspects which directly affect human activity and includes a useful description of coastal landslides. The accompanying 1:50,000 sheet is well drafted, clearly marks the western limit of the Wroxham Crag below the glacial Drift, includes offshore geology (see *Quaternary Newsletter*, 95, 47–48) along with tidal information and has two schematic Drift sections.

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David Nowell
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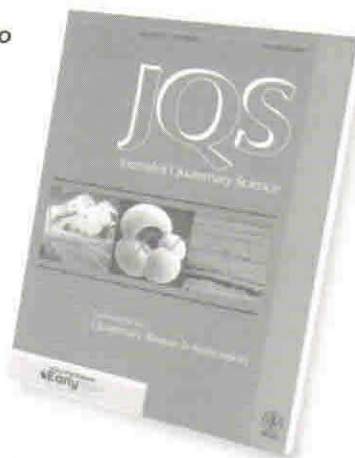
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