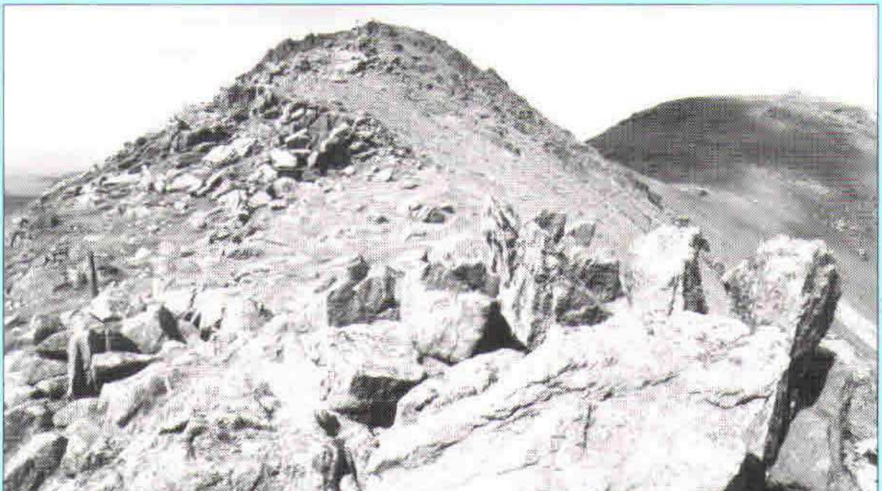
NUMBER 98 OCTOBER 2002

QN

Quaternary Newsletter



A publication of the

Quaternary Research Association

QUATERNARY NEWSLETTER

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Instructions to authors

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

Suggested word limits are as follows: obituaries (2000 words); articles (3000 words); reports on meetings (2000 words); reports on QRA grants (500 words); reviews (1000 words); letters to the Editor (500 words); abstracts (500 words). Authors submitting work as Word documents that include figures must send separate copies of the figures in .eps 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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COVER PHOTOGRAPH:
Frost-shattered bedrock on the south ridge of Arenig Fawr, Wales. There is no evidence of glacial action in this area. The main summit (854 m) is the peak to the right. Photo kindly supplied by Philip Hughes. (See article on pp. 15-17).

ARTICLES

A LABORATORY SIMULATION OF THE SUBGLACIAL DEFORMING BED (THE DEFORMATION TANK)

Robert J. Watts and Simon J. Carr

Introduction

It has become evident that the investigation of contemporary and Quaternary glacier and ice-sheet dynamics has become increasingly dependant upon fuller understanding of the role of the subglacial deformation of sediments (Murray, 1997; Hart and Rose, 2001). However, such investigations have depended almost entirely on field investigation of subglacial deformation in contemporary or Quaternary sediments, and laboratory-based experiments into sediment deformation under subglacial conditions have little precedence, due to the nature and magnitude of the stress and hydraulic conditions required. Although a number of researchers have attempted to model subglacial deformation with the aid of shear-box (Murray and Dowdeswell, 1992), triaxial (Boulton and Dobbie, 1993) and ring-shear equipment (Iverson *et al.*, 1998; Muller and Schluchter, 2001), none of these approaches can replicate to within an order of magnitude the nature of normal and shear stresses, porewater pressures or particle-size distributions found beneath contemporary glaciers (Hart and Rose 2001). With no current apparatus design capable of simulating subglacial sediment deformation at a scale even approaching that which would be deemed realistic, it has been necessary to design and construct a new piece of experimental apparatus termed the deformation tank (Figure 1).

This paper briefly describes the design of a prototype deformation tank (DT) and the initial results gained from it. This paper is intended to demonstrate a current direction of research in understanding subglacial deformation and the DT is designed simply to see whether a large sediment sample can be deformed under conditions that begin to approach those that can be compared with subglacial conditions. As such, the focus in the earliest stages has been the engineering of the first principles of the tank, to see whether this approach can yield meaningful data. We do not pretend that this is a finished piece of apparatus for which we can fully detail all the relevant parameters.

The deformation tank

The design criteria for this sediment tank are unusual. The tank itself must contain the sediment and the pore water throughout the deformation phase of any experiment whilst enabling the soil or sediment unhindered lateral movement so that deformational features can be created.

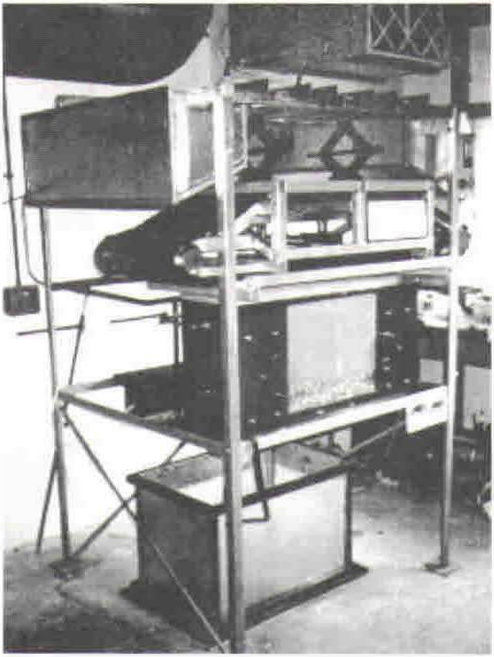

Figure 1. The prototype deformation tank (DT) housed at the Department of Geography, University of Southampton.

The static confinement of the sediment unit is acheived by virtue of steel back and floor panels (3 mm thick) and a front panel constructed from a 5-mm perspex sheet to aid the observation of sediment deformation. The internal dimensions of the sediment box are 0.5 m wide, 0.5 m high and 0.3 m deep. Whilst constrained in the sediment box, the sediment in the tank can be subjected to a variable downforce via an oversized lid section that slides vertically over the outside of the upper rim of the tank. To enable sediment deformation and lateral (down-shear) movement, a self-contained system of linked lateral water bags was constructed. As the sediment deforms in the direction of one of the bags, the water held within this bag is put under increased pressure, whilst the opposing experiences decreased pressure. By linking the two water bags the pressures are always equalled out between the bags so enabling them to maintain a passive supporting role to the deforming sediment, without constraining lateral deformation (Figure 2).

Shear stress is applied to the sediment surface by a very slow moving (158 mm hr^{-1}) 'tank-track' belt that runs in a continuous loop across the oversized lid section of the sediment tank. This belt makes contact with the sediment surface through a hole 0.5 m by 0.3 m in size cut into the lid section of the sediment tank. As the belt overrides the sediment a series of rollers helps maintain the rigidity of the belt, whilst providing as little friction as possible. Normal stress is applied

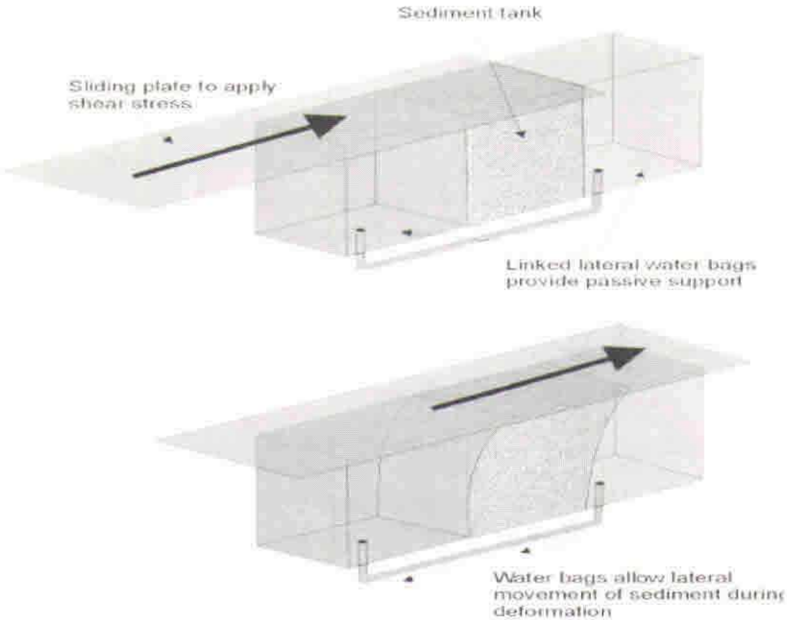

Figure 2. Schematic diagram illustrating the role of linked lateral water bags central to the effectiveness of the DT. By providing a passive lateral support, the water bags contain the sediment sample, whilst allowing lateral movement of the sediment during deformation.

to the lid of the DT through an arrangement of jacks, which requires the construction of a large framework against which the jacks push. The top of the box is currently not perfectly sealed, and thus pore-water pressures may vary within the sample, and as such effective stress conditions are likely to be somewhat transient during the experiments. Further development of the DT will include providing a tight seal at the top of the sediment tank.

Using the current set of normal and shear mechanisms, a range of moderate to high stress regimes may be replicated, with calculated maximum normal and shear stresses of 1471 and 160 kPa respectively (assuming 100% efficiency in stress transmission to the sample). These figures equate with the stresses produced by a glacier 170 m thick, with a surface slope of around 6°. As such, the normal and shear stress applied to the sediment tank approaches the order of magnitude found within small glacier systems, and is significantly more representative than deformation using simple shear-box, triaxial and ring-shear apparatus.

Experimental set-up and results

The overriding aim of the initial experiments using the DT was to assess the role that sediment type plays in determining sediment deformation form. It was hoped that by controlling overburden and water pressures as far as possible throughout the experimental series the sediment type variable would be isolated and thus its effects on deformation assessed. Three sediment types were examined: (i) fine sands and clay, (ii) coarse sands and (iii) fine gravels and coarse sands.

In order to trace any sediment deformation during the series of experiments, two lengths of 4-mm thick rubber were inserted into the sediment unit. The markers were placed vertically 250 mm and 400 mm from the left hand side of the sediment unit along a central plane. The duration of the experiments was set at four hours with each experiment repeated five times. Whilst pilot studies had demonstrated that deformation could occur after as short a duration as one hour, the need to accentuate the differences in form and extent of deformation between the sediment types necessitated a longer experimental duration.

The deformation forms for all three grain sizes showed some common responses to the deformation process (Figure 3). All of the experiments demonstrated a decrease in deformation with increasing depth, although not all responses from the sediment units were uniform. Whilst maintaining the curved pattern of deformation suggested by mathematical theory (Boulton and Hindmarsh, 1987; Kamb, 1991), all three sediment types show evidence of a non-uniform stepped deformation form as a consequence of the formation of shear zones, forming 'S'-type deformation profiles. These suggest an uneven deformation/depth profile with the sediment unit reacting not simply as separate units at a granular level but at a much larger scale, as separate sediment zones (Hindmarsh, 1997). The well-defined zones can be associated not just with a discernible deformation form but also with distinctive deformation processes. The general pattern for this type of deformation is summarised in Figure 4.

Four distinct zones of deformation are shown in Figure 4. (A) Zone 'A' is a zone of rapid sediment displacement, probably reflecting high shear stresses and low effective pressures. The result is a zone of high strain rates that decrease only slightly with increasing depth. (B) Zone 'B' encompasses the main 'shear zone' within the DT. It is suggested here that the sediment experiences lateral shearing, enabling a rapid decrease in strain rate to be transferred down through the sediment unit. (C) The sediment within Zone 'C' reacts in response to this reduced transfer of shear stress with sediment strain rate decreasing only slightly with depth. (D) Sediment in Zone 'D' experiences a sudden shut-off of the deformation processes, possibly due to the interplay of increased effective pressure and an inherent sediment yield strength threshold below which the sediment will not deform.

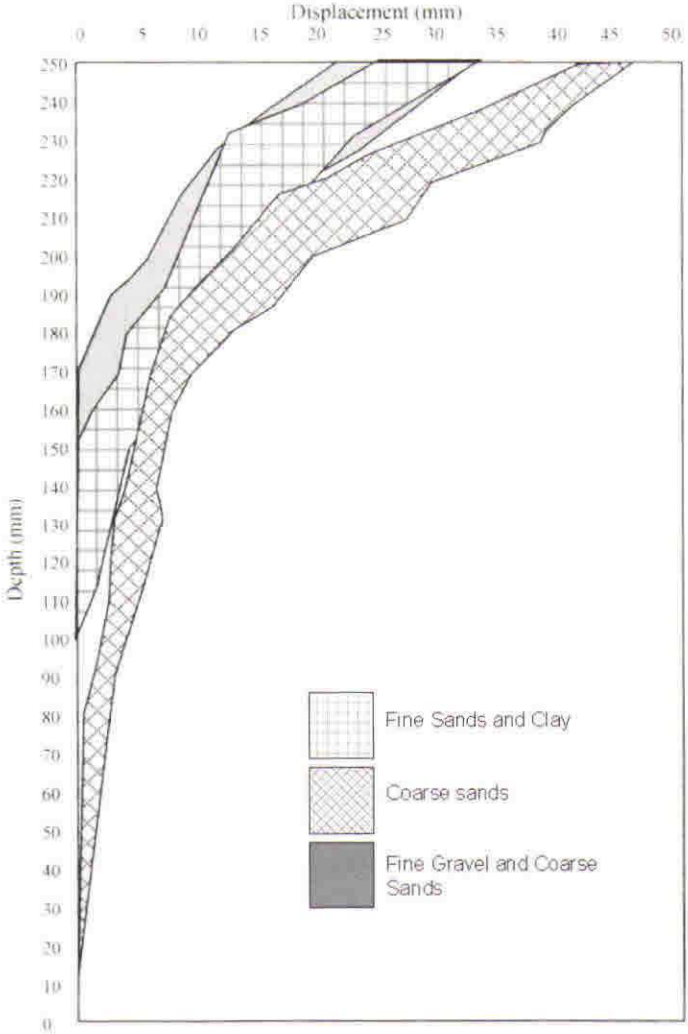

Figure 3. Displacement profiles created by the DT for the three samples outlined in the text. Each profile reflects the envelope of lateral displacement indicated by the rubber markers. It is notable that the different sediment textures have resulted in different degrees of deformation.

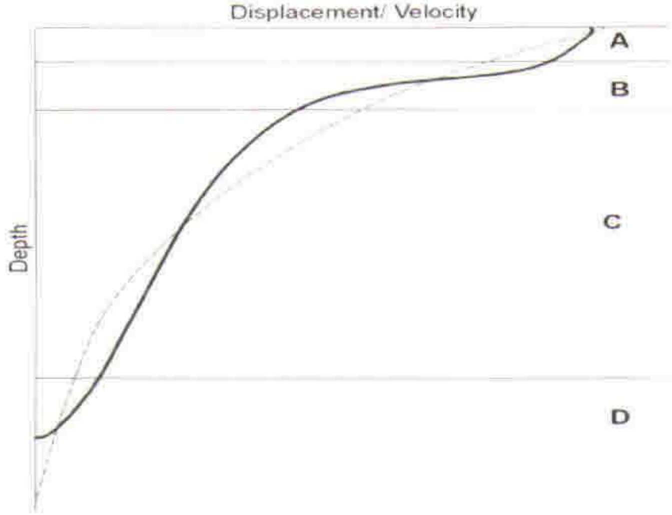

Figure 4. Idealised 'S'-type profile curve of subglacial deformation, and the four zones of deformation, plotted against a schematic summary of the displacement data supplied by the DT. This curve can be identified in the displacement profiles of the three samples shown in Figure 3.

The division of the deforming layer into contrasting sediment layers as a means of describing the deforming sediments depth profile has been utilised for many years from field evidence (Boulton *et al.*, 1974; Benn and Evans, 1996). Such field observations provide useful comparisons for the laboratory-based experiments. The upper sheared horizon (A) as described by Boulton *et al.* (1974) can be seen to coincide with zones A,B and C of the experimental model (Figure 4), whilst their lower unsheared horizon (B) is comparable to the sediment below the threshold layer described in zone D.

The DT has been used in further experiments designed to replicate the formation of some of the classic glacitectonic structures described in the vicinity of West Runton, Norfolk, by Hart *et al.* (1990) and Hart (1995). Classic features such as chalk lineations (Figure 5), augens and flow structures around a competent clast (pressure shadows) have been reproduced, validating theoretical models of the formation of such structures through subglacial glacitectonic processes. Whilst it is tempting to suggest from the initial experiments that the DT supports a plastic rheology, rather than a viscous model of subglacial deformation, further development and instrumentation of the apparatus will be required to validate such a hypothesis with any confidence.

Figure 5. Formation of classic glacitectonic chalk lineations using the DT. Three vertical bands of ground chalk (obtained from natural exposures at West Runton, Norfolk) inserted into the sediment tank have been deformed by the DT to produce 'typical' displacement profiles, as well as lineations through pure strain in the uppermost 15-18 mm of sediment.

Conclusions

The results of the DT experiments are both promising and informative. The technique shows potential for the future expansion and exploration of subglacial deformation theory. For the first time, it has been possible to simulate, within orders of magnitude, the nature of the subglacial deforming bed. Furthermore, the large size of the sediment sample and the use of linked lateral water bags to provide a passive support significantly reduce the edge effects associated with simulating deformation compared with other experimental approaches. In this early stage, however, it must be noted that the stress parameters are based on calculated values: the actual stresses applied to the sediment have yet to be adequately instrumented. Future development of the DT will include the addition of a range of instrumentation (pressure transducers, tilt cells, dragspools) to allow the operator greater knowledge of the behaviour of the sediment during experiments, as well as the incorporation of a pressurised water system to better control pore-water pressures within the deforming sediment.

However, at the entry level, the comparative analysis of the observed results of DT experiments with those derived from theory and/or fieldwork has helped to reinforce the general form of relationships between those variables significant to subglacial deformation. The creation of a distinctive 'S'-type deformation form in the laboratory suggests a possible link between this 'S' deformation form and a high-shear environment under which the sediment deforms in a brittle manner along distinct shear planes. Finally, it has proven possible to validate glacitectonic models in the formation of 'classic' deformation features (lineations, augens and pressure shadows). Whilst there is significant development work still to be done, it is apparent that the application of the DT will provide significant new insights into the nature of the subglacial deforming bed.

Acknowledgements

The authors would like to thank Shaun John for help with the building of the deformation tank. This research was partly funded by NERC grant 9/991 (RJW). The authors would like to thank the two anonymous reviewers for their helpful comments on an earlier draft.

References

Alley, R.B., Blankenship, D.D., Bentley, C.R. and Rooney, S.T. (1986). Deformation of till beneath ice stream B, West Antarctica. *Nature*, 322, 57-59.

Alley, R.B., Blankenship, D.D., Bentley, C.R. and Rooney, S.T. (1987). Till beneath ice stream B: 3. Till deformation: Evidence and implications. *Journal of Geophysical Research*, 92, 8921-8929.

Benn, D.I. and Evans, D.J.A. (1996). The interpretation and classification of subglacially-deformed sediments. *Quaternary Science Reviews*, 15, 23-52.

Boulton, G.S., Dent, D.L. and Morris, E.M. (1974). Subglacial shearing and crushing, and the role of water pressures in tills from south-east Iceland. *Geografiska Annaler*, 56A, 135-145.

Boulton, G.S. and Dobbie, K.E. (1993). Consolidation of sediments by glaciers: relations between sediment geotechnics, soft-bed glacier dynamics and groundwater flow. *Journal of Glaciology*, 39, 26-44.

Boulton, G.S. and Hindmarsh, R.C.A. (1987). Sediment deformation beneath glaciers: Rheology and geological consequences. *Journal of Geophysical Research*, 92 (B9), 9059-9082.

Boulton, G.S. and Jones, A.S. (1979). Stability of temperate ice caps and ice sheets resting on beds of deformable sediment. *Journal of Glaciology*, 24, 29-44.

Clarke, G.K.C. (1987). Subglacial Till: A physical framework for its properties and processes. *Journal of Geophysical Research*, 92, B9, 8942-8984.

Clarke, G.K.C., Collins, S.G. and Thompson, D.E. (1984). Flow, thermal structure and subglacial conditions of a surge-type glacier. *Canadian Journal of Earth Sciences*, 21, 232-240.

Hart, J.K. (1995). Glacial erosion, deposition and deformation associated with a deformable bed. *Progress in Physical Geography*, 19, 173-191.

Hart, J.K. and Rose, J. (2001). Approaches to the study of glacier bed deformation. *Quaternary International*, 86, 45-58.

Hart, J.K., Hindmarsh, R.C.A. and Boulton, G.S. (1990). Different styles of subglacial glaciotectonic deformation in the context of the Anglian ice sheet. *Earth Surface Processes and Landforms*, 15, 227-241.

Hindmarsh, R. (1997). Deforming beds: Viscous and plastic scales of deformation. *Quaternary Science Reviews*, 16, 1039-1056.

Iverson, N.R., Hooyer, T.S. and Baker, R.W. (1998). Ring-shear studies of till deformation: Coulomb-plastic behaviour and distributed strain in glacier beds. *Journal of Glaciology*, 44, 634-641.

Kamb, B. (1991). Rheological nonlinearity and flow instability in the deforming-bed mechanism of ice stream motion. *Journal of Geophysical Research*, 96, 16585-16595.

Muller, B.U. and Schluchter, C. (2001). Influence of the glacier bed lithology on the formation of a subglacial till sequence- ring-shear experiments as a tool for the classification of subglacial tills. *Quaternary Science Reviews*, 20, 1113-1125.

Murray, T. (1997). Assessing the paradigm shift: deformable glacier beds. *Quaternary Science Reviews*, 16, 995-1016.

Murray, T. and Dowdeswell, J.A. (1992). Water throughflow and the physical effects of deformation on sedimentary glacier beds. *Journal of Geophysical Research*, 97, 8993-9002.

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NUNATAKS AND THE SURFACE ALTITUDE OF THE LAST ICE-SHEET IN SOUTHERN SNOWDONIA, WALES: A COMMENT ON HUGHES (2002)

Danny McCarroll and Colin K. Ballantyne

Hughes (2002) has recently proposed a maximum altitude of the last ice sheet in southern Snowdonia, based on observations of the upslope transition from evidence for glacial erosion (ice-moulded and striated bedrock) to forms indicative of periglacial weathering (frost-shattered rock, tors and blockfields). A similar approach has been widely employed in NW Scotland (e.g. Ballantyne *et al.*, 1998) and supported by measured differences in the degree of rock surface weathering (e.g. McCarroll *et al.*, 1995; Ballantyne and Hallam, 2001) and in the differential representation of gibbsite (Ballantyne, 1994, 1997) in soils above and below trimlines that mark the inferred limit of glacial erosion. Differences in the exposure ages of rock surfaces above and below the inferred upper limit of Late Devensian glacial erosion in NW Scotland have been validated by cosmogenic isotope dating (Stone *et al.*, 1998). A similar approach has been employed to reconstruct the altitude and configuration of the last ice sheet in Snowdonia (McCarroll and Ballantyne, 2000).

Hughes' observations are limited to the three highest mountains south of Snowdonia proper: Aran Fawddwy (905 m), Cadair Idris (893 m) and Arenig Fawr (854 m). As part of a wider study of the glaciation of Wales, we have independently investigated all three mountains, but reached rather different conclusions regarding the maximum altitude of glaciation in two of these areas. Our observations are summarised below.

Cadair Idris

Ballantyne (2001) has outlined the evidence for the upper limit of the last ice sheet on Cadair Idris, and inferred a maximum altitude for the last ice sheet of c. 740-750 m on the western part of the mountain, based mainly on clear evidence for the westwards passage of ice across the col between the main summit (893 m) and the southern summit (Craig Cau) at 791 m. This inference is supported by the presence of gibbsite in samples from three out of four soil pits excavated above 750 m, and the absence of this diagnostic clay mineral from three samples from pits below 750 m. Hughes (2002) places a periglacial trimline along the 750 m contour, and his conclusions for this mountain therefore accord with the observations and map in Ballantyne (2001).

Aran Fawddwy

Hughes (2002) describes the summit of Aran Fawddwy as being 'capped by a small tor' and notes that the summit area 'displays clear evidence of frost shattering'. He concludes that the transition between glacial and periglacial terrain lies between the 750 m and 800 m contours. Although there is abundant evidence of superficial frost shattering of bedrock (acid tuff) along much of the long plateau between the summit of Aran Fawddwy (905 m) and the north summit of Aran Benllyn (885 m), such shattering is superimposed on rounded, glacially-moulded bedrock, with accumulations of frost-shattered debris mainly at the base of outcrops (Figure 1). The main summit itself is clearly ice-moulded, and supports perched glacially-transported boulders (Figure 2). The north summit has conspicuous quartz veins cutting through it, and boulders of vein quartz are scattered to the east of each outcrop, implying eastwards transport by glacier ice. X-ray diffraction analysis of the clay fraction of samples from soil pits excavated at 895 m and 875 m failed to detect the presence of gibbsite. Collectively, the evidence for Aran Fawddwy implies over-riding by eastwards-moving ice, and thus a much thicker ice mass than Hughes' observations suggest.

Figure 1. Superficial frost shattering of ice-moulded bedrock at 830 m on Aran Fawddwy.

Arenig Fawr

Hughes (2002) places a trimline at 750 m on Arenig Fawr, describing the summit as displaying 'classic frost-shattered features' and suggesting that 'blockfields are in evidence all around the main peak'. Our observations and conclusions differ from his account. The acid volcanic rocks that comprise this

Figure 2. Ice-moulded bedrock and glacially-transported perched boulders at the summit of Aran Fawddwy (905 m), indicating that the last ice sheet overran the mountain.

mountain are well jointed, and there are examples of frost-shattered outcrops well below the proposed trimline, such as Craig y Hyrddod at 700 m. There is also, however, evidence of glacial over-riding well above Hughes' proposed limit. On the west side of the ridge at 770 m, for example, there is a large perched boulder in which the banding is vertical rather than horizontal as in the underlying bedrock, implying glacial transport rather than *in-situ* weathering. The main summit and ridge to the north have exposed bedrock slabs, which we interpret as ice-scoured, and there is no well-developed blockfield. Excavations on the flattest areas near the summit revealed that the debris veneer is very thin, with soil pits reaching depths of only 30 cm. No gibbsite was found in samples from these pits.

Discussion

Recognizing ice-sheet trimlines on the basis of geomorphological contrasts alone is often not straightforward. Occasionally, as on Cadair Idris, the contrast between ice-scoured bedrock and intensively frost-shattered terrain is clear and abrupt. More often there is a gradual upslope transition from ice-scoured bedrock, abraded by thick, debris-rich basal ice, to higher terrain where the ice was less powerful and so the evidence for glaciation is less clear. A particular problem is that different lithologies exhibit differential susceptibility to

Lateglacial frost shattering. Well-jointed rocks have often experienced extensive shattering (sometimes producing thick blockfields) *since* the last ice sheet reached its maximum thickness, under the severe periglacial conditions that prevailed during the initial stages of ice-sheet downwastage and during the Loch Lomond (Younger Dryas) Stade of *c.* 12.9-11.5 cal ka BP (Ballantyne, 1998). The acid volcanics that underlie high ground in southern Snowdonia have experienced moderate shattering since the last glacial maximum, producing localised accumulations of frost-weathered debris (Figure 1) that apparently led Hughes (2002) to the conclusion that Aran Fawddwy and Arenig Fawr were not over-ridden by the last ice sheet. The evidence for glacial erosion at or near the summits of these mountains (Figure 2) suggests otherwise, as does the absence of gibbsite in soils sampled from above his proposed trimlines on these mountains.

The observation that the summits of both Aran Fawddwy (905 m) and Arenig Fawr (854 m) were over-ridden by ice during the last glaciation, rather than protruding as nunataks as suggested by Hughes (2002), is important because it implies that Hughes has greatly underestimated both the thickness of ice and the ice surface gradient in this region. The trimline altitudes proposed by Hughes suggest that the ice surface in southern Snowdonia reached a maximum altitude of *c.* 750 m over a very wide area, descending less than 50 m as it moved to the west coast. Our conclusions suggest that to the west of Aran Fawddwy the ice was at least 160 m thicker than Hughes' interpretation implied (i.e. >910 m), and that the ice surface descended southwestwards towards Cadair Idris with an average gradient of at least 10 m km^{-1}.

Our observations and measurements in Snowdonia and at sites elsewhere in Wales do not support the concept of a simple Welsh ice sheet centred over the Migneint Plateau, as suggested by Whittow and Ball (1970) and Addison (1983, 1990) and used as the basis for subsequent models (see McCarroll and Ballantyne, 2000). Our evidence implies several centres of ice dispersal that may or may not have attained their maximum dimensions contemporaneously. One such centre lay in southern Snowdonia between Cadair Idris and the Arans. The dating of the last glacial maximum in different parts of Wales currently rests on very tenuous evidence, however, and we await the results of a programme of cosmogenic isotope exposure-age dating before publishing our reconstruction of the last Welsh ice sheet.

References

Addison, K. (1983). *Classic Glacial Landforms of Snowdonia.* The Geographical Association. Classic Landforms Guide, 3, Sheffield, 48 pp.

Addison, K. (1990). Introduction to the Quaternary in North Wales. In: Addison, K., Edge, M. J. and Watkin, R. (eds) *The Quaternary of North Wales: Field Guide.* Quaternary Research Association, Coventry, 1-19.

Ballantyne, C.K. (1994). Gibbsitic soils on former nunataks: implications for ice-sheet reconstruction. *Journal of Quaternary Science*, 9, 73-80.

Ballantyne, C.K. (1997). Periglacial trimlines in the Scottish Highlands. *Quaternary International*, 38/39, 119-136.

Ballantyne, C.K. (1998). Age and significance of mountain-top detritus. *Permafrost and Periglacial Processes*, 9, 327-345.

Ballantyne, C.K. (2001). Cadair Idris: a Late Devensian Palaeonunatak. In: Walker, M.J.C. and McCarroll, D. (eds) *The Quaternary of West Wales: Field Guide*. Quaternary Research Association, London, 126-131.

Ballantyne, C.K. and Hallam, G. (2001). Maximum altitude of Late Devensian glaciation on South Uist, Outer Hebrides, Scotland. *Proceedings of the Geologists' Association*, 112, 155-167.

Ballantyne, C.K., McCarroll, D., Nesje, A., Dahl, S-O, Stone, J.O. and Fifield, L.K. (1998). The last ice sheet in north-west Scotland: reconstruction and implications. *Quaternary Science Reviews*, 17, 1149-1184.

Hughes, P.D. (2002). Nunataks and the surface altitude of the last ice sheet in southern Snowdonia, Wales. *Quaternary Newsletter*, 97, 19-25.

McCarroll, D. and Ballantyne, C.K. (2000). The last ice sheet in Snowdonia. *Journal of Quaternary Science*, 15, 765-778.

McCarroll, D., Ballantyne, C.K., Nesje, A. and Dahl, S-O. (1995). Nunataks of the last ice sheet in northwest Scotland. *Boreas*, 24, 305-323.

Stone, J.O., Ballantyne, C.K. and Fifield, L.K. (1998). Exposure dating and validation of periglacial weathering limits, NW Scotland. *Geology*, 26, 587-590.

Whittow, J.B. and Ball, D.F. 1970. North-west Wales. In: Lewis, C.A. (ed.) *The Glaciations of Wales and Adjoining Areas*, Longman, London, 21-58.

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NUNATAKS AND THE SURFACE ALTITUDE OF THE LAST ICE-SHEET IN SOUTHERN SNOWDONIA, WALES: A REPLY TO MCCARROLL AND BALLANTYNE (2002)

Philip D. Hughes

The comments of McCarroll and Ballantyne (this issue) provide important new data regarding the possibility of nunataks above the Late Devensian ice-sheet in southern Snowdonia. The gibbsite evidence was not available to Hughes (2002) and the possibility that the periglacial features formed during the retreat of the Late Devensian ice-sheet was clearly recognised. However, some of the comments by McCarroll and Ballantyne regarding the periglacial evidence are not entirely valid. They are dealt with below, together with some comments regarding the evidence of glacial action on these summits.

Arenig Fawr

The assertion that "the summit ridge of Arenig Fawr displays classic frost-shattered features" (Hughes 2002) is clearly demonstrated in Figure 1 and in the cover photo. There is no evidence of the frost shattering being superimposed onto ice-moulded bedrock.

The fact that frost-shattered features occur below the proposed trimline, such as at Craig-y-Hyrddod (700 m), is recognised by Hughes (2002) and is discussed when considering the age of the periglacial features. Here, Hughes notes that frost-weathered bedrock occurs on slopes outside of the limits of a probable Loch Lomond Stadial glacier on bedrock showing macro-scale evidence of past glacial action.

The perched boulder described by McCarroll and Ballantyne occurs at 770 m, which is only 20 m above what is recognised by Hughes (2002) as a trimline that *roughly* follows the 750 m contour.

The exposed bedrock slabs on the main summit ridge do not, on their own, constitute evidence of ice scour. No striae are reported and the slabs could equally be products of bedrock weathering along preferred jointing in this area. The blockfields mentioned by Hughes (2002) exist on the eastern slopes of Arenig Fawr, not on the summit ridge. This is why McCarroll and Ballantyne (2002) do not find them "on the main summit and the ridge to the north".

Aran Fawddwy

Firstly, Hughes (2002) does not describe the summit of Aran Fawddwy as being "capped by a small tor". He describes the south summit of this peak at *c.* 870 m (Grid Reference: SH 860220) as being capped by a small tor.

Figure 1. A tor-like feature on the southern ridge of Arenig Fawr at *c.* 780 m.

The perched boulders described by McCarroll and Ballantyne do not provide strong evidence of glacial transport. The glacial origin of many small perched boulders (<1 m diameter) on the summit ridge of the Arans is questionable, especially since several such boulders lie near sheep pens, walls and cairns constructed using boulders derived from mountain-top detritus. Of course, if the perched rocks are of non-local origin then this is a different matter entirely and such rocks must have been transported by glacier ice.

Whilst McCarroll and Ballantyne note that frost shattering is widely evident along the main ridge, they suggest that this is superimposed onto ice-moulded bedrock. This may be the case, but why should the poorly-preserved ice moulding be Devensian in age and not the result of earlier glaciations? The absence of gibbsite in the two soil pits dug on the summit ridge of this mountain and Arenig Fawr is negative evidence. For example, in north Snowdonia less than 60% of the soil pits above the proposed trimline of McCarroll and Ballantyne (2000) contained gibbsite. Deeply-weathered gibbsitic soils may not be widely preserved on the summit ridge of the Arans due to processes other than ice action (*e.g.* erosion by water or wind) during the Late Pleistocene.

The issue of polycyclic glacial erosion is important in understanding the glacial history of mountain areas of the British Isles and it is not sufficient to consider glacial erosional landforms as products solely of the last glaciation. Earlier glaciations, such as during the Wolstonian and the Anglian, would have probably been characterised by thicker ice than during the Late Devensian. As a result, ice is likely to have overridden summits that perhaps protruded as nunataks during the Late Devensian, resulting in periglacial features being superimposed on to glacially-moulded bedrock. This also has important implications for the development of gibbsitic soils, since mountain tops glaciated during the Anglian, but not in subsequent glacial phases, are more likely to have developed gibbsitic soils than those glaciated during later phases, such as the Wolstonian. Regional variations in the presence or absence of gibbsite atop mountain summits would therefore be determined by differing ice-sheet geometries during different glaciations. However, the conditions under which gibbsitic soils form are controversial. Indeed it is questionable whether gibbsite could even have formed during the Late Pleistocene (E.A. FitzPatrick, *personal communication*).

Finally, a maximum ice-sheet altitude of 750-800 m in the areas presented by Hughes (2002) does not necessarily mean that the ice surface was at that altitude over a wide area. A higher ice centre could have occurred somewhere southwest of the Arenigs at a point equidistant from the Arans and Cadair Idris. However, this would imply a higher surface altitude than the ice sheet in north Snowdonia and would have implications regarding the dominance of the two ice centres. This theoretical issue would not be so problematic if the ice centres were not at their maximum contemporaneously – a possibility which McCarroll and Ballantyne consider in their model of glaciation.

In conclusion, the comments of McCarroll and Ballantyne are not sufficient to negate the possibility that nunataks protruded above the last ice sheet in southern Snowdonia. The periglacial features of the summit areas described in Hughes (2002) may well have formed during ice-sheet retreat and later, though further data are required. For example, cosmogenic isotope exposure dating from these summit areas, if possible, would further test the possibility that the summits stood above the last ice sheet.

References

Hughes, P.D. (2002). Nunataks and the surface altitude of the last ice sheet in Snowdonia. *Quaternary Newsletter*, 97, 19-25.

McCarroll, D. and Ballantyne, C.K. (2000). The last ice sheet in Snowdonia. *Journal of Quaternary Science*, 15, 765-778.

McCarroll, D. and Ballantyne, C.K. (2002). Nunataks and the surface altitude of the last ice sheet in Snowdonia. *Quaternary Newsletter*, 98, 10-14.

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REPORTS

THE QUATERNARY OF CENTRAL GERMANY (THURINGIA AND SURROUNDINGS)

QRA Short Field Meeting, 13th - 16th May 2002

Monday 13th May – The Lower Pleistocene of Thuringia

Nineteen participants, including some from the UK, France, Germany and Yugoslavia, attended the QRA Short Field Meeting to central Germany. The meeting was formally opened by **Rich Meyrick** (Weimar). **Ralf-Dietrich Kahlke** (Director of the Forschungsstation für Quartärpaläontologie – Institute of Quaternary Palaeontology – Weimar) led the excursion to the south-western part of Thuringia, beyond the mountain range of the Thüringer Wald.

The first stop, at Untermaßfeld, was reached after a short walk from the present floodplain of the River Werra to terrace deposits of the Lower Pleistocene. The site is of great importance for the number and variety of mammalian faunal remains (*c*.50% have articulated skeletons). Ralf-Dietrich Kahlke gave a well-illustrated and detailed overview of the history of the excavations in the pit. Coarse fluviatile sands, derived from calcareous Lower Triassic sandstone bedrock, are thought to have been deposited during a series of high-magnitude flood events. Over 100 taxa have been recovered from the sequence. Large mammals include several species of deer, horse, hippopotamus, elephant, lynx, puma, cheetah, jaguar, brown bear, hyaena and sabre-toothed cat. Approximately 20% of the bones exhibit gnawmarks from scavengers. The palaeomagnetic record shows a reversal just below the basal bone horizon, which is correlated to the Jaramillo Event (1.07 Ma BP). The presence of the QRA at Untermaßfeld raised the interest of local journalists and the site visit was immortalised in the German press.

A traditional German lunch was taken in a guesthouse on top of Dolmar hill, a Miocene-age basaltic lava plateau, which offered excellent views of the Werra Valley and the surrounding Thüringer Wald. A short walk was taken around an adjoining Celtic fortification, which consisted of a ring-wall constructed of earth and stone, although any archaeological features within the enclosure had been destroyed.

Tuesday 14th May – Glacial Depositional Environments

The group, led by **Lothar Eissmann** (Leipzig), departed from Weimar to visit several Middle Pleistocene exposures within the Elsterian and Saalian ice limits in the Leipzig area.

The first site, Profen, is a working opencast lignite mine. The Quaternary succession contains early Saalian gravels, which have borne large mammal fauna, overlain by the first Saalian Till. This is succeeded by glaciofluvial outwash of the late Saalian, which showed evidence of periglacial processes in the uppermost horizons and contained erratics from Norway, Sweden, Finland and Russia. The sequence is capped by a Weichselian loess deposit, which exhibited several phases of palaeosol development. Dates for the loess-palaeosol sequence are presently being obtained. One of the striking features of the site was the extensive development of diapiric features - the average displacement was approximately 15 m and the maximum 50 m. The deformation occurred immediately after the emplacement of the early Saalian gravels and before the subsequent ice advance. It was noted by the gallery that similar gravitational deformation structures are observed in sections on the north Norfolk coast.

A picnic lunch, provided by the Institute of Quaternary Palaeontology, was spent overlooking the picturesque Zwenkau opencast mine. A brief description of the Quaternary sediments was provided, including the early Elsterian gravel overlain by varved lake deposits and the first Elsterian till. **Danielle Schreve** (Royal Holloway), on behalf of Jim Rose, presented Lothar Eissmann with the most recent copy of *Quaternary Science Reviews*. This Special Issue, guest edited by Professor Eissmann, contains papers on the *Tertiary and Quaternary Geology of the Saale-Elbe Region of eastern Germany*.

After lunch, the group visited the internationally-renowned site of Markkleeburg. A recent excavation here had been backfilled, so no current exposures were observed, although the history of site investigations was described. Over 10,000 artefacts assigned to the Mousterian culture have been recovered through the last century. However, the geological record suggested that the handaxes were derived from sediments deposited between Elsterian ice advances. **Mark White** (Durham) suggested that this is consistent with other records in Europe, where Mousterian typology is now being found earlier in the geological record than previously expected. It also suggests that the raw material for hand-axe fabrication was only brought to central Germany after the advance of Elsterian ice.

The last visit of the day was to the Espenhain opencast coal mine situated to the southeast of Leipzig. Lothar Eissmann and **Kerstin Hoffman** (Leipzig) described a sequence consisting of a basal Elsterian flow till overlain by glaciolacustrine silts and clays with sporadic sand lenses. At this locality, the lacustrine deposits had been truncated during the deposition of a till. There was debate amongst the lithostratigraphers as to whether the till was of Elsterian or Saalian age.

Wednesday 15th May - Post Elsterian interglacial travertines I

The group headed to the north west of Weimar, to the site of Bilzingsleben. The site was introduced by **Dietrich Mania** (Jena). The Bilzingsleben site is located on the second of a suite of terraces of the River Wipper, which flows through the northern part of the Thuringian Basin. The Wipper valley was inundated by ice from the Elsterian glaciation, which provides a chronostratigraphic marker for deposits in the upper part of the valley. Mania described the terrace development in the valley as similar to the Bridgland model for the Thames terraces, except that the interglacial deposits in the Wipper valley are formed of travertine. There are 6 cycles repeated between the Elsterian and the present day. This contradicts the findings of Eissmann, who believes that there are fewer terraces in the Wipper valley, based on an interpretation of the terraces with no interglacial deposits between the Holsteinian and the Eemian.

The floral and faunal components of the site, including the molluscan and mammal remains, were discussed. The site is also of great importance for the hominid remains found in the second terrace. Mania described the evidence for human occupation at the site, namely circular structures and concentrations of burning very close to the river margin. In addition to this was the chance to see the quite exceptional covered excavation of the occupation layer in the travertine, laden with butchered faunal remains and broken bones. A late *Homo erectus* skull has been recovered from this layer. Even the most hardened sedimentologists could not fail to be impressed by the sheer concentration of faunal remains present in the excavation. Small group discussions debated the chronology of the terrace development, with latest theories suggesting that Bilzingsleben II should be correlated with Oxygen Isotope Stage (OIS) 11, and possibly a substage within this interglacial.

The group then visited the excavation offices of Mania and examined part of the collection of Pleistocene faunas and artefacts from Bilzingsleben and the nearby site of Neumark Nord.

Following a picnic lunch, Rich Meyrick led the group around Burgtonna, essentially a travertine deposit with associated lake marls. Meyrick suggested that a unique sedimentary environment, not fully understood at present, existed at the site where travertine deposits formed a barrier to drainage, allowing the formation of lakes, which were infilled by the deposition of marls. The lakes and barriers form a series of three cascades, with a drop of 10-15 m between each barrier. The marls are rich in molluscs, ostracods, *Chara* angiosperms and the impressions of field maple, ivy and holly leaves.

A detailed description of the vertebrate fauna from Burgtonna was then given by **Lutz Maul** (Forschungsstation für Quartärpaläontologie, Weimar). Mammalian faunas recovered from the carbonate deposits show 9 distinctive faunal assemblages, initially indicating closed woodland and reaching a climatic and environmental optimum in Stage 3. In Stage 4 the exotic species disappear as the environment fluctuates between open woodland steppe to a more closed/light woodland. The final assemblage indicates more open conditions with a colder climate. The carbonate deposits are thought to have formed through the Eemian and the overlying chernozem and loess mark the transition to the Weichselian. Of interest is the presence of *Hystrix vinogradovi* (porcupine) burrows in the overlying sediments. This species is traditionally thought to be indicative of colder conditions, although thermophilous Mollusca are found in the burrows. **Simon Parfitt** (Natural History Museum), in a wide-ranging discussion of the site, suggested that the displacement between the spring deposits is greater than the difference in heights in the Bilzingsleben terraces, which have been assigned to different oxygen-isotope stages by Mania, and intimated that this is a possible explanation for the sequence at Burgtonna.

Thursday 16th May - Post Elsterian interglacial Travertines II

The final day of the field trip featured travertine deposits exposed at Ehringsdorf, to the south of Weimar. The site lies in a graben structure, in which the Ilm River has deposited a series of four travertines, including one forming in the present interglacial.

Ralf-Dietrich Kahlke provided a historical context to the excavations of the site, described the lithostratigraphy and summarised the range of biological specimens found in the sediments of the quarry. The base of the sequence comprises late Middle Pleistocene gravels overlain by a flood loam bearing a mixed assemblage of faunal remains including *Mammuthus primigenius* and pond tortoise. This is succeeded by 18 m of the Lower Travertines, from which 50 hominid bones, 10,000 faunal remains and 7,000 artefacts have been recovered. There is evidence of *in situ* burning (in the form of hearths), and the faunal record indicates the climatic optimum of the interglacial was reached in the middle part of these travertines, although a transition to more steppic conditions has been inferred from the top of the unit. Solution of the upper part of the Lower Travertines has allowed the collection of more faunal remains within the karst features, from which the microfauna indicate a more continental climate.

The karst features are overlain by redeposited loess (the 'Pariser' horizon) from which Mollusca and vertebrate remains have been recovered and a brown palaeosol has been identified containing faunal remains that indicate optimal conditions in an interglacial. Overlying this is the Upper Travertine, which is subdivided into 4 horizons. The mammalian faunal record differs from that observed in the Lower Travertines, since there is a marked increase in more open-ground taxa. There is also evidence of a charcoal layer and Palaeolithic occupation on the upper surface of the Upper Travertine. Sediments have filled fissures within the travertine and appear to comprise a redeposited black soil, comparable to the 'Pariser' horizon. This is overlain by coversands containing remains of reindeer and woolly mammoth, considered indicative of the Weischelian.

At a witness section with exposures of the travertines, Ralf-Dietrich Kahlke detailed the twelve faunal groups identified in the Ehringsdorf sediments. This precipitated a far-reaching discussion of the evidence and timing of events in the late Middle Pleistocene based upon the sites that had been visited on this field meeting.

Kahlke explained that there are three opinions as to the age of the sediments at Ehringsdorf: (1) the Lower Travertines are Eemian in age and the Upper Travertine represents Weichselian interstadials; (2) the Lower Travertines are of intra-Saalian age (OIS 7) and the Upper Travertine is Eemian; and (3) the entire sequence is pre-Eemian in age, corresponding to an intra-Saalian temperate episode (OIS 7). Kahlke himself is open-minded about the age of the sediments, although there are Uranium-series dates from the Lower Travertines that corroborate a pre-Eemian age for at least this part of the sequence.

Danielle Schreve compared the sequence to the chronostratigraphic models developed for the Thames terraces and proposed a simple model for the Ehringsdorf sediments, whereby both Lower and Upper Travertines may be encompassed within OIS 7. This is based upon the presence of biostratigraphically-diagnostic mammalian species which are only known from pre-Eemian contexts in Europe, the particular stage of morphological evolution in other taxa, such as the water vole (*Arvicola*), and the similarity in patterns of faunal turnover between Ehringsdorf and the OIS 7 interglacial sites in the UK. Kahlke raised several problems with comparing faunas of central Europe to the UK based on the effect of continentality on these assemblages, stating that Thuringia has differences to even the Rhine area, which is less continental. There is also the problem of hiatuses within the Ehringsdorf sequence represented by the erosional features on the upper part of the Lower Travertines and the formation of a well-developed palaeosol, which might require a substantial period of time to form. **Andy Currant** (Natural History Museum) concurred with Kahlke that the potential for large parts of the sequence to have been removed should not be overlooked, but continued to suggest that it is possible to compare large mammal faunas in Germany and the UK.

During refreshments in the gardens of the Schloss Belvedere, which overlooks the Ilm valley and the city of Weimar, Rich Meyrick pointed out the location of the sites visited during the trip and remarked on their close geographical relationships. He also highlighted how rich the valley is in archaeological sites (over 1000), mainly Neolithic – when the major prehistoric population expansion occurred – with a few Mesolithic and Palaeolithic sites also in the area.

After a barbeque lunch in the grounds of the Institute of Quaternary Palaeontology, the group toured the facilities and collections at the Institute and at the city's recently-developed and very impressive Archaeological Museum. The innovative preparation and preservation techniques of the Institute were described and the opportunity was provided to see the extraordinary volume of remains that is stored there.

The field meeting closed in front of the historic statue of Goethe and Schiller in the centre of the city. On behalf of the QRA, **Richard Preece** (Cambridge) thanked the organisers and our local hosts. Polished blocks of travertine from Ehringsdorf were given from the Institute as souvenirs of the meeting.

Our thanks must go to Danielle Schreve and Rich Meyrick for their faultless organisation of a thoroughly enjoyable and informative field meeting, and for the production of well-illustrated, informative field guide. Also thanks must go to our German hosts at the Institute for their kind hospitality during the week. The travertine sites were most impressive, the scale of which are rarely seen in the UK. Everyone seemed to agree that the meeting had been a good opportunity to observe Quaternary successions in continental Europe.

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INQUA PLENARY MEETING IN LONDON TO DEBATE AN OVERHAUL OF THE INQUA COMMISSION STRUCTURE

This Plenary meeting, held at Royal Holloway (University of London) on 17 April 2002 at the request of the INQUA Executive Committee, was attended by all Executives and some INQUA National Representatitives, as well as representatives of several of INQUA's Commissions.

The following representatives were present: Z.A. An, J.A. Catt, A. Chivas, J. Clague, C. Clark, E. Derbyshire, S. Elias, P.L. Gibbard, K. Gregory, S. Haldorsen, D. Keen, S. Leroy, D. Liverman, J.J. Lowe, L. Marks, N.A. Mörner, T. Partridge, S.C. Porter, D. Schreve, N.J. Shackleton, I.J. Smalley, I. Stewart, C. Turney and M. J.C. Walker.

The Background

The single aim of the meeting was to debate the Executive's draft proposal for a new Commission structure following the XVI Congress in Reno, Nevada, in July 2003. Arising from discussions at the XIV (Berlin) and XV (Durban) congresses, it was proposed to render INQUA's activities more coherent by (a) reducing the number of Commissions, and (b) developing a number of INQUA inter-Commission 'core' projects. INQUA's bye-laws state that Commissions are approved for a maximum of two consecutive inter-Congress periods only, a rule that has been only loosely applied in some cases in the past. The bye-laws also state that Commissions should have formal membership, another requirement that has not always been followed. It was proposed that the smaller number of newly created Commissions envisaged by the Executive should be charged with the responsibility of ensuring coverage of the full range of INQUA's scientific interests. Some further background was provided by the record of the meeting of the INQUA Executive held in Gdansk in March 2001.

The Executive's draft paper proposed that the following five new, over-arching Commissions be established: three new Commissions on "Palaeobiology" and "Terrestrial deposits and Processes", and enlargement of the present Commissions on "Human Evolution and Palaeoecology", "Palaeoclimate" and "Stratigraphy and Chronology". Examples of 'core' projects cited were "Marine Isotope Stage 11" and "INTIMATE" (both currently Working Groups of the Commission on Palaeoclimate), "Palaeodiversity" and "Hazards and Catastrophes".

The Discussion

The ensuing discussion was lively and occasionally intense. An early item of focus was the need for a clear recognition of the "bottom up" nature of Commissions, a fundamental component in sustaining the core of INQUA's scientific product. Any real or perceived move for replacement of this with a "top down" on the part of the Executive is likely to be vehemently opposed. This concern was firmly supported by several members, including Executive officers, not least because of the likely difficulty of finding dynamic leaders for new Commissions with "Executive-defined" titles and areas of work; there would be a practical difference in the functions and functioning of any five designated Commissions compared to the current "bottom up" model.

Several interventions from the Executive reminded the meeting that the problem as currently conceived arose partly because of an increase in the number of Commissions with no commensurate increase in INQUA's budget. It was felt that there is little doubt that the situation was exacerbated by the introduction of the "project-based" funding system; the unease that this introduced gave rise to charges of unfairness, on one side, and, on the other, to suggestions that Commissions be abolished. The International Council had come down firmly in favour of reducing the number of Commissions.

There was also strong sympathy with the view that the Commissions as currently constituted are the driving force of INQUA, that the energy and initiative provided by the "bottom up" structure that achieves results on only modest INQUA funding lie at the heart of that drive, and that the term "Commission" has intrinsic value as it is part of the recognized "linguistic currency" of the majority of ICSU-related Unions and should not readily be abandoned or modified in such a way as to denote groups with much greater scope and more complex functions. The fact that one weakness in the "bottom up" structure in the past has been that some INQUA Commissions consisted of little more than two or three leaders was seen as a failure of Executive management, rather than an argument in favour of changing the nature and function of Commissions. The contrasts and similarities between INQUA Commissions and IGCP Projects were also briefly discussed, and it was suggested that the IGCP culture of using "seed money" to generate much greater income from other, often national, sources, might be a way forward. While it was recognized that some INQUA Commissions had followed this track, it was accepted that it was not one that had been generally followed.

Alerted to the realization that the discussion was being driven by the inability of INQUA to finance adequately scientific effort across a broad range of Commissions, the participants gave some attention to the question of present and potential funding. The meeting was reminded that the budget was dictated by subscriptions from the nation-states adhering to INQUA. Funding to

Commissions in the past two inter-Congress periods has actually risen, and has never been higher. At the same time, there exist formidable obstacles to an organization such as INQUA tapping into international sources of grant income, other than the openings provided by the generation of outstanding original science projects involving a broad range of international groups attacking a set of key issues in a timely and novel way.

In view of the fact that a number of Scientific Unions have set up over-arching structures while, at the same time, retaining scientific Commissions, the view that INQUA's five over-arching entities might be labelled "Sections" within which approved Commisions would operate progressively gained support. Turning to the titles of the five newly proposed Commissions, it was recognized that practice is evolving in INQUA and similar organizations, in that greater efforts are being made to extend collaboration to Commissions and similar bodies in other Scientific Unions. As INQUA is, by definition, interdisciplinary, crossing perceived disciplinary boundaries is, or should be, mandatory; this must underpin the exercise involving the defining and naming of the five new structural entities. There was considerable discussion of the nomenclature proposed by the Executive, especially in regard to "Terrestrial deposits and Processes", the revised title "Surface processes and Deposits" eventually being agreed. The meeting eventually overcame a series of objections concerning some of the operational aspects of the other four major Sections, but the likelihood is that such over-arching structural entities would encourage stimulation of independent projects and working groups (both allowed for in INQUA's Statutes), encourage the interaction of Commissions and Sub-Commissions, facilitate the setting up of collaboration with other Unions, as well as making a clearer statement to the outside world of INQUA's mode of operation and field of view.

The 'core' projects proposal occupied less time than the debate about Commissions, although it generated some heat and light as thoughts turned to the means of selecting them. Such projects will require clear regulation of reporting sequences, target thresholds and clear objectives; they will be expected to tap external funding and, as such, an external time limit will be imposed, leaving little risk that they will generate some of the problems associated with some former Commissions. Moreover, the capacity for 'core' projects within INQUA's structure would open up the possibility of INQUA serving as an 'umbrella' organization for some outstanding projects. Likely themes for projects should be discussed at the forthcoming Congress in July 2003. For practical reasons, the Executive Committee would have to act initially as the 'core' project selection committee, to be joined by the Section Leaders in due course. An 'emergency' procedure, providing an avenue for submission of novel and timely projects, will almost certainly be established if the proposal as a whole is approved. It is likely that there will be a specified maximum number of approved 'core' projects for each inter-Congress period, and certainly fewer than six.

The outcome

There was strong support for retention of the term Commission, specifically for INQUA's inter-Congress research programmes. It was also agreed that the status implied in the term 'Commission of INQUA' would strengthen the efforts of Commission leaders in their search for external research funding.

The proposal to set up a framework including five over-arching research areas as a reflection of the full spectrum of INQUA's activities received general support. There was quite strong support for the view that these should have a distinctive designation (Sections), with the name 'Commission' being retained for INQUA's research programmes.

Funding should be allocated to the new bodies (Sections), which would disburse funding to the Commissions.

Within this major reorganizational process, an assurance was given that Commissions currently operating effectively should not be terminated at the Reno Congress, but should be allowed to continue for the normal term.

There was general agreement that the new structure should encourage stronger links between Commissions.

There was strong support for the proposed Core Research Projects. This approval carried with it the expectation that Section Leaders would be closely involved in the selection and approval of any future Core Research Projects.

In closing his summing up of the discussion of this primary agenda item, the chairman (J.J. Lowe) concluded that the way is now clear to formulate a draft set of recommendations to serve as a guide to assist the Executive Committee in moving forward to a new and more efficient mode of operation.

Several other issues were discussed at the meeting. Dr. Gibbard outlined for the meeting the details of the recent proposal by the International Commission on Stratigraphy (ICS) to subsume the Quaternary within the Neogene. The implications of this proposal were discussed at some length, including consideration of the distinctive role of the INQUA Commision on Stratigraphy, and the need for improved communication between INQUA and the ICS. Further details on this important matter can be obtained from Dr Phil Gibbard (PLG1@cus.cam.ac.uk).

The Secretary-General made a statement on INQUA's efforts to attain full membership of ICSU, in a climate in which our sister organization (the

International Union of Geological Sciences) continues to give less than its full support to such efforts while, at the same time, involving INQUA in the International Geological Congresses often, as in the case of the 2004 Congress, without consultation with the INQUA Executive.

The meeting ended with a presentation of details of the forthcoming XVI INQUA Congress in July 2003 by S. Porter and J. Clague. There was some suggestion that any new Core Research Projects might be linked to the Plenary sessions planned for the Congress, and that the input of individual INQUA members on the organization of such Plenary sessions would be welcomed. Further details of the plans for the Reno Congress can be found on the INQUA website, and expressions of interest in the Congress should be registered at http://inqua2003.dri.edu.

Finally, the President of INQUA, Professor N.J. Shackleton, thanked Professor J.J. Lowe for his chairing of the meeting.

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STRATIGRAPHICAL INVESTIGATIONS AT THREE KEY QUATERNARY SITES IN NE SCOTLAND

Introduction

The three sites discussed below were visited during the recent QRA field meeting to NE Scotland (Merritt *et al.*, 2000). Preparations for the meeting revealed important new information that has a strong bearing on the interpretation of the individual sequences and for the understanding of the Pleistocene glacial stratigraphy of NE Scotland. A brief review of the recent work and some preliminary conclusions is given here.

Teindland Quarry SSSI (NJ 297 570), near Elgin

Work has focused on the sedimentology of the Woodside Diamicton Formation (WDF) (Merritt *et al.*, 2000). The interpretation of the WDF has proved controversial in the past but most authors agree on a glacigenic origin (see references in Hall *et al.*, 1995a). Hall *et al.* (1995a) have clarified the age of the underlying buried soil and associated pollen assemblages and studied the WDF, concluding that it was deposited as debris flow and lacustrine sediments in a subglacial cavity. They identified continuity in deposition between underlying sands (Badentinian Sand Bed, BSB) and the WDF, suggesting deposition may have occurred during Oxygen Isotope Stage (OIS) 4.

The WDF is up to 2.5 m thick and consists of bedded and laminated diamicton facies of varied texture (Hall *et al.*, 1995a). It overlies an erosion surface dipping gently to the north and west that cuts down through the BSB and buried soil into sands beneath. Below this, sands are deformed into recumbent and sheath folds. Near the base of the diamicton attenuated lenses and boudins of reworked soil material are present together with bodies of internally deformed laminated silts and fine sands. In the main body, augen structures are visible together with further probable sheath folds. Shear surfaces are visible and dip to the north and west. Where it is possible to determine the 3D form of the folds in the section they verge to the south or southeast.

The deformation structures indicate tectonic transport towards the south and southeast. This is oblique to the dip of the underlying buried soil and oblique or opposed to the dip of the present land surface. It is therefore most unlikely that the diamicton is the product of solifluction. The preliminary interpretation is that the WDF represents glacitectonite and deformation till facies (Benn and

Evans, 1998) deposited beneath ice advancing towards the south or southeast. This work has not confirmed continuity of deposition between the BSB and the WDF and so the later could have been deposited at a number of times after the close of OIS 5. A full description and interpretation of the genesis of the WDF at Teindland is in preparation.

Howe of Byth Quarry (NJ 839 753), near Fraserburgh

Extensive sections in a new pit to the north of that first reported by Hall *et al.* (1995b) have become available. Detailed descriptions have been made of the gravel and diamicton facies forming the Howe of Byth Gravel Formation (HBGF) (Hall and Connell, 2000; Merritt *et al.*, 2000). This unit is an ice-proximal fan deposited during the retreat of a Moray Firth ice-stream. Sand lenses have given luminescence dates of 45.5 and 36.8 ka BP (Hall *et al.*, 1995b; Duller *et al.*, 1995).

Exposures have revealed numerous examples of vertically-oriented clasts and weakly-developed involutions in the top 1 – 1.5 m of the HBGF immediately beneath the overlying Byth Till Formation (BTF). The structures are interpreted as a former periglacial land surface which represents a cold, but non-glacial, phase younger than 36.8 ka BP but older than the Late Devensian age ascribed to the BTF (Hall *et al.*, 1995b). The structures may have formed either before or after the Tolsta Interstadial (32.8 – 28.7 ^{14}C ka BP, Whittington and Hall, 2002), a time when the Scottish Ice Sheet appears to have been limited in extent. No terrestrial organic sediments from this time period have yet been discovered in NE Scotland.

A sample for luminescence dating was taken from the gravels immediately overlying the BTF. If dating is successful it will provide additional evidence to constrain the age of the BTF. A detailed review of the new evidence from the quarry is in preparation.

Oldmill Quarry (NK 024 439), near Peterhead

This quarry presently provides excellent sections (up to 8.0 m) in the Whitehills Glacigenic Formation (WGF) (Merritt and Connell, 2000; Merritt *et al.*, 2000), generally poorly exposed in Buchan. The massive and laminated diamicton facies, and associated rafts of sand, are considered to have been emplaced by the Moray Firth ice-stream, advancing south-eastwards, in an early phase of the Late Devensian glaciation. Detailed section drawings and sedimentological logs have been made. Clast fabrics have been measured in the diamicton facies and the orientation of deformation structures recorded. Interpretation of the genesis of the diamicton/raft assemblage is in progress and will be reported elsewhere.

The WGF overlies up to 10.4 m of glaciodeltaic deposits with an erosional, locally sheared, contact. They appear slightly weathered and ice-wedge casts and a possible gelifluction deposit have been reported to be preserved at this contact (Merritt and Connell, 2000). A sample for luminescence dating has been taken from the glaciodeltaic sediments to establish their age. It is possible that they correlate with the Howe of Byth Gravel Formation (see above), thus providing further evidence in Buchan for glaciation during OIS 3. However, other possibilities exist and the sediments may be much older and relate to a pre-OIS 5e glaciation.

Acknowledgements

I wish to thank the QRA for a grant from the Research Fund that supported this work. I am very grateful to site owners for access: Forest Enterprise (particularly Mr Andy Chadwick) and SNH for permission to work at Teindland Quarry SSSI; Mr Mark Lovie, Lovie Ltd, at Howe of Byth Quarry; Mr David Buchan for access to Oldmill pit. Professor Colin Ballantyne (University of St. Andrews) is acknowledged for his support and interest in a luminescence dating programme in NE Scotland. I would like to thank Dr Andrew Murray (University of Aarhus, Denmark) for his ongoing analysis of luminescence samples from two of these sites and others in NE Scotland. I benefited greatly from advice in the field, and assistance with sample collection, from both Dr Murray and Dr Alastair Gemmell (University of Aberdeen). I thank Dr Adrian Hall (Fettes College, Edinburgh), Mr Jon Merritt (BGS, Edinburgh) and Dr Doug Peacock (Edinburgh) for discussions on the Quaternary geology of NE Scotland over many years. I would also like to thank Mr Mike Charnley for his excellent field assistance.

References

Benn, D.I. and Evans, D.J.A. (1998). *Glaciers and Glaciation.* Arnold, London.

Duller, G.A.T., Wintle, A.G. and Hall, A.M. (1995). Luminescence dating and its application to key pre-Late Devensian sites in Scotland. *Quaternary Science Reviews*, 14, 495-519.

Hall, A.M. and Connell, E.R. (2000). Howe of Byth Quarry. In: Merritt, J.W., Connell, E.R. and Bridgland, D.R. (eds) *The Quaternary of the Banffshire Coast and Buchan: Field Guide.* Quaternary Research Association, London, 72-74.

Hall, A.M., Duller, G.A.T., Jarvis, J. and Wintle, A.G. (1995b). Middle Devensian ice-proximal gravels at Howe of Byth, Grampian Region. *Scottish Journal of Geology*, 31, 61-64.

Hall, A.M., Whittington, G., Duller, G.A.T. and Jarvis, J. (1995a). Late Pleistocene environments in lower Strathspey, Scotland. *Transactions of the Royal Society of Edinburgh: Earth Sciences*, 85, 253-273.

Merritt, J.W. and Connell, E.R. (2000). Oldmill Quarry. In: Merritt, J.W., Connell, E.R. and Bridgland, D.R. (eds) *The Quaternary of the Banffshire Coast and Buchan: Field Guide.* Quaternary Research Association, London, 68-71.

Merritt, J.W., Connell, E.R. and Bridgland, D.R. (eds) (2000) *The Quaternary of the Banffshire Coast and Buchan: Field Guide.* Quaternary Research Association, London.

Whittington, G. and Hall, A. M. (2002). The Tolsta Interstadial, Scotland: correlation with D-O cycles GI-8 to GI-5? *Quaternary Science Reviews*, 21, 901-915.

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HOLOCENE HILLSLOPE EROSION AT MYNYDD DU, SOUTH WALES

Quaternary Research Fund support has enabled coring and retrieval of lake sediments at Mynydd Du, south Wales. This short report outlines the scientific rationale for this work, preliminary findings, and the proposed plan for further work.

Context

While many authors have suggested evidence for phases of increased erosion of steep slopes in upland Europe during the Holocene (e.g. Berrisford and Matthews, 1997), the timing and causes of such activity are poorly documented (Gordon and Leys, 2001). In particular, there is debate as to whether episodes of erosion are broadly synchronous within and between regions, and whether they represent local anthropogenic influences, general climatic trends, an increase in the frequency or intensity of localised extreme rainstorms, or a combination of such factors (e.g. Ballantyne, 1991; Hinchliffe, 1999; Curry, 2000). This project aims to reconstruct the timing, rates and causes of erosion of steep slopes at Mynydd Du (Figure 1), and to identify erosional synchroneity or asynchroneity at local and regional scales. Accordingly, it represents the first attempt to establish a history of such erosion in southern Britain, and to identify possible trends across upland Britain and further afield. Clarification of the causes of enhanced sediment erosion and reworking will be of particular value in informing and designing conservation management strategies in sensitive upland landscapes.

Preliminary findings

The rockfall talus sheets at Mynydd Du support what are arguably the finest examples of debris flows in southern Britain, with widespread hillslope erosion evident in the form of active and vegetated gullies and debris cones. Some of these landforms reveal a complex stratigraphy of debris-flow deposits, slopewash sediments and intercalated buried *in situ* palaeosols. Radiocarbon dating of 20 samples indicates that the onset of slope reworking pre-dated *c*. 4.8-4.4 cal ka BP. Preliminary analyses of pollen spectra for these palaeosols indicate a dominance of grasses and shrubs, but with a substantial representation of arboreal pollen that suggests a now-absent woodland cover, possibly representing a link between anthropogenic activity (*cf.* Leighton, 1997) and hillslope erosion. At the western end of the Mynydd Du escarpment, debris flows feed into a small (<1 km^2) cirque lake, Llyn y Fan Fach, whose level was artificially raised in 1917 (from *c*. 500 m to *c*. 503 m O.D.) through the construction of a concrete dam. During July 2001 the lake level was temporarily lowered, briefly exposing part of the lake floor and creating a unique opportunity to core eleven boreholes and remove three sediment cores from the site. This work was undertaken in September 2001.

The location of these cores is illustrated in Figure 1. They display numerous intercalated organic-rich units and inwashed minerogenic horizons. Transect 3

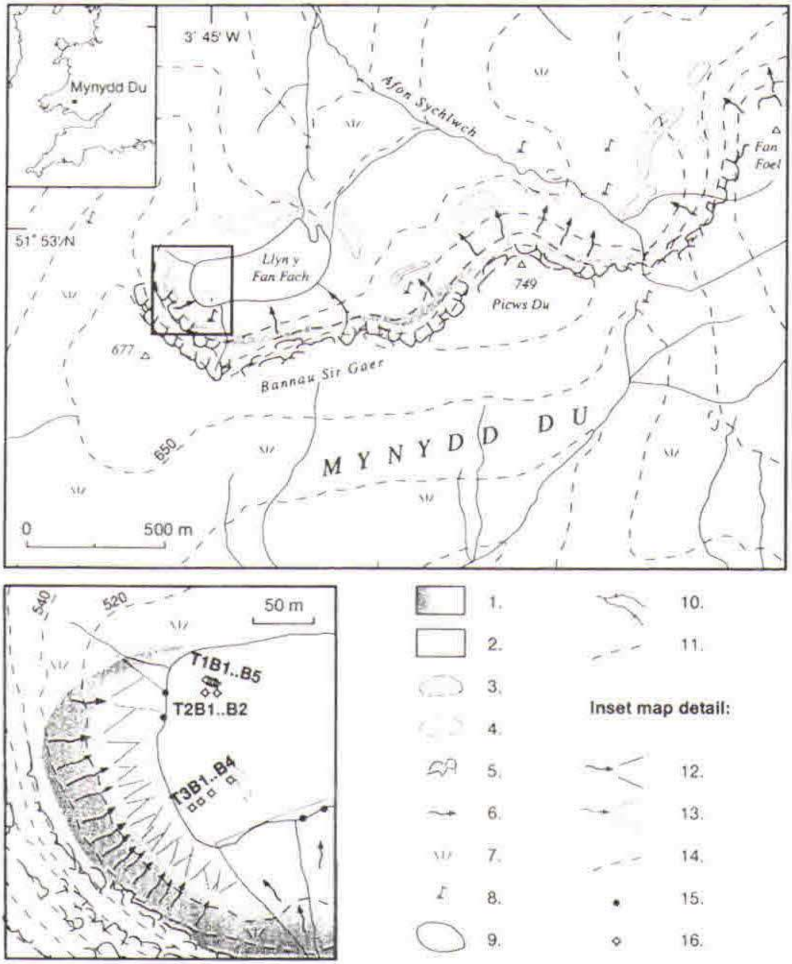

Figure 1. Location and geomorphology of the Mynydd Du site. Key: 1. Talus slope; 2. Frost-weathered debris; 3. Depositional ridge or mound; 4. Depositional ridge below lake level; 5. Steep escarpment; 6. Debris flows; 7. Heath vegetation; 8. Thick peat cover; 9. Water body; 10. Streams; 11. Contours (m O.D., ~50 m intervals); 12. Active debris flow and cone; 13. Relict debris flow and cone; 14. Contours (~20 m intervals); 15. ^{14}C-dated section; 16. Borehole.

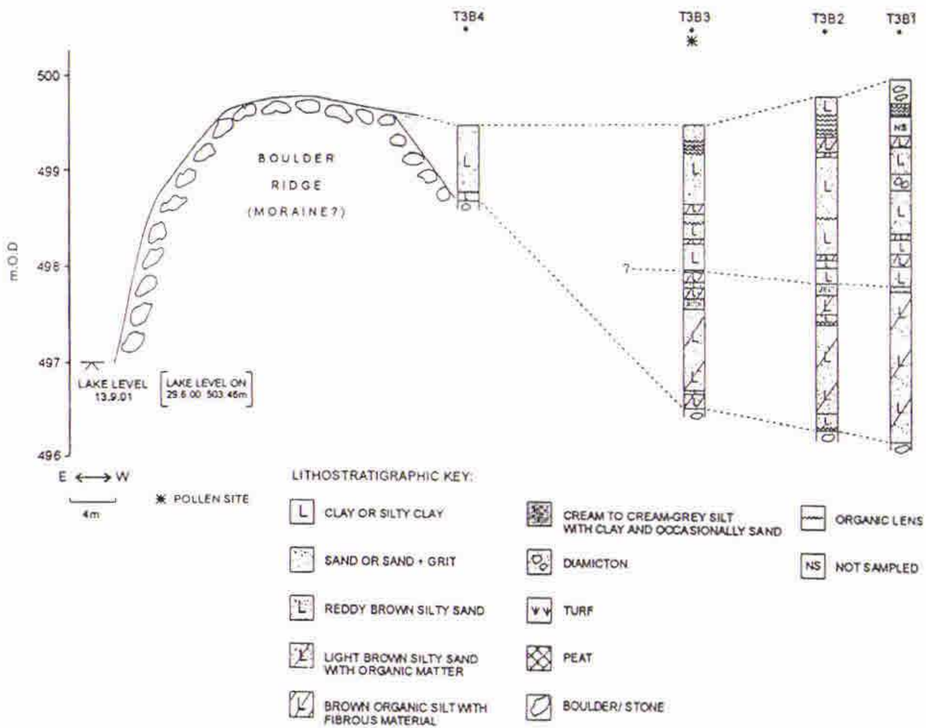

Figure 2. Stratigraphy of Transect 3 cores at Llyn y Fan Fach (Curry and Jennings, unpublished data). See Figure 1 for the location of borehole transects.

(Figure 2), for example, records an extensive lower organic silty sand unit which, in boreholes T3B4, 3, 2 and 1, is overlain by a cream-coloured clay-silt marl. In boreholes T3B4, 2 and 1 this is in turn overlain by a mostly inorganic reddy brown silty sand. This stratigraphy is similar to that found in the other two transects. Exploratory pollen samples from the lower unit at T2B2 and T3B3 indicate an at least partially-wooded environment. The cream-coloured marl layer is usually found around 497.6 m to 498.1 m O.D., immediately above the lower 'organic' unit, and appears to be an important stratigraphic marker horizon, though its full environmental significance is as yet unknown. This deposit contains very few diatoms, and preliminary pollen analysis of it at T2B2 suggests deposition in a damp, lake-margin location at a time when the forest cover was opening up, as shown by reduced arboreal pollen and an increase in shrubs and grasses.

Future work

The next stages of the research programme include (i) particle-size, mineral magnetic and elemental analyses of the minerogenic and organic sediments to establish their origin and rate of sediment accumulation; and (ii) detailed palynological analysis and radiocarbon dating of organic-rich sediments to address questions regarding timing and causes of erosion on the adjacent slopes. Anticipated wider implications of this research surround former and future climatic change, including impacts of past climate change on an upland site with projections of likely impacts associated with near-future climate changes, links between past and present anthropogenic activity and slope erosion, and their application to upland management and conservation. Reconstruction of the rates of recent erosion and detailed sedimentological analyses of reworked deposits may shed light on assumed but rarely explained links between overgrazing and erosion in marginal upland environments, and may contain significant conservation implications for livestock and visitor carrying capacities in popular but fragile montane settings. Results of dating and pollen analyses should indicate whether widespread erosion at Mynydd Du coincided approximately with periods of enhanced slope instability elsewhere in upland Britain, or whether local events and site-specific factors have dominated such activity. Together with dates relating to periods of reworking of sediment-mantled hillslopes in northern Britain, these various datasets will provide the first reliable evidence for temporal patterns (or otherwise) of slope instability across the British Isles, and will permit further correlation with other European datasets.

Acknowledgements

Thanks are expressed to the Quaternary Research Association for their financial support, to Simon Jennings and John Walden for their collaboration on this project, and to Mike Walker and Rick Battarbee for valuable comments on the marl layer.

References

Ballantyne, C.K. (1991). Late Holocene erosion in upland Britain: climatic deterioration or human influence? *The Holocene,* 1, 81-85.

Berrisford, M.S. and Matthews, J.A. (1997). Phases of enhanced rapid mass movement and climatic variation during the Holocene: a synthesis. *Paläoklimaforschung*, 19, 409-440.

Curry, A.M. (2000). Holocene reworking of drift-mantled hillslopes in the Scottish Highlands. *Journal of Quaternary Science,* 15, 529-541.

Curry, A.M. and Black, R. (In prep.) Structure, sedimentology and evolution of rockfall talus, Mynydd Du, south Wales.

Gordon, J.E. and Leys, K.F. (eds). (2001). *Earth Science and the Natural Heritage: interactions and integrated management.* The Stationery Office, Edinburgh.

Hinchliffe, S. (1999). Timing and significance of talus slope reworking, Trotternish, northern Skye, NW Scotland. *The Holocene,* 9, 483-494.

Leighton, D.K. (1997). *Mynydd Du and Fforest Fawr: the evolution of an upland landscape in South Wales.* Royal Commission on the Ancient and Historic Monuments of Wales, Aberystwyth.

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GLACIAL MELTWATER EROSION AND SEDIMENTATION IN THE LOWER AFON TEIFI, WEST WALES

The nature of events during the Late Devensian glaciation of the Irish Sea is controversial because of the debate concerning the relative importance of glaciomarine and glacioterrestrial environments. At present little consensus exists regarding events at this time, principally because most previous studies have relied heavily on interpretation of the sedimentological record, which by nature is often ambiguous (Eyles and McCabe, 1989; McCarroll and Harris, 1992; Thomas *et al.*, 1998). However, recent work has shown that features of Late Devensian glacial meltwater erosion in the Cheshire area are a valuable tool in ice-sheet reconstruction (Sambrook Smith and Glasser, 1998; Glasser and Sambrook Smith, 1999). This initial work suggests that many of the questions that remain ambiguous from purely sedimentological-based studies can be resolved when linked to evidence from erosional landforms. For example, Glasser and Sambrook Smith (1999) showed that a terrestrial ice sheet best explained the pattern of meltwater flow and that the ice sheet was relatively thin (c. 700 m) over the Irish Sea. To date, this approach has only been applied in the Cheshire area and its applicability to larger geographical areas remains to be tested.

The aim of this study was therefore to undertake a combined geomorphological and sedimentological study of glacial meltwater channels in the lower reaches of the Afon Teifi, in the Cardigan area of southwest Wales. This is an ideal location for an integrated glacial meltwater erosion and sedimentation study because of its location at the margin of the Irish Sea Ice Sheet, the likelihood of Irish/Welsh Ice Sheet interaction, and the abundant evidence for glacial meltwater erosion in subaerial, subglacial and glaciolacustrine settings (Bowen and Gregory, 1965; Fletcher and Siddle, 1998; Hambrey *et al.*, 2001). The lower Afon Teifi in particular is an ideal field area in which to attempt such a study for a number of reasons, principally because the area has many well-developed Quaternary glacial meltwater features, both erosional and depositional. These include channel-forms that have previously been interpreted as the result of overspill from ice-dammed lakes (Charlesworth, 1929; Jones, 1965), as subglacial meltwater channels (Bowen and Gregory, 1965; John, 1970; Bowen, 1967, 1971), and as ice-marginal glaciofluvial channel systems. In addition, recent investigations undertaken by the British Geological Survey have demonstrated that the area is locally underlain by a variety of different glacigenic sediments, including lacustrine sediments deposited by a late-Devensian ice-contact glacial lake, Llyn Teifi (Waters *et al*, 1997; Fletcher and Siddle, 1998; Wilby, 1998; Hambrey *et al*, 2001), and iron-cemented conglomerates of possible pre-late Devensian age (Hambrey *et al.*, 2001). These deposits are important stratigraphic markers in the Quaternary sedimentary record, and their presence or absence can be used to assign relative ages to features of glacial meltwater erosion and sedimentation.

Maps of glacial erosion and sedimentation in the lower Afon Teifi around the town of Cardigan were produced from both aerial photography and fieldwork. Data concerning depth to bedrock in the area have also been compiled in order to erect a sub-drift contour map of the lower Palaeozoic rockhead as part of collaborative research project with the British Geological Survey. Combined with the sedimentary evidence, the sub-drift rockhead and surface glacial meltwater channel maps enable a detailed palingenetic reconstruction to be made of the Quaternary drainage evolution of the lower Afon Teifi. This reconstruction reveals a complex evolution in the establishment of the present drainage system. Evidence exists for a variety of channel types, including (i) channels of primary subglacial origin, (ii) subglacially-modified pre-late Devensian tributaries of the Afon Teifi (iii) drift-plugged abandoned courses of the main Afon Teifi, (iv) lateglacial and post-late Devensian gorges, and (v) stacked soft-bedded channel sequences. A relative chronostratigraphy based principally on the sedimentological evidence reveals an evolutionary sequence far more complicated than previously described, pointing to extensive modification of the lower Afon Teifi region by glacial meltwater, possibly relating to two periods of Pleistocene glaciation. Overall, this study has important implications for the reconstruction of Quaternary glacial environments, in particular for studies integrating glacial meltwater erosion and sedimentation. A paper detailing the features of glacial meltwater erosion and deposition and their role in the drainage evolution of the lower Afon Teifi is currently in preparation for publication.

Acknowledgements

The support of the QRA Quaternary Research Fund is gratefully acknowledged.

References

Bowen, D.Q. (1967). On the supposed ice-dammed lakes of South Wales. *Transactions of the Cardiff Naturalists Society*, 93, 4-17.

Bowen, D.Q. (1971). The Pleistocene succession and related landforms in north Pembrokeshire and south Cardiganshire. In: Bassett, D.A. and Bassett, M.G. (eds) *Geological Excursions in South Wales and the Forest of Dean*. Cardiff: Geologists Association, 260-266.

Bowen, D.Q. and Gregory, K.J. (1965). A glacial drainage system near Fishguard, Pembrokeshire. *Proceedings of the Geologists' Association*, 74, 275-281.

Charlesworth, J.K. (1929). The South Wales end-moraine. *Quarterly Journal of the Geological Society of London*, 85, 335-358.

Eyles, N. and McCabe, A.M. (1989). The Late Devensian (<22,000YBP) Irish Sea basin: the sedimentary record of a collapsed ice sheet margin. *Quaternary Science Reviews*, 8, 307-351.

Fletcher, C.J.N. and Siddle, H.J. (1998). Development of glacial Llyn Teifi, west Wales: evidence for lake-level fluctuations at the margins of the Irish Sea ice sheet. *Journal of the Geological Societ of London*, 155, 389-399.

Glasser, N.F. and Sambrook Smith, G.H. (1999). Glacial meltwater erosion of the Mid-Cheshire Ridge: implications for ice dynamics during the Late Devensian glaciation of northwest England. *Journal of Quaternary Science*, 14, 703-710.

Hambrey, M.J., Davies, J.R., Glasser, N.F., Waters, R.A., Dowdeswell, J.A., Wilby, P., Wilson, D. and Etienne, J.L. (2001). Late Devensian glacigenic sedimentation in the Cardigan area of southwest Wales. *Journal of Quaternary Science*, 16, 455-482.

John, B.S. (1970). Pembrokeshire. *In:* Lewis, C. A. (ed). *The Glaciations of Wales and Adjoining Regions*. Longman, London, 229-265.

Jones, O.T. (1965). The glacial and post-glacial history of the lower Teifi valley. *Quarterly Journal of the Geological Society of London,* 121, 247-281.

McCarroll, D. and Harris, C. (1992). The glacigenic deposits of western Lleyn, North Wales: terrestrial or marine? *Journal of Quaternary Science*, 7, 19-29.

Sambrook Smith, G.H. and Glasser, N.F. (1998). Late Devensian ice sheet characteristics: a palaeohydraulic approach. *Geological Journal*, 33, 149-158.

Thomas, G.S.P., Chester, D.K. and Crimes, P. (1998). The Late Devensian glaciation of the eastern Lleyn Peninsula, North Wales: evidence for terrestrial depositional environments. *Journal of Quaternary Science*, 13, 255-270.

Waters, R.A., Davies, J.R., Wilson, D. and Prigmore, J.K. (1997). A geological background for planning and development in the Afon Teifi Catchment. *British Geological Survey Technical Report* WA/97/35.

Wilby, P.R. (1998). The Quaternary Sequence of the Buried Valley of the Teifi near Cardigan: A sedimentological investigation of three cored boreholes. *British Geological Survey Technical Report WA/98/33C.*

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CONTEMPORARY FORAMINIFERA OF THE GREAT BARRIER REEF COASTLINE, AUSTRALIA: IMPLICATIONS FOR SEA-LEVEL STUDIES

Introduction

Contemporary foraminiferal investigations have largely been carried out on temperate saltmarshes from the Atlantic (e.g. Gehrels, 2000) and the Pacific coasts of North America (e.g. Jennings and Nelson, 1992), and the Atlantic seaboard of Europe (e.g. Horton *et al.*, 1999). These studies suggest a vertical zonation of foraminifera where the species distribution in intertidal environments is a direct function of altitude, with the duration and frequency of intertidal exposure as the most important factors. However, similar studies from the tropical or sub-tropical environments of Australia to support this conclusion are sparse (e.g. Wang and Chappell, 2001), and furthermore, many of these studies are somewhat ambiguous as the elevations were not levelled to an absolute altitude, and many were concerned with the marine rather than mangrove setting.

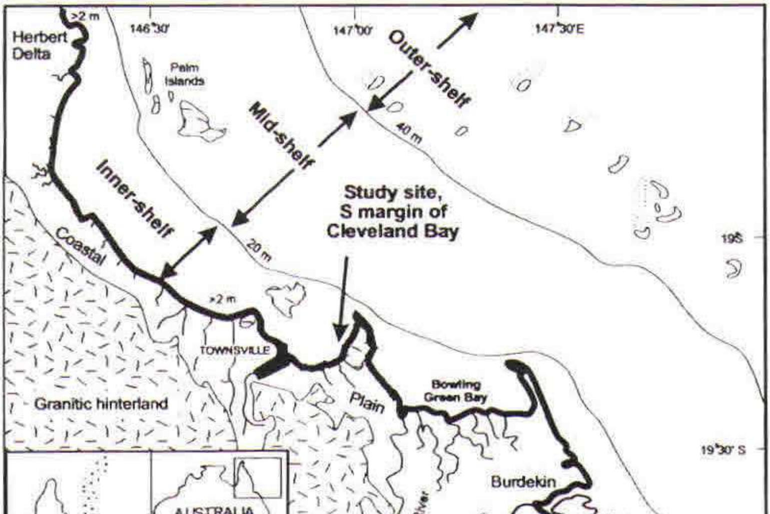

Figure 1. Location map of Cocoa Creek, Great Barrier Reef Coastline, Australia.

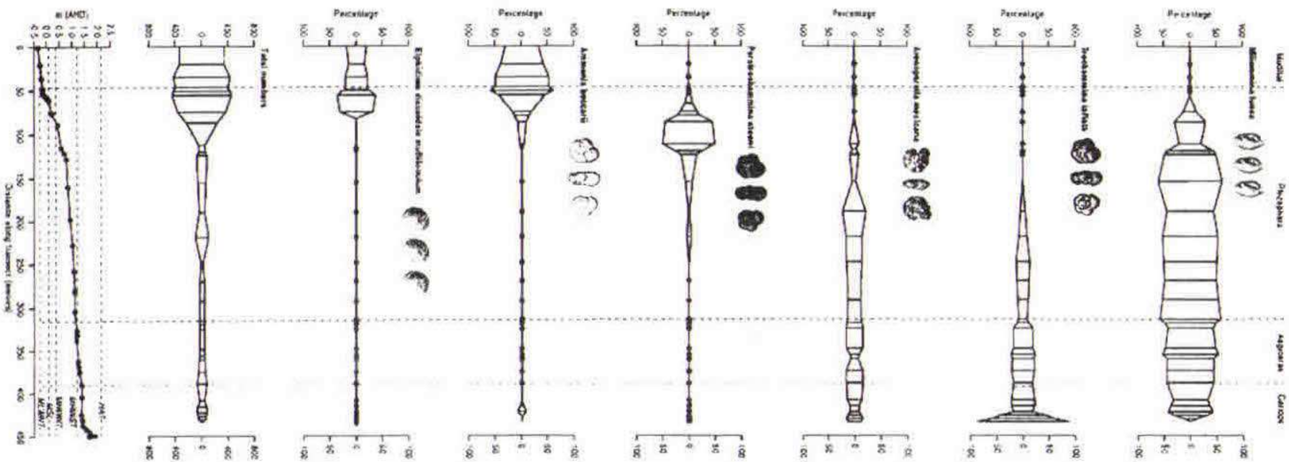

Figure 2. Relative dead foraminiferal abundance of 6 foraminiferal species and foraminiferal populations from Cocoa Creek. The elevation, tidal heights, floral zonation and sampling stations are indicated.

Study area – *Cocoa Creek, The central Great Barrier Reef coastline*

Cocoa Creek is one of three tidal mangrove creek systems in the southern part of Cleveland Bay (Figure 1). The main channel of Cocoa Creek meanders for 9.5 km through a chenier plain, and extends 1.2 km seawards of the mouth across shallow intertidal mudflats. At the mouth of the creek, and along much of the southern margin of Cleveland Bay, is a 30-150 m-wide fringing mangrove swamp, with the trees of up to 7 m in height. Samples of surface sediment were collected from a transect which crossed the intertidal zone, from the most seaward chenier ridge through a mangrove swamp and out onto an unvegetated low-intertidal mudflat.

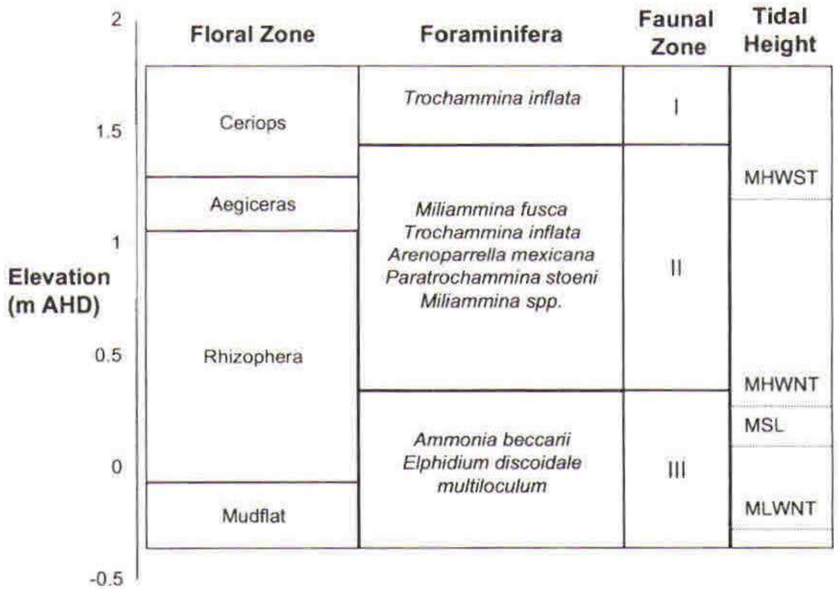

Figure 3. Summary of floral assemblages, floral zones, foraminiferal assemblages, foraminiferal faunal zones and tidal data for Cocoa Creek.

Contemporary foraminiferal distributions

Thirty-six foraminiferal species were identified from the study of surface samples from Cocoa Creek. The foraminiferal assemblages are dominated by 4 agglutinated species, *Miliammina fusca*, *Trochammina inflata*, *Arenoparrella mexicana* and *Paratrochammina stoeni*, and two calcareous species, *Ammonia beccarii* and *Elphidium discoidale multiloculum* (Figure 2). Unconstrained cluster analysis based on unweighted Euclidean distance (no transformation or standardisation of the data) was used to classify contemporary samples into more-or-less homogeneous clusters (Figure 3).

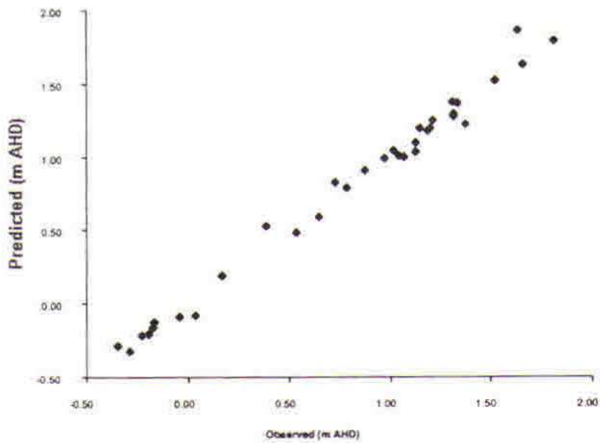

Figure 4. Scatter plots showing the relationship of the observed elevation (m AHD) versus foraminiferal-predicted elevation (m AHD).

- Cluster I coincides broadly with the Ceriops mangrove floral zones and is dominated by *T. inflata* with different percentages of *M. fusca*, *H.* spp. and *A. mexicana*.
- Cluster II corresponds to the seaward margin of the Ceriops, all of the Aegiceras and much of the Rhizophera mangrove floral zone. The foraminiferal assemblage is dominated by agglutinated species, notably *M. fusca*, with low frequencies of *T. inflata*, *A. mexicana*, *M.* spp and *P. stoeni*, and a minor calcareous component.
- Cluster III coincides with the seaward fringes of the Rhizophera and mudflat floral zone. It is dominated by calcareous species, notably *A. beccarii*, *E. discoidale multiloculum*, *Miliolinella spp.* and *Parrellina verriculata*.

Implications for sea-level studies

In the last decade saltmarsh foraminifera from temperate environments have become the method of choice when evaluating sea-level variations, especially for high-resolution studies such as the late Holocene, where decicentimetre changes are of interest (e.g. Gehrels, 2000). To test whether this statement applies to tropical mangrove foraminifera, a transfer function has been developed using a unimodal-based technique known as weighted averaging partial least squares (WA-PLS), following Juggins and ter Braak (1997), based on 25 species and 34 samples from Cocoa Creek. Figure 4 shows the relationship between observed and foraminifera-predicted elevation, which illustrates the strong performance of the WA-PLS transfer functions ($r^2 = 0.98$). Indeed, these results suggest that extremely precise and accurate reconstructions of former sea levels are possible. The transfer function provides an error estimate (RMSEP = 0.08 m) for sample-specific former sea-level reconstructions, which is as good as all other local and regional foraminiferal-based transfer functions from temperate marshes with similar tidal ranges (Edwards and Horton, 2000; Horton *et al.*, 2000, 2002; Gehrels, 2000; Gehrels *et al.*, 2001).

Although there are a number of limitations associated with the contemporary (e.g. spatial, temporal and infaunal variability) and fossil (e.g. post-depositional change) data, sea-level reconstructions using a microfossil-based transfer function have advantages in terms of precision, speed of response and applicability over traditional methods currently employed in sea-level research. With an increasing demand for high-resolution studies of sea-level change it is imperative that the new generation of techniques employed are of the highest possible precision and accuracy. We can then begin to address outstanding issues in sea-level research from the Great Barrier Coastline

Acknowledgements

We acknowledge and greatly appreciate the funding by Quaternary Research Association, in addition to support from British Ecological Society, Menzies Foundation, Nuffield Foundation, the Royal Society and the Australian Research Council. The authors thank Sarah Woodroffe, Matt Wright, Chris Wynn and John Whittaker for their help in the field and laboratory, and taxonomic identification.

References

Edwards, R.J. and Horton, B.P. (2000). High Resolution Records of Relative Sea-Level Change from U.K. Salt-marsh Foraminifera. *Marine Geology*, 169, 41-56.

Gehrels, W.R. (2000). Using foraminiferal transfer functions to produce high-resolution sea-level records from salt-marsh deposits, Maine, USA. *The Holocene*, 10, 367-376.

Gehrels, W.R., Roe, H.M. and Charman, D.J. (2001). Foraminifera, testate amoebae and diatoms as sea-level indicators in UK saltmarshes: a quantitative multiproxy approach. *Journal of Quaternary Science*, 16, 201-220.

Horton, B.P., Edwards, R.J., Lloyd, J.M. (1999). UK intertidal foraminiferal distributions: implications for sea-level studies. *Marine Micropaleonotology*, 36, 205-223.

Horton, B.P., Edwards, R.J. and Lloyd, J.M. (2000). Implications of a microfossil transfer function in Holocene sea-level studies. In: Shennan, I. and Andrews, J.E. (eds) *Holocene land-ocean interaction and environmental change around the western North Sea.* Geological Society Special Publication, 166, 41-54

Jennings, A.E. and Nelson, A.R. (1992). Foraminiferal assemblage zones in Oregon tidal marshes - relation to marsh floral zones and sea-level. *Journal of Foraminiferal Research*, 22, 13-29.

Juggins, S. and ter Braak, C.J.F. (1997). *CALIBRATE.* Department of Geography, University of Newcastle.

Wang, P. and Chappell, J. (2001). Foraminifera as Holocene environmental indicators in the South Alligator River, Northern Australia. *Quaternary International*, 83-85, 47-62.

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RADIOCARBON (AMS) DATING OF THE *BETULA* POLLEN RISE IN THE ISLE OF MAN

A Quaternary Research Fund grant has enabled the early Holocene rise of *Betula* pollen in the Isle of Man to be dated for the first time. Rapid sea-level rise isolated the Isle of Man from Britain by about 11,000 ^{14}C years BP (Lambeck, 1996), and from Ireland rather earlier. The northern plain of the island, composed mainly of glacigenic till and sandur deposits, contains numerous kettle-hole and pingo depressions which have preserved long sequences of Late Glacial and Holocene sediments (Dackombe and Thomas, 1985). Earlier research concentrated upon Late Glacial environmental history, and published and dated pollen and stratigraphic records have been available for some time from the pre-Holocene successions at the base of these depressions (Mitchell, 1958; Dickson *et al.*, 1970). Interest in Late Glacial history was stimulated by the recovery of skeletons of Giant Deer (*Megaloceros giganteus*) from the Late Glacial deposits as these were being dug for marl, particularly in the 19th century. The Holocene environmental record was neglected and the postglacial history of Manx forest development was not radiocarbon dated. The timing of the rise of the earlier Holocene tree taxa remained speculative, in contrast to the well-dated pollen zone boundaries in adjacent areas of Britain and Ireland (e.g. Godwin *et al.*, 1957; Moar, 1969, Hibbert *et al.*, 1971, Smith and Pilcher 1973). Dickson *et al.* (1970) had, however, reported pollen evidence for a lengthy phase of pre-forest vegetation after the transition to the Holocene and before the establishment of *Betula* woodland. The possibility that open conditions may have persisted on the Isle of Man for a long period in the early Holocene has been given added interest by the radiocarbon dating of *Megaloceros* remains from a depression near Ballaugh to 9225±85BP (Gonzalez *et al.*, 2000). The hypothesis that the persistence of non-woodland ecological conditions may have allowed the late survival of the Giant Deer on the Isle of Man requires testing, in particular by firmly establishing the date of the establishment of *Betula* woodland on the island.

As part of a recent research project (Innes *et al.*, in press), new pollen sequences have been recovered from the northern plain of the Isle of Man to test the age and distribution of early Holocene pre-forest plant communities and to provide suitable sediment for dating the *Betula* rise. Sites at Pollies and Curragh y Cowle were chosen (Figure 1), the former very close to the depression from which the *Megaloceros* remains dated by Gonzalez *et al.* (2000) were recovered. Both of these new sites showed long sequences of sediments after the Late Glacial (c.f. Loch Lomond) Stadial which were dominated by pollen of herbaceous and low shrub taxa indicative of open conditions and which would be of early Holocene age. At Pollies, radiocarbon dating had shown that the *Juniperus* maximum, a key feature in the Late Glacial to Holocene transition

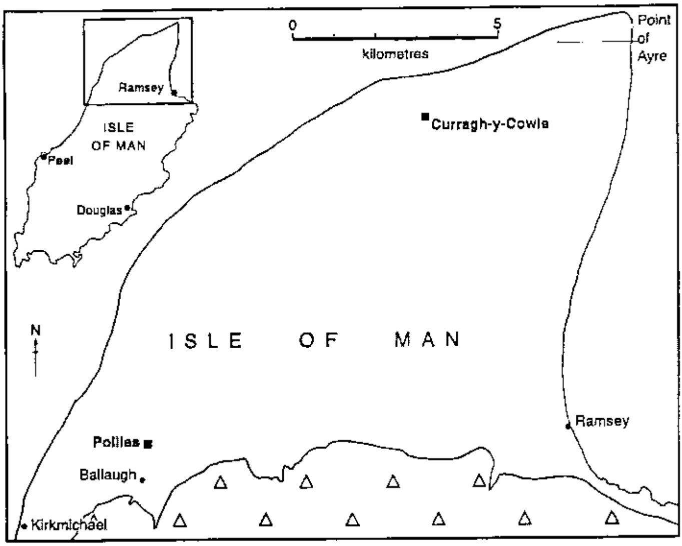

Figure 1. Location map showing study sites at Pollies and Curragh-y-Cowie. Open triangles indicate upland.

from herbaceous to woodland dominance, did not occur until c.9450BP. At Curragh y Cowle the establishment of *Corylus* did not occur until c.8800BP. Bio-stratigraphically, the rise of *Betula* pollen should be recorded at both sites between these existing dates. The sharp rise in *Betula* pollen, where it replaces herb and *Juniperus* pollen as the dominant and signifies the establishment of birch woodland, was dated by AMS at Pollies to 9320±55BP (GU-9708) and at Curragh y Cowle to 9275±50BP (Gu-9709). In both cases maximum *Betula* frequencies, and so closed birch woodland, occurred a few centimetres above the dated levels.

Comments

Although slightly later than the rational limit of *Betula* (*sensu stricto*), these two dates give closely comparable, reliable ages for the major spread of birch woodland on the northern plain of the Isle of Man and its replacement of open herb and shrub communities. They are also in sequence chronologically with dates on other early Holocene pollen-stratigraphical features from the profiles. Fully closed *Betula* forest would have occurred even later than these two ages, which average close to 9300BP. Comparison of these two Manx dates with dates on the spread of *Betula* in adjacent areas of Britain and Ireland shows them to be in every case significantly later. The birch rise at several sites in Northern Ireland (Smith and Pilcher, 1973), at Scaleby Moss in Cumbria

(Godwin *et al.*, 1957), at Bigholm Burn in south-west Scotland (Moar, 1969) and at Red Moss in Lancashire (Hibbert *et al.*, 1971) occurs around 9600BP. The interpolated date of Tipping (1995) at Kirkpatrick Fleming, in south-west Scotland, is only slightly later at c.9500BP. The two late Manx dates are comparable with that of 9225±85BP reported by Gonzalez *et al.* (2000) on the *Megaloceros* remains from near Ballaugh. In this island environment where there is as yet no evidence of the presence of human hunters this early in the Holocene (McCartan, 1999), it is possible that relict populations of the open-habitat adapted *Megaloceros* may have persisted until major environmental change, the establishment of woodland, removed their ecological niche and led to their extinction. The late rise of Manx Holocene woodland demonstrated by the new dates provides an environmental context and ecological rationale in which the hypothesis of *Megaloceros* survival several centuries into the Holocene remains tenable.

Acknowledgements

Thanks to Gordon Cook of SURRC, East Kilbride, for the radiocarbon dates and to Oliver of the Department of Geography, Queen Mary for the figure. The British Ecological Society contributed funds to supplement the Quaternary Research Association grant.

References

Dackombe, R.V. and Thomas, G.S.P. (1985). *Field Guide to the Quaternary of the Isle of Man.* Quaternary Research Association, Cambridge.

Dickson, C.A., Dickson, J.H.P. and Mitchell, G.F. (1970). The Late Weichselian flora of the Isle of Man. *Philosophical Transactions of the Royal Society of London,* B 258, 31-79.

Godwin, H., Walker, D. and Willis, E.H. (1957). Radiocarbon dating and postglacial vegetation history: Scaleby Moss. *Proceedings of the Royal Society of London*, B 147, 352-366.

Gonzalez, S., Kitchener, A.C. and Lister, A.M. (2000). Survival of the Irish Elk into the Holocene. *Nature,* 405, 753-754.

Hibbert, F.A., Switsur, V.R. and West, R.G. (1971). Radiocarbon dating of Flandrian pollen zones at Red Moss, Lancashire. *Proceedings of the Royal Society of London,* B 177, 161-176.

Innes, J.B., Chiverrell, R.C. and Blackford, J.J. (in press). History of the Flora of the Isle of Man. In Chiverrell, R.C. and Thomas, G.S.P. (eds) *A New History of the Isle of Man: Volume 1: the Manx Environment.* Liverpool University Press, Liverpool.

Lambeck, K. (1996). Glaciation and sea-level change for Ireland and the Irish Sea since Late Devensian/Midlandian time. *Journal of the Geological Society of London*, 153, 853-872.

McCartan, S.B. (1999). The Manx early Mesolithic: a story in stone. In Davey, P.J. (ed) *Recent Archaeological Research on the Isle of Man*. Oxford, BAR British Series 278, 5-11.

Mitchell, G.F. (1958). A Lateglacial deposit near Ballaugh, Isle of Man. *New Phytologist*, 57, 256-263.

Moar, N.T. (1969). Late Weichselian and Flandrian pollen diagrams from south-west Scotland. *New Phytologist*, 68, 433-467.

Smith, A.G. and Pilcher, J.R. (1973). Radiocarbon dates and vegetational history of the British Isles. *New Phytologist*, 72, 903-914.

Tipping, R.M. (1995). Holocene evolution of a lowland Scottish landscape: Kirkpatrick Fleming. Part II, regional vegetation and land-use change. *The Holocene*, 5, 83-96.

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LATE QUATERNARY GLACIGENIC FACIES ASSOCIATED WITH ICE-STREAM RECESSION IN THE IRISH SEA, SCREEN HILLS, SOUTH-EAST IRELAND

Over the last two decades there has been a major debate as to whether the shelly drifts exposed around the terrestrial margins of the Irish and Celtic seas (the Irish Sea Drifts) are subglacial tills deposited by a grounded Irish Sea Ice Stream (ISIS) or are glacimarine sediments deposited during ice-stream retreat. Resolution of this issue is important because the ISIS was the largest ice stream to drain the last British Ice Sheet and its dynamics were crucial to the geometry and volume of the ice sheet as a whole. Accurate reconstructions of the extent and dynamics of the ice stream are therefore key inputs to models of the British Ice Sheet and its relative sea-level fluctuations, and, more broadly, are critical for determining the contribution of this ice sheet to eustatic sea-level rise since the LGM. Furthermore, although the geomorphological record of ice streams has been the focus of much recent research (e.g., Stokes and Clark, 1999; Clark and Stokes, 2001; Wellner *et al.*, 2001; Ó Cofaigh *et al.*, 2002; Canals *et al.*, 2002), relatively little emphasis has been placed on the sedimentary signatures of such systems, despite their presumable importance in subglacial sediment transport.

The Screen Hills of County Wexford, south-east Ireland, is one of the largest accumulations of glacigenic sediment associated with the ISIS. It marks the first major stillstand of the ice stream during its late Devensian retreat. Contrasting interpretations of this deposit range from a large prograded glacimarine delta (Eyles and McCabe, 1989) to glacilacustrine sediments and subglacial tills (Thomas and Summers, 1983). The objectives of the present investigation are to reconstruct the depositional environments at the margin of the ISIS during formation of the Screen Hills and to investigate the relationship between the sedimentary facies and ice-stream dynamics.

Fieldwork was carried out during the summer of 2001 in collaboration with ***Dr. David Evans*** (University of Glasgow) and involved sedimentological and structural geological investigations of Quaternary sediments exposed in coastal sections along the Screen Hills and south of Wexford harbour. Glacial geomorphology was also mapped from aerial photographs in order to assess the geomorphic signature of ice-marginal oscillations in the Screen Hills.

The main focus of investigation was on the genesis and palaeo-glaciological significance of the Ballinclash Member, which caps the Quaternary succession at the Screen Hills. Sedimentological and structural geological data indicate that the Ballinclash Member formed by a combination of subglacial deformation (producing glacitectonites and deformation till) and ice-marginal subaquatic deposition during short-lived onshore oscillations of the ISIS. Deformation tills within the Ballinclash Member are the product of subglacial cannibalisation and reworking of pre-existing glacilacustrine sediments. The basal member of the Screen Hills succession, the Macamore Member (Thomas and Summers, 1983), and its south coast stratigraphic equivalent "Irish Sea Till" (Ó Cofaigh and Evans, 2001a and b) record the onshore flow of the ISIS. The overlying Knocknasilloge Member records a period of ice-stream recession punctuated by readvances that folded and thrust the Macamore and Kocknasilloge members into a series of glacitectonic ridges containing buried glacier ice. The Screen Member was deposited in ice-contact fans during stillstands in retreat. The readvances/stillstands recorded at the Screen Hills were probably topographically controlled, and resulted from stabilisation of the ice stream as it receded into the strait between Pembrokshire and SE Wexford. The sedimentological data are consistent with a glacilacustrine/glaciterrestrial interpretation of the Screen Hills (cf. Thomas and Summers, 1983) and no evidence was found in support of a glacimarine depositional environment.

Finally, a range of diagnostic criteria for the identification of dynamic, possibly surging, ice-stream margins onshore have been identified based upon this investigation (Evans and Ó Cofaigh, submitted) and on previous work from the south coast of Ireland (Ó Cofaigh and Evans, 2001a and b). These include thrust-block moraines, tectonised pitted outwash and stacked sequences of glacitectonites, deformation tills and intervening stratified deposits.

Research into the glacigenic sequences of southern and south-eastern Ireland is on-going and, in combination with sedimentological data from other locations, including Antarctica, will further understanding of till genesis under marine-based palaeo-ice streams.

Acknowledgements

The Quaternary Research Association is gratefully acknowledged for its financial contribution to fieldwork in south-eastern Ireland in 2001.

References

Canals, M., Casamor, J.L., Urgeles, R., Calafat, A.M., Domack, E.W., Baraza, J., Farran, M. and De Batist, M. (2002). Sea-floor evidence of a subglacial sedimentary system off the northern Antarctic Peninsula. *Geology*, 30, 603-606.

Clark, C.D. and Stokes, C.R. (2001). Extent and basal characteristics of the M'Clintock Channel Ice Stream. *Quaternary International*, 86, 81-101.

Evans, D.J.A. and Ó Cofaigh, C. (submitted). Evidence for a dynamic Irish Sea Ice Stream during the last glaciation. *Boreas*.

Ó Cofaigh, C., and Evans, D.J.A. (2001). Deforming bed conditions associated with a major ice stream of the last British ice sheet. *Geology*, 29, 795-798.

Ó Cofaigh, C. and Evans, D.J.A. (2001). Sedimentary evidence for deforming bed conditions associated with a grounded Irish Sea Glacier, southern Ireland. *Journal of Quaternary Science*, 16, 435-454.

Ó Cofaigh, C., Pudsey, C.J., Dowdeswell J.A. and Morris, P. (2002). Evolution of subglacial bedforms along a paleo-ice stream, Antarctic Peninsula continental shelf. *Geophysical Research Letters*, 29 (8), 10.1029/2001GL014488.

Eyles, N. and McCabe, A.M. (1989). The Late Devensian (22, 000 BP) Irish Sea Basin: the sedimentary record of a collapsed ice sheet margin. *Quaternary Science Reviews*, 8, 307-351.

Thomas, G.S.P. and Summers, A.J. (1983). The Quaternary stratigraphy between Blackwater Harbour and Tinnaberna, county Wexford. *Journal of Earth Sciences, Royal Dublin Society*, 5, 121-134.

Stokes, C.R. and Clark, C.D. (1999). Geomorphological criteria for identifying Pleistocene ice streams. *Annals of Glaciology*, 28, 67-74.

Wellner, J.S., Lowe, A.L., Shipp, S.S. and Anderson, J.B. (2001). Distribution of glacial geomorphic features on the Antarctic continental shelf and correlation with substrate: implications for ice stream behaviour. *Journal of Glaciology*, 47, 397-411.

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$\delta^{13}C$ OF TREE-RING LIGNIN AS AN INDIRECT MEASURE OF CLIMATE CHANGE

Introduction

High-resolution palaeoclimatic data are essential for testing numerical models of climate change and the global carbon cycle. If the long tree-ring chronologies, originally established for the purpose of dendrochronology, are to be fully exploited as an indirect measure of past climatic variability, additional techniques are required to obtain this information. The determination of the $\delta^{13}C$ value of tree-ring cellulose has been successfully used to reconstruct past climates. However, under both aerobic and anaerobic conditions, the polysaccharide components of vascular plants (mainly cellulose and hemicelluloses) are more prone to rapid degradation than lignin. This study investigates the $\delta^{13}C$ value of tree-ring lignin as a proxy measure of past climates.

Methods

An absolutely dated ring-width chronology was established for oaks (*Quercus robur* L.) growing at Sandringham Park in eastern England. Carbon isotope values were determined on α-cellulose (Robertson *et al.*, 1997) and Klason lignin isolated from annual latewood samples over the period AD 1895-1999 (Figure 1).

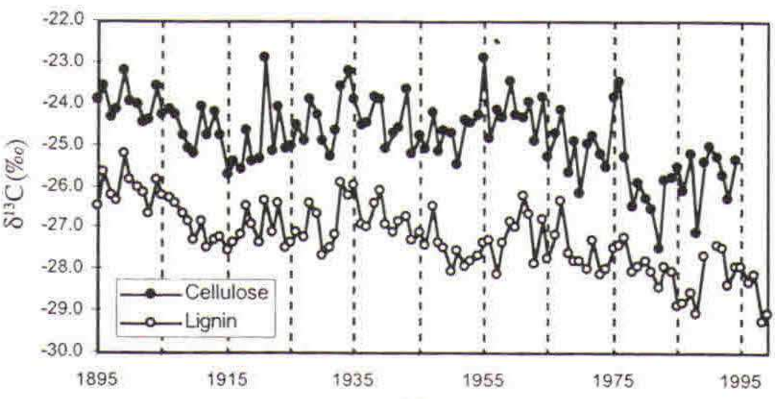

Figure 1. Annual Sandringham $\delta^{13}C$ values (AD 1895-1999) for tree SP19. Over the common period (AD 1895-1994), the mean α-cellulose $\delta^{13}C$ value= 24.760 (n=100; s_{n-1}= 0.87) and the mean lignin $\delta^{13}C$ value=27.170 (n=99; s_{n-1}=0.76). Mean $\Delta_{cellulose\text{-}lignin}$= -2.4‰.

Results

The anthropogenic decrease in $\delta^{13}C$ values attributed to the burning of fossil fuels and the release of carbon through deforestation (Keeling *et al.*, 1979) is evident in both the α-cellulose and lignin time-series (Figure 1). To investigate the high-frequency climate dependence and the relationship between cellulose and lignin formation, these anthropogenic influences and other long-term trends were removed from the time-series during standardisation, where each measured value was divided by a 'fitted' value (Robertson *et al.*, 1997).

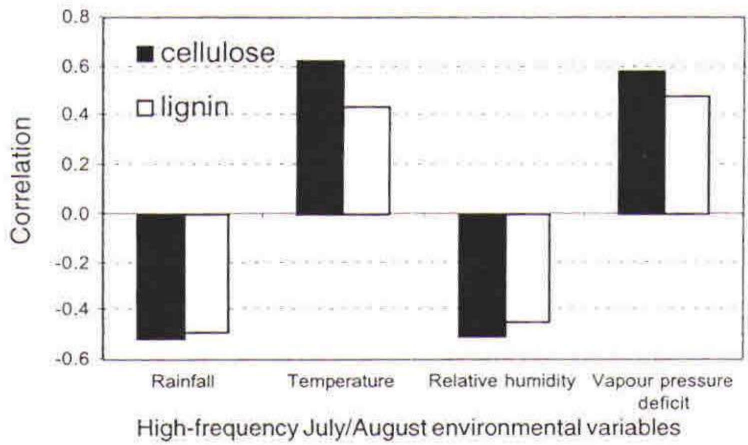

Figure 2. Relationship between high-frequency Sandringham cellulose and lignin carbon isotope indices for tree SP19 and high-frequency environmental variables. All correlations (r) are significant at $p<0.01$.

The high-frequency variance in the carbon isotope indices of latewood cellulose and lignin was correlated with combined July and August high-frequency environmental variables, indicating that they were formed at similar times (Figure 2). The $\delta^{13}C$ values of α-cellulose were more sensitive to climate than the $\delta^{13}C$ values of lignin. Similar results were reported by Mazany *et al.* (1980) for 10-year bulk samples of ponderosa pine. However, the difference between the mean correlation between carbon isotope indices from these wood constituents and environmental variables was not statistically significant ($p>0.01$), supporting the view that $\delta^{13}C$ value of tree-ring cellulose or lignin could be used as an indirect measure of past climate (Robertson *et al.*, submitted).

Conclusions

The high-frequency variance in the carbon isotope indices of latewood lignin and cellulose was highly correlated with combined high-frequency July and

August environmental variables indicating that they or their precursors were formed from material fixed at similar times. Therefore, $\delta^{13}C$ values of latewood from α-cellulose or lignin could be used as an indirect measure of past climates. Lignin has the advantage that it is more resistant to decay than cellulose under a wide range of environmental conditions.

Acknowledgements

I am grateful to Mike Saville and the Royal Estate of Sandringham for permission to sample trees and to many colleagues for their support during this collaborative research. In particular, I thank Steve Leavitt and Li Cheng (University of Arizona), Debbie Hemming (Weizmann Institute of Science), Roy Switsur and Tony Carter (University of Cambridge), Neil Loader and Danny McCarroll (University of Wales Swansea) and John Waterhouse (Anglia Polytechnic University). This research would not have been possible without the provision of a Quaternary Research Fund grant towards analysis costs and the award of an Agnese Haury Fellowship at the Laboratory of Tree Ring Research, University of Arizona.

References

Keeling, C.D., Mook, W.G. and Tans, P.P. (1979). Recent trends in the $^{13}C/^{12}C$ ratio of atmospheric carbon dioxide. *Nature*, 277, 121-123.

Mazany, T., Lerman, J.C. and Long, A. (1980). Carbon-13 in tree-ring cellulose as an indicator of past climates. *Nature*, 287, 432-435.

Robertson I., Switsur V.R., Carter A.H.C., Barker A.C., Waterhouse J.S., Briffa K.R. and Jones P.D. (1997). Signal strength and climate relationships in the $^{13}C/^{12}C$ ratios of tree-ring cellulose from oak in east England. *Journal of Geophysical Research*, 102(D16), 19507-19516.

Robertson, I., Loader, N.J., McCarroll, D., Carter, A.H.C., Cheng, L. and Leavitt, S.W. (submitted). $d^{13}C$ of tree-ring lignin as an indirect measure of climate change. *Water, Air and Soil Pollution*.

Wilson, A.T. and Grinsted, M.J. (1977). $^{12}C/^{13}C$ in cellulose and lignin as palaeothermometers. *Nature*, 265, 133-135.

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NEW RESEARCH WORKERS AWARD SCHEME

GLACIO-FLUVIAL TRANSFER PROCESSES IN A NORWEGIAN HIGH ARCTIC CATCHMENT

A six-week field investigation into the spatial and temporal variability of fluvial sediment transfer was carried our in the Midre Lovénbreen catchment, a 5.5 km² polythermal glacier (78°56'N and 12°10'E), located within Kongsfjorden on the north-west of Svalbard close to the research base of Ny-Ålesund. Past research has shown that the magnitude and variability of runoff are poor predictors of sediment transfer processes and are inadequately represented in existing hydrological models. The aim is to develop a spatially distributed model that will represent sediment transfer processes operating within the proglacial zone of a High Arctic glacier, to establish sediment transfer budgets and temporal scales of processes.

The main achievements of the field season were collection of streamflow time series at multiple at ice-proximal and ice-distal sites around the catchment. Up to 40 days runoff and turbidity data, more than 90 individual discharge measurements, and bedload samples were obtained. Figure 1 highlights raw

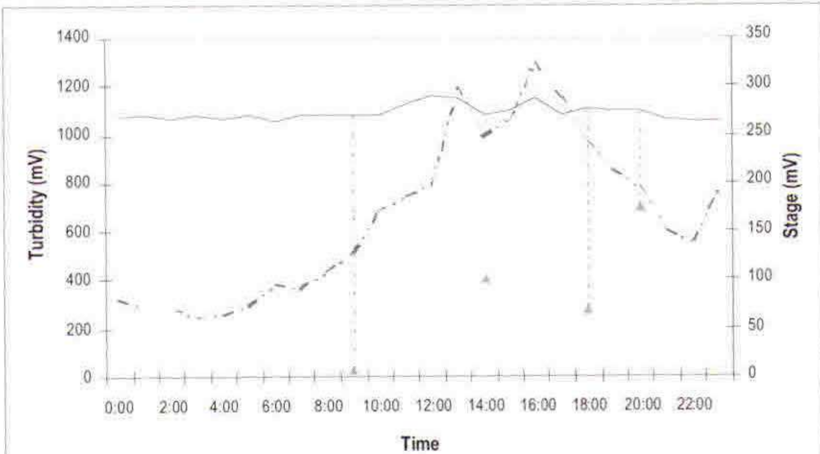

Figure 1. Stage, turbidity and bedload data for the western outlet stream for the 10th July.

data for the outlet of the proglacial basin of the western drainage stream for 10th July, showing stage (as yet to be converted to discharge), turbidity (as yet to be converted to suspended sediment concentration) and bedload data.

Further data reduction and laboratory analysis are required in order to meet the original objectives of the project. Hydrometric and fluvial sediment transport data have been collected at a high spatial and temporal resolution for a High Arctic catchment. When the full dataset has been analysed it will be possible to determine a proglacial fluvial sediment budget for Midre Lovénbreen, including suspended sediment and bedload data, indicating whether the glacier fore field is a net source or sink of sediment.

Preliminary Results and Work in Progress

The work highlighted above will be used in conjunction with data collected during a field season in the previous year to construct both a seasonal total sediment budget, and an inter-seasonal total sediment budget. It is hoped that this will give some insight into the reaction of small polythermal arctic glaciers to undergoing a century of glacial retreat and the effect of this on the sediment regime. Preliminary results indicate that a highly variable discharge regime throughout a season has a greater impact and control on sediment budgets in comparison to steady changes through the season. If enhanced high-latitude atmospheric warming promotes an intensified hydrological cycle and further glacier retreat, this effect maybe intensified through the coming century. These results highlight the need for further investigation into the range of processes driving fluvial sediment transfer at the sub-catchment scale if we are to forecast future arctic fjord systems.

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DEBRIS FROM THE BASAL ICE LAYER OF GLACIERS AND ICE SHEETS

Ice at the base of a glacier is chemically and physically distinctive from the overlying glacier ice and is referred to as basal ice. It reflects sub-glacial processes and includes basally-derived sediment. The basal layer is, in many glaciers, composed of different facies: stratified facies, dispersed facies and debris bands. It has been suggested that the debris bands are structurally derived from the stratified facies due to compression at the margin (Knight, 1994).

Previous research focussing upon the fine-grained particles of both the stratified facies and the debris bands at the Russell Glacier, Greenland, concluded that they were indistinguishable (Knight, 1994). However, the pebble-sized debris has not been analysed and research in Svalbard (Hambrey *et al.*, 1999) has provided evidence that a difference between the stratified facies and the debris bands may exist. This difference was indicated using co-variance plots of the RA index and the C40 index, a technique presented by Benn and Ballantyne (1994).

The fieldwork at the Russell Glacier investigated whether it was possible to distinguish between debris in the stratified facies and in the debris bands. Sediments from ice-marginal moraines were also analysed to provide comparison with the debris from the basal ice. This comparison could provide a technique that allows the reconstruction of the basal layer of former ice margins, allowing reconstruction of the compression, basal thermal regime, hydrology and local temperature at the margin. For a technique to be developed, sampling would need to take place in moraines where glaciations have occurred before. A comparison of results could then allow insight to whether or not similar processes were occurring at the margin of previous ice sheets.

The research involved field measurements of clasts from the stratified facies, debris bands and the moraine at the margin of the ice sheet near Kangerlussuaq, western Greenland. This was to establish whether the clasts from the two layers could be distinguished using Benn and Ballantyne's (1994) method.

Preliminary results have indicated that the pebble-sized debris in the debris bands contains a higher percentage of very angular and angular material than occurs in the stratified facies, making them statistically distinct. Future sampling at the Russell Glacier could provide information relating to any processes governing the higher amount of very angular and angular material within the debris bands.

References

Benn, D. I. and Ballantyne, C. K. (1994). Reconstructing the transport history of glacigenic sediments: a new approach based on the co-variance of clast form indices. *Sedimentary Geology*, 91, 215-227.

Hambrey, M.J., Bennett, M.R., Dowdeswell, J.A., Glasser, N.F. and Huddart, D. (1999). Debris entrainment and transfer in polythermal valley glaciers. *Journal of Glaciology*, 45, 69-86.

Knight, P.G. (1994). Two-facies interpretation of the basal layer of the Greenland ice sheet contributes to a unified model of basal ice formation. *Geology*, 22, 971-974.

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FLUVIAL RESPONSES TO RAPID CLIMATE CHANGE IN EASTERN ENGLAND DURING THE LAST GLACIAL PERIOD

The aim of the project "Fluvial responses to rapid climate change during the last glaciation in Eastern England" is to assess at which scales fluvial systems respond to rapid climate fluctuations. The catchments studied in the northern Fenland (Rivers Nene and Welland) were chosen to minimise the effects of non-climatic forcing factors. To achieve this end, the catchments are small, low-relief, outside the limits of glacial advance, and relatively unaffected by sea-level changes. The project has involved detailed description of the sites studied to determine major changes in sedimentation, and dating of the units identified (QN 91, pp. 42-43). Significant variability has been observed within the fluvial sequences, enabling catchment-scale models of change to be outlined.

Dating of the sediments has been undertaken using both radiocarbon and optically stimulated luminescence (OSL) techniques. The use of OSL in parallel with radiocarbon dating is essential for studying the last glacial period, given the time limitations of the radiocarbon technique and the rare occurrence of suitable organic material. This is one of the first applications of both techniques to fluvial sediments in Britain, which is a strength, since "comparison of luminescence dates with independent age control is a vital aspect of quality control" (Clarke *et al.*, 1999, p. 174). Key to the success of the comparison between radiocarbon and OSL dates has been a group of dating samples which were chosen as 'tie-points' for the broader chronology. At each 'tie-point' site, OSL samples span the full stratigraphical succession, and at least one radiocarbon date calibrates these profiles. Direct calibration of these age estimates is achieved through sampling of plant macrofossils for radiocarbon analysis and of sand for luminescence dating from the same channel fills.

AMS radiocarbon dating was carried out by the NERC Radiocarbon laboratory, East Kilbride. OSL analyses were undertaken by Rebecca Briant in the Godwin Laboratory, University of Cambridge, on the quartz fraction of the coarse sand grains in each sample (90-125 μm), using the Single Aliquot Regenerative approach (Murray and Wintle, 2000). Funding from the QRA New Research Workers Award scheme enabled determination of radiation dose rates using Neutron Activation Analysis (NAA) to ascertain levels of Uranium, Thorium and Potassium in the sediments.

It is interesting to note from figure 1 that radiocarbon ages seem to consistently underestimate the OSL ages beyond 40,000 calendar years B.P., (35,000 radiocarbon years B.P.). This finding may corroborate the 'gut feeling' of many Quaternary workers that radiocarbon dates in this time range should be treated as minimum estimates. Alternatively, some may argue that it represents 'partial bleaching' of the fluvial sediments in the older time range. However, the close relationship between radiocarbon and OSL ages younger than 40,000 calendar

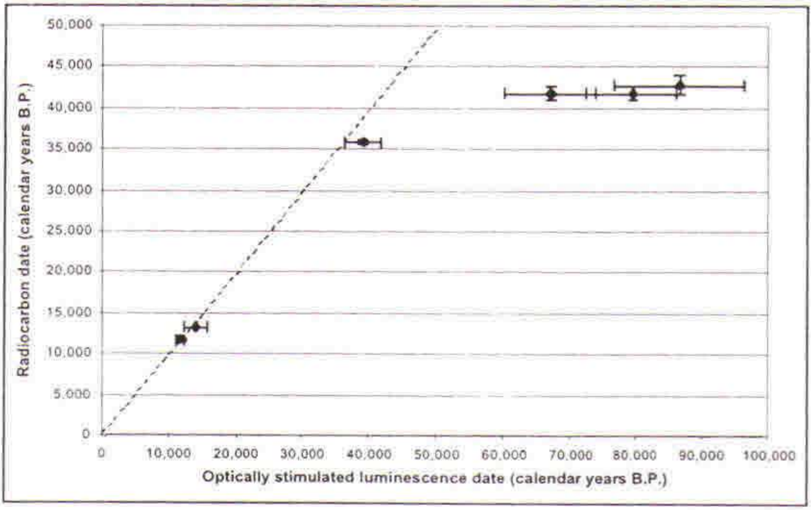

Figure 1. Comparison of radiocarbon and optically stimulated luminescence (OSL) dates from four fluvial sequences in the Nene and Welland valleys, in the northern Fenland. The dotted line shows a 1:1 relationship between the dates produced. All radiocarbon dates presented (CAMS-73413, AA-40472, CAMS-73420, AA-41161, AA-41737, AA-41739) are calibrated, to allow for comparison with OSL dates, although the lack of an internationally accepted radiocarbon calibration beyond 24,000 y B.P. is noted. Radiocarbon calibration follows Stuiver *et al.* (1998) for dates within 24,000 y B.P.; and Beck *et al.* (2001) for dates beyond 24,000 y B.P.

years B.P. suggests that not all fluvial sediments suffer from partial bleaching. Thus partial bleaching may not necessarily be the correct explanation for the discrepancy seen. The large error bars observed are an inherent feature of older OSL ages, due to the exponential shape of the growth curve.

References

Clarke, M.L., Rendell, H.M. and Wintle, A.G. (1999). Quality assurance in luminescence dating. *Geomorphology*, 29, 173-185.

Murray, A.S. and Wintle, A.G. (2000). Luminescence dating of quartz using an improved single-aliquot regenerative-dose protocol. *Radiation Measurements*, 32, 57-73.

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CALVING DYNAMICS AT THE LAKE-TERMINATING GLACIAR LEONES, CHILEAN PATAGONIA

The Patagonian Icefields are the largest in the Southern Hemisphere outside of Antarctica, with a combined area of 17 200 km^2. Their presence at such low latitudes means the outflow glaciers terminate in a wide diversity of climatic environments. Despite their size and importance, they are still poorly understood, for example in terms of their iceberg calving behaviour (Van der Veen, 2002; Hughes, 2002). This creates the potential for a rapidly changing terminus position, which may be explained in terms of the internal dynamic behaviour.

Methodology

Fieldwork undertaken September-November 2001 gathered fundamental glaciological and limnological data from Glaciar Leones. Repeat surveys of the ice front were used to monitor the terminus velocity and rate of terminus change. Studies of the lake included vertical temperature profiling of the water column. Water depths were also mapped, with particular attention paid to the area closest to the ice front, in order to test the water depth-calving rate hypothesis of Brown *et al.* (1982). In support of these data, meteorological data both near the glacier and at the far end of the lake were gathered.

Outcomes

Preliminary analysis of the data suggests that the calving rate is at least comparable to other lake-calving glaciers in the region (Warren *et al.*, 2001), with ice velocities at the terminus of ~ 0.5–2 m day^{-1}. Calving from the 45 m-high cliff takes place into water ~ 80 m deep, and the 10 km-long lake is in places up to 330 m deep. A well-developed warm layer with surface water temperatures of 5-7°C was present, warmer than many lake-calving outlets on the NPI (~3°C). Considerable waterline-notch development on the ice cliff was evident, and additional ice loss is derived from the calving of subaqueous ice "feet".

Figure 1 shows the long profile of Lago Leones, with typical temperature profiles for the proximal and distal regions. Mixing in the proximal zone is mostly due to meltwater input, which was also responsible for a < 1 m rise in the lake level that took place. A thermocline developed in the distal zone, and extended towards the glacier as the summer progressed, bringing warmer surface waters closer to the waterline of the ice cliff. Heat was also transferred towards the ice front by the winds blowing up the lake from Glaciar Fiero. It was not possible to quantify the melt notch development due to safety restrictions. However, the visibility of the notch would imply that melting is important for the overall calving rate by driving undercutting (Vieli *et al.*, 2001).

Figure 2 illustrates a regional comparison of the water depth-calving rate relation. Whilst the R^2 values are not strong, the graph does highlight the

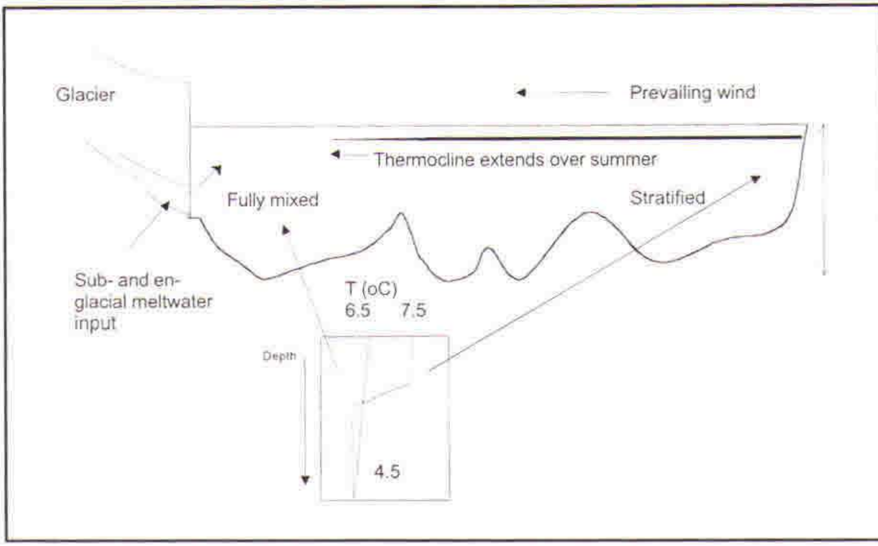

Figure 1. Long profile of the lake, illustrating typical temperature profiles measured, conditions of stratification, and the progressionof the thermocline towards the ice front over the summer season.

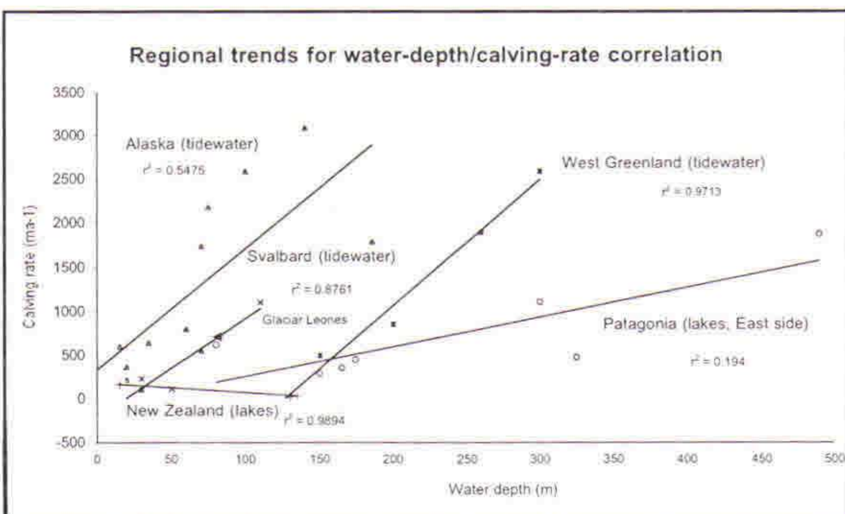

Figure 2. Water depth/calving correlation, showing the marked difference in calving magnitude between freshwater and tidewater glaciers. The calving coefficient is reflected in the best fit line slope.

general correlation and, in particular, the order of magnitude difference between freshwater and tidewater rates (Funk and Röthlisberger, 1989; Van der Veen, 2002; Warren *et al.*, 2001), to which the Leones data contributes. However, the correlation in itself is not a causative explanation for calving. A complimentary modelling approach is currently in progress, which will be tested using data from both 2001 and the forthcoming 2002 fieldtrip, to work towards a more suitable causative solution to calving behaviour.

Sediment sampling in the lake was not carried out, due to some early setbacks necessitating efforts to be concentrated on the above. It is anticipated that it will be investigated at Leones in October 2002. Neither was it possible to undertake any surface ablation measurements near the glacier terminus, due to intense crevassing preventing access.

Further study of both Glaciar Leones and Glaciar Fiero, located nearby, is intended. Similar data will be gathered from Fiero, where different internal controls operate compared to those at Leones, due to the differences in size of icebergs produced and the crevasse density. At Leones suspended sediment concentration, and the resultant significance for subaqueous melting, will be investigated, and ice velocity measurements will allow the annual calving rate to be extrapolated.

Acknowledgements

I would like to thank Raleigh International and the Venturers who worked with me at Leones, often in adverse conditions. In addition, thanks go to all those who provided financial support, without which my fieldwork would not be possible.

References

Brown, C.S., Meier, M.F. and Post, A. (1982). Calving speed of Alaska tidewater glaciers with applications to the Columbia Glacier, Alaska. *U.S. Geological Survey Professional Paper* 1258-C, 13 pp.

Funk, M. and Röthlisberger, H. (1989). Forecasting the effects of a planned reservoir which will partially flood the tongue of Unteraargletscher in Switzerland. *Annals of Glaciology*, 13, 76-81.

Hughes, T. (2002). Calving Bays. *Quaternary Science Reviews*, 21, 267-282.

Vieli, A., Funk, M. and Blatter, H. (2001). Flow dynamics of tidewater glaciers: a numerical modelling approach. *Journal of Glaciology*, 47, 595-606.

Warren, C.R., Glasser, N.F., Harrison, S., Winchester, V., Kerr, A.R. and Rivera A. (1995a). Characteristics of tidewater calving at Glaciar San Rafael, Chile. *Journal of Glaciology*, 41, 273-289.

Warren, C.R., Benn, D.I., Winchester, V. and Harrison, S. (2001). Buoyancy-driven lacustrine calving, Glaciar Nef, Chilean Patagonia. *Journal of Glaciology*, 47, 135-146.

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EXTENSIVE SUB-GLACIAL WATER ESCAPE STRUCTURES AT THE NORTHERN MARGIN OF MYRDALSJÖKULL GLACIER, ICELAND

This report describes water-escape structures (WES) in the sediments of the undulating till plain at Sléttjökull, the northern margin of Myrdalsjökull, southern Iceland. Van der Meer *et al.* (1999) described WES along a transect from the present-day ice margin to the 1900 ice-marginal moraine, a distance of 1.2 km. They interpreted that the widespread occurrence of WES must point to some extraordinary circumstances, and concluded that the sequence reveals that an overproduction of subglacial meltwater, attributed to the 1918 Katla eruption (beneath the Myrdalsjökull glacier) was blocked by a frozen glacier toe, and increasing water pressure led to the formation of the WES. These WES originate in a till unit and disappear down-ice into underlying sands and gravels. The WES start with finely laminated silt or clay. These laminae join and form funnel shapes that come together to form larger sets of sand, silt and clay laminae that break through the base of the till and through the outwash. From a distance they have a stepped appearance because they contain knee-bends, varying the orientation of the WES between sub vertical and horizontal. The horizontal orientation occurs at the contact with fine grained outwash layers.

WES observed in the present study along a 10 km stretch of the northern margin of the glacier were found to form a continuous belt. Over thirty WES sites were recorded between the glacier margin and the 1900 ice-marginal moraine (a maximum of about 1.5 km from the glacier margin). The WES could be divided into three zones: (1) a belt of small WES was found in close proximity to the 1900 moraine, (2) a more extensive belt of interconnected huge WES, closer to the present day glacier margin, and in the far west of the ground covered, (3) a belt of small WES within ~ 50 m of the present-day ice margin.

There is one exception to the pattern described above. There is a site within the zone of simple WES, close to the 1900 ice-marginal moraine, where there is a very complex and large structure. This site is located on the southern slopes of an isolated bedrock hill that is almost 100 m high. It is probable that the complex WES developed at this location as subglacial water pressure at the time of WES formation would have been high around this bedrock obstacle.

The simple and small structures close to the 1900 end moraine, and close to the glacier margin at the far west end of the study area, are typically less than 10 m long and composed of single WES less than 10 cm wide. They may contain few or no vertical offshoots along their length.

The more complex and bigger WES, closer to the ice margin, can exceed 60 m in length from their contact with the overlying till to where they finally disappear beneath the exposure. In these complex WES there are several horizontal structures connected by a number of vertical fissures and in places multiple WES cut through each other at right angles. The horizontal structures are often 0.5 to 1 m thick.

In places the till overlying the WES suddenly thickens where it overlies a vertical offshoot of the structure suggesting that till thickness is influenced by the change in underlying sediment (Kjaer *et al.*, in press).

Acknowledgements

The New Research Workers Award has assisted in the funding of fieldwork. This work was carried out with Professor Jaap J.M. van der Meer. It is part of an on going research project initiated in 1977 and organised by Dr Johannes Krüger of the Institute of Geography, University of Copenhagen.

References

Kjaer, K., Krüger, J. and Meer, J.J.M. van der. (in press). What determines the thickness of till? An Icelandic perspective. *Quaternary Science Reviews.*

Krüger, J. (1994). Glacial processes, sediments, landforms, and stratigraphy in the terminus region of Myrdalsjökull, Iceland. *Floia Geographica Danica*, 21, 101-109.

Meer, J.J.M. van der, Kjaer, K. and Krüger, J. (1999). Subglacial water-escape structures, Sléttjökull, Iceland. *Journal of Quaternary Science*, 14, 191-205.

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ABLATION PROCESSES AND SURFACE EVOLUTION OF DEBRIS COVERED GLACIERS, NGOZUMPA GLACIER, KHUMBU HIMAL, NEPAL

Introduction

Debris-covered glaciers in the Himalayas have downwasted rapidly over recent decades in response to regional climatic warming (Kadota *et al.*, 2000), resulting in an increase in the occurrence of supraglacial lakes, which over time can expand and coalesce to pose a significant threat of glacial lake outburst floods (Richardson and Reynolds, 2000). While it has already been established that thin surficial debris accelerates melt and thick debris inhibits melt, the manner in which this general relationship relates to surface relief evolution and development of supraglacial lakes remains poorly understood.

This research is part of a PhD project that aims to model the surface evolution of debris-covered glaciers in order to evaluate the locations and timescale over which potentially dangerous supraglacial lakes form in the Himalayas. Fieldwork undertaking experiments to define parameter limits for this model was carried out in autumn 2001on the Ngozumpa Glacier in the Sagarmatha National Park in the Eastern Nepal Himalayas.

Field methods

Debris thickness, slope profiles and local relief were measured at three points on the glacier, *c.* 1, 3 and 7 km from the glacier terminus. The downglacier trends, which can be taken as a rough proxy for evolution over time, show debris thickness, cone height and cone basal area all increasing downglacier and slope form changing from linear to more sinusoidal debris slopes, as a result of mass movement. Clast size analysis of the slope profiles was used to assess how slope activity contributes to redistributing and sorting the surface debris.

Week-long temperature profiles through the debris layer were undertaken at 3 sites adjacent to the weather station to determine the variation in heat flux through the different debris types present on the glacier; silty debris, diamict and cobbles. The surface layer temperatures all show large diurnal fluctuation, demonstrating that melt estimations based on one daily measurement of surface temperature (Nakawo and Young, 1999) are unlikely to be representative. Below the surface, the results suggest significantly different thermal regimes in the 3 types of debris (Figure 1).

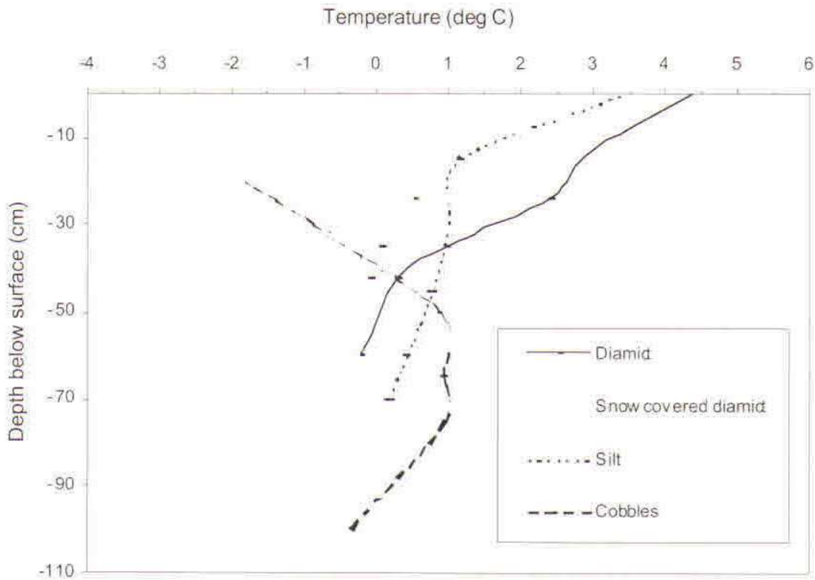

Figure 1. Mean temperature profiles through 3 types of supraglacial debris on the Ngozumpa Glacier. Markers indicate the positions of the 6 thermistors in each array. The debris thickness at the silt and cobble sites exceeded 1 m; thus the deepest measurement is not the temperature measured at the ice interface.

A snowfall event during the diamict experiment demonstrates that the temperatures throughout the profile very rapidly tends towards 0°C. Thus, contrary to previous suggestions (Nakawo and Rana, 1999), heat storage in the debris layer is unlikely to be significant.

The mean temperature of the silt layer contained a latent heat exchange zone (freezing band) centred at 20 cm depth. Daytime (6 am-6 pm) melting dominates over the effect of nocturnal freezing for the duration of the experiment, creating a cold layer in the mean temperature profile. A thermistor array has been left in the debris recording an annual cycle of temperatures in order to assess the significance of seasonal variations of internal moisture (and its freezing and melting) on the thermal properties of the debris.

The temperature in cobbles is dominated by convection to a depth of 40 cm, which is deeper than previous literature suggests (Conway and Rasmussen, 2000). This has implications for the application of existing models of heat transfer through supraglacial debris, which assume conduction to be the primary mode of thermal flux.

Further work

The above findings have been incorporated into a preliminary model of surface evolution. Retrieval of data from the thermistors and meteorological station remaining on the glacier, in autumn 2002, will provide data on the thermal and ablation regime of the glacier through an annual cycle. Further work to improve on existing methods of calculating sub-debris ablation from meteorological variables is being undertaken at Larsbreen in Svalbard in July 2002, with the support of UNIS.

Acknowledgements

The fieldwork undertaken was partly funded by a QRA New Research Workers Award. Additional financial contributions came from The Russell Trust of the University of St Andrews, The Carnegie Trust for the Universities of Scotland and The Dudley Stamp Memorial Fund of the Royal Society. The support from each of these organisations is gratefully acknowledged. Thanks also go to Dr Doug Benn and Kat Hands for assistance in the field.

References

Conway, H. and Rasmussen, L.A. (2000). Summer temperature profiles within supraglacial debris on Khumbu Glacier, Nepal. In: Nakawo, M., Raymond, C.F., Fountain, A. (eds) *Debris Covered Glaciers*. (Proceedings of a workshop held in Seattle, Washington, USA, September 2000) IAHS Publication No. 264, 89-97.

Harris, S.A. and Pedersen, D.E. (1998). Thermal regimes in coarse blocky materials. *Premafrost and Periglacial Processes*, 9, 107-120.

Kadota, T., Seko, K., Aoki, T., Iwata, S. and Yamaguchi, S. (2000). Shrinkage of the Khumbu Glacier, east Nepal from 1978-1995. In: Nakawo, M., Raymond, C.F., Fountain, A. (eds) *Debris Covered Glaciers*. (Proceedings of a workshop held in Seattle, Washington, USA, September 2000) IAHS Publication No. 264.

Nakawo, M. and Rana, B. (1999). Estimate of ablation rate of glacier ice under a supraglacial debris layer. *Geografiska Annaler*, 81A, 695-701.

Richardson, S.D. and Reynolds, J.M. (2000). An overview of glacial hazards in the Himalayas. *Quaternary International*, 65, 31-47.

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UPPER ICE LIMITS OF THE LGM ON MOUNTAINS OF THE BEARA PENNINSULA, SOUTHWEST IRELAND

Introduction

During the Late Midlandian Glenavy stadial (*c.* 26-13 ka BP), much of southwest Ireland was extensively glaciated by local valley ice and large ice streams from a dispersal centre located over the Kenmare valley (*c.* 20 km south of the Macgillycuddy's Reeks) (Farrington, 1954; McCabe, 1986; Warren, 1979, 1991).

Attempts have been made elsewhere in North West Europe at reconstructing the vertical dimensions of Quaternary ice masses based on the identification of high-level weathering limits referred to as periglacial trimlines. The term periglacial trimline refers to the maximum elevation to which glacier ice has eroded or 'trimmed' a pre-existing zone of frost-weathered rock or debris on a hillslope (Ballantyne and Harris, 1994). Areas where such reconstructions have been attempted include the north west of Scotland (Ballantyne *et al.*, 1998), the southwest Lake District (Lamb and Ballantyne, 1998), Snowdonia, north Wales (McCarroll and Ballantyne, 2000), western Norway (McCarroll and Nesje, 1993) and most recently South Uist, Outer Hebrides (Ballantyne and Hallam, 2001).

The aim of this report is to outline pilot research into former maximum upper ice-sheet limits on two of the highest mountains (Knockboy and Coomnadiha, 706 and 644 m O.D, respectively) of the Beara peninsula, southwest Ireland.

Research methods

Fieldwork in 2001 involved collecting Schmidt hammer rebound (R-values) values and bedrock dilation joint measurements from 10 bedrock outcrops on Knockboy Mountain (*I.O.S. grid ref. 10040 06310*) and 10 on Coomnadiha Mountain (*I.O.S. grid ref. 084700 063005*). Schmidt hammer and dilation joint measuring methods were chosen in order to test the degree of bedrock surface weathering and to subsequently distinguish between previously glaciated surfaces and those which remained unglaciated as nunataks. R- values were recorded following the procedure outlined by McCarroll (1987, 1989), and Anderson *et al.* (1998) and bedrock dilation joints measured following Ballantyne (1982).

Testing generated data sets of 500 Schmidt hammer r-values (25 hits at each location) and 600 bedrock joint measurements (15 horizontal and 15 vertical measurements from each location).

Bulk soil samples were collected from the C-horizons of soil pits on both mountain summits. It is planned to conduct XRD analysis on the clay (<2 micron) size fraction of these samples in an attempt to attain as to whether or not the samples contain gibbsite. Gibbsite ($Al(OH)_3$ – Aluminium hydroxide) is a product of intense soil and bedrock weathering processes and is therefore often found in soils which escaped glacial erosion but experienced prolonged intense periglacial weathering (c.f. Ballantyne, 1994).

Area Investigated	***Coomnadiha***	***Knockboy***	***Former nunataks of the Macgillycuddy's Reeks***
Total number of test locations	10	10	40
Altitudinal range (m)	562 – 706	434 - 657	543 - 983
Number of blows recorded	250	250	1000
Mean R-value	25.68	31.4	14.53
Number of joint measurements	300	300	1200
Mean joint depth (mm)	2.63	2.05	16.34

Table 1. Mean R-value and joint measurement data from Coomnadiha and Knockboy mountains compared with data collected from locations identified as former nunataks (data from Macgillycuddy's Reeks).

Results Discussion and conclusions

R-value and bedrock dilation joint measurement data are summarized in Table 1 and are presented along with a second data set from mountains of the Macgillycuddy's Reeks. This second data set was collected from locations demonstrating clear geomorphic evidence of prolonged periglacial weathering (e.g. frost-shattered detritus, tors, blockfields and blockslopes) and therefore assumed to have remained above the former maximum upper ice limit as nunataks. Comparison of these data sets reveals marked differences between the two. The mean R-values from unglaciated former nunatak locations are significantly lower than values collected from Coomnadiha and Knockboy and the mean dilation joint depths are significantly higher. This evidence infers a much lower degree of bedrock surface weathering for the outcrops tested on Coomnadiha and Knockboy compared with the highly weathered outcrops on the former nunatak summits of the Reeks. This evidence combined with field observations of evidence for glacial erosion (e.g. glacially-moulded bedrock and erratic blocks) and a lack of evidence of periglacial weathering suggests that the two summits under investigation were previously over ridden by glacial ice. This glacial event is attributed to the last glacial maximum in Ireland (Late Midlandian) and implies that the thickness of this ice mass exceeded 706 m O.D. (the summit of Knockboy).

This conclusion supports the evidence indicating former ice-sheet flow directions (i.e. striations and other glacially-moulded features), which suggests that Kenmare was the former ice-sheet centre (*c.f.* Bryant, 1968; Warren, 1979). Since the mountains under investigation are only 10 km southeast (Knockboy) and 10 km south (Coomnadiha) of the inferred ice-sheet centre, they are therefore very close to the location of inferred former maximum ice-sheet thickness. This conclusion supports evidence from the southern slopes and shoulders of the Macgillycuddy's Reeks, 20 km north of the inferred former ice-sheet centre, which demonstrates periglacial trimlines and indicates a minimum former ice limit of 700 m O.D.

The conclusion also implies that investigation on mountains further to the south of the inferred ice centre (Kenmare) may yield evidence of periglacial trimlines and therefore provide evidence of an ice-sheet profile sloping away from the inferred centre.

References

Anderson, E., Harrison, S., Passmore, D.G. and Mighall, T.M. (1998). Geomorphic evidence of Younger Dryas glaciation in the Macgillycuddy's Reeks, South West Ireland. *Quaternary Proceedings*, 6, 75-90.

Ballantyne, C.K. (1982). Depths of open joints and the limits of former glaciers. *Scottish Journal of Geology*, 18, 250-252.

Ballantyne, C.K. (1994). Gibbsitic soils on former nunataks: implications for ice sheet reconstruction. *Journal of Quaternary Science*, 9, 73-80.

Ballantyne, C.K. and Harris, C. (1994). *The Periglaciation of Great Britain*. Cambridge University Press.

Ballantyne, C.K. and Hallam, G.E. (2001). Maximum altitude of Late Devensian glaciation on South Uist, Outer Hebrides, Scotland. *Proceedings of the Geologists' Association*, 112, 155-167.

Ballantyne, C.K., McCarroll, D., Nesje, A., Dahl, S.O. and Stone, J.O. (1998). The last ice sheet in North West Scotland: Reconstruction and implications. *Quaternary Science Reviews*, 17, 1149-1184.

Bryant, R.H. (1968). A study of the glaciation of South Iveragh, Co. Kerry. Unpublished PhD Thesis, University of Reading.

Farrington, A. (1954). A note on the correlations of the Kerry-Cork glaciation with those of the rest of Ireland. *Irish Geography*, 3, 47-53.

Lamb, A.L. and Ballantyne, C.K. (1998). Palaeonunataks and the altitude of the last ice sheet in the S. W. Lake District, England. *Proceedings of the Geologists' Association*, 109, 305-316.

McCarroll, D. (1987). The Schmidt hammer in geomorphology: Five sources of instrument error. *British Geomorphological Research group technical bulletin*, 36, 16-27.

McCarroll, D. (1989). The potential limitations of the Schmidt hammer for relative-age dating; field tests on neoglacial moraines, Jotunheimen, southern Norway. *Arctic and Alpine Research*, 21, 268-275.

McCarroll, D. and Nesje, A. (1993). The vertical extent of ice sheets in Nordfjord, Western Norway, measuring the degree of rock surface weathering. *Boreas*, 22, 255-265.

McCarroll, D. and Ballantyne, C.K. (2000). The last ice sheet in Snowdonia. *Journal of Quaternary Science*, 15, 765-778.

Warren, W.P. (1979). Moraines on the northern slopes and foothills of the Macgillycuddy's Reeks, south-west Ireland. In Schluchter (ed) *Moraines and Varves*. Balkema, Rotterdam, 223-236.

Warren, W.P. (1991). Glacial deposits of south west Ireland. In Ehlers, J., Gibbard, P.L. and Rose, J. (eds) *Glacial deposits in Great Britain and Ireland*. A.A. Balkema, 415-420.

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PLATEAU-VALLEY GLACIER SYSTEMS AND THEIR RECONSTRUCTION: SYDBREEN, AN EXAMPLE FROM NORTH NORWAY

Introduction

Sydbreen, a 4.5-km long valley glacier, is located in the Lyngen Alps in north Norway (Figure 1), and has its conventional accumulation area lying at ~1300-1000 m a.s.l. However, the glacier also receives substantial input via avalanching from the surrounding plateau ice caps of Jiehkkevárri and Bálggesvárri, which rise to a maximum of 1833 m a.s.l. The ice avalanching onto Sydbreen from the plateaux above produce distinct cones, wave ogives and individual flow septa. The glacier to the north is called Midtbreen and was formerly joined to Sydbreen. The two glaciers separated in the 1980s: Sydbreen's snout has been receding at a rate of ~10 m/yr throughout the 1990s.

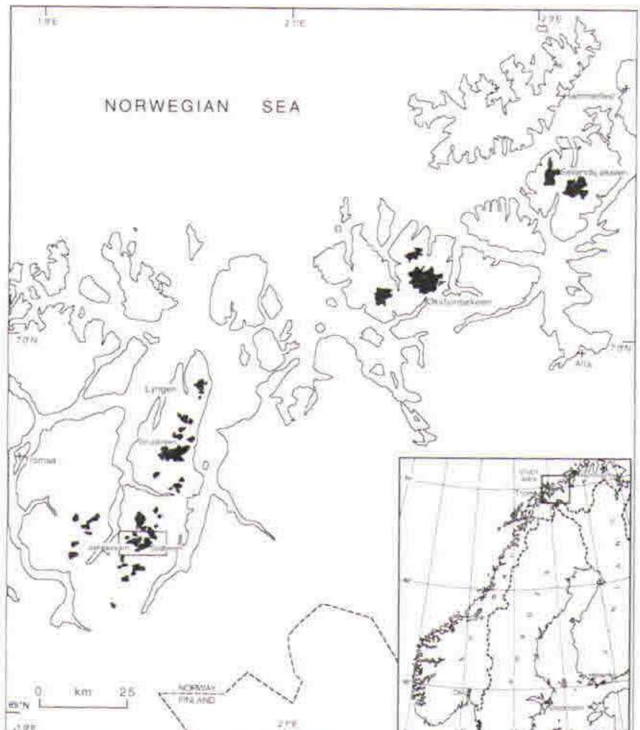

Figure 1. The location of the study area in north Norway, including other ice masses. The box indicates the study area, in the southern half of the Lyngen peninsula.

The two southern septa on Sydbreen, fed by Bálggesvárri and the col, both pinch out along the southern margin of the glacier 2.5 and 1 km from the present snout position respectively. The regional firn line (~1000 m a.s.l.) is presently above the majority of Sydbreen (Rea *et al.*, 1998). The glacier is at present almost entirely fed by ice avalanching onto the glacier from the Jeihkkevárri plateau (Gordon *et al.*, 1995, Whalley *et al.*, 1989, 1995). On the lower reaches of the glacier, in excess of 3 m of ice melt can occur during the ablation season, as was experienced in the summer of 2000. However, there is substantial year-to-year variation; ice ablation was limited to 1 m or less in the summer of 2001 due to reduced solar radiation and lower mean temperatures. Sydbreen has an ELA higher than may normally be calculated for a contemporary valley glacier due to the significant accumulation from Jeihkkevárri. This has been calculated by Rea *et al.*, (1999) to be between 640 - 840 m a.s.l. Although, the regional firn line is thought to be ~1000 m a.s.l. Sydbreen's continuing existence and present low altitude snout (~450 m a.s.l.) result from the lowering of the ELA by the accumulation from the surrounding plateaux.

Advances in GPS equipment has made investigations on glaciers, and other landforms, to be carried out around the world with greater ease, accuracy and speed than ever before (Eiken *et al.*, 1997, Gandolfi *et al.*, 1997, Jacobsen and Theakstone 1997, Jacobsen *et al.*, 1997, Manson *et al.*, 2000, and Theakstone *et al.*, 1999). This had led to increases in the accuracy that is now obtainable using portable GPS's, allowing more diverse landforms and processes to be studied. Surveying using GPS has also helped in the speed and ease of operation, especially in difficult terrain. Differential GPS (DGPS) has been used in this study to investigate surface velocity variations, ablation changes and the relationship (if any) with its accumulation sources.

Rationale

It is hoped that the work on Sydbreen will provide insight into the relationship between glaciers and their accumulation sources. This is especially important in areas of former glaciation (e.g. the Cairngorms), where valley glacier reconstructions need to include plateau ice contributions, thereby affecting the ELA reconstructions (Rea *et al.*, 1999; Sissons, 1979).

Methods

During the summer of 2000, DGPS measurements were made on the surface of Sydbreen. Stakes that were drilled into the ice along a transect across the glacier and had their positions fixed using the DGPS (Leica SR530) at intervals throughout the field season. Velocity measurements were continued in the spring and summer of 2001 to allow some inter-annual comparisons. Some further experiments were also conducted, which aimed to (1) study small-scale velocity variations, (2) test ideas of glacier motion (stick-slip and creep during accumulation and ablation), and (3) test the capabilities of the DGPS for glaciology.

Sydbreen's forefield was accurately surveyed in order to indicate the glacier's retreat from the late 1980s, and to record position data of identifiable features for future digital photogrammetric work. In addition, a suite of Little Ice Age (and younger) moraines was mapped. These moraines were previously dated using lichenometry (Ballantyne, 1990), who suggested a maximum LIA advance of between 1910-1920. Older, pre-LIA moraines were also mapped for the first time.

Results and future work

It was found that velocities across Sydbreen were between 15 - 19 m/yr, which although low is in keeping with this type of low gradient valley glacier. Overall it appears that there is only a negligible difference between glacier velocity during the winter and summer. Even though there is there is a substantial increase in air temperature and meltwater, it appears to have little affect on glacier motion. Possible reasons for this include either: there is a significant amount of water flowing through the glacier in winter or an increase in meltwater does not increase the amount basal sliding. The latter would depend on the composition of the basal layer and/or bedrock interface.

The survey data are presently being used to investigate volumetric changes in the glacier since the LIA. This is being carried out in conjunction with meteorological records that go back 130 years. The results from this fieldwork were subsequently added to with data obtained in the spring and summer of 2001. It is hoped that the data from these field seasons will help understanding of plateau valley glacier systems and their interaction with climate.

Acknowledgements

The QRA is gratefully acknowledged for its financial contribution to the fieldwork in north Norway.

References

Ballantyne, C.K. (1990). The Holocene glacial history of Lyngshalvøya, northern Norway: chronology and climatic implications. *Boreas*, 19, 93-117.

Eiken, T., Hagen, J.O. and Melvold, K. (1997). Kinematic GPS survey of geometry changes on Svalbard glaciers. *Annals of Glaciology*, 24, 157-163.

Gandolfi, S., Meneghel, M., Savatore, M.C. and Vittuari, L. (1997). Kinematic global positioning system to monitor small Antarctic glaciers. *Annals of Glaciology*, 24, 326-330.

Gordon, J.E., Whalley, W.B. and Gellatly, A.F. (1995). Fluctuations of glaciers in Lyngsdalen, Troms, Norway, during the 20th Century. *Zeitschrift Für Gletscherkunde und Glazialgeologie*, 31, 125-134.

Jacobsen, F.M. and Theakstone, W.H. (1997). Monitoring glacier changes using a global positioning system in differential mode. *Annals of Glaciology*, 24, 314-319.

Jacobsen, F.M., Theakstone, W.H. and Knudsen N.T. (1997). Surface velocity and strain-rate variations at the glacier Austre Okstindbreen, Okstindan, Norway, 1976-95. *Annals of Glaciology*, 24, 320-325.

Manson, R., Coleman, R., Morgan, P. and King, M. (2000). Ice velocities of the Lambert Glacier from static GPS observations. *Earth Planets Space*, 52, 1031-1036.

Rea, B.R., Whalley, W.B., Evans, D.J.A., Gordon, J.E. and McDougall, D.A. (1998). Plateau icefields: geomorphology and dynamics. In Owen L.A. (ed) *Mountain Glaciation. Quaternary Proceedings*, 6, 35-54.

Rea, B.R., Whalley, W.B., Dixon, T.S., and Gordon, J.E. (1999). Plateau icefields as contributing areas to valley glaciers and the potential impact on reconstructed ELA's: a case study from the Lyngen Alps, North Norway. *Annals of Glaciology*, 28, 97-102.

Sissons, B. (1979). The Loch Lomond advance in the Cairngorm Mountains. *Scottish Geographical Magazine*, 95, 66-82.

Theakstone, W.H. Jacoksen, F.M. and Knudsen, N.T. (1999). Changes of snow cover thickness measured by conventional mass balance methods and by global positioning system surveying. *Geografiska Annaler*, 81 A, 767-776.

Whalley, W.B., Gordon, J.E. and Gellatly, A.F. (1989). Effects of topographic and climatic controls on 19th and 20th century glacier changes in the Lyngen and Bergsfjord areas, north Norway. In Oerlemans, J. (ed) *Glacier fluctuations and climatic change*. Kluwer, 153-172

Whalley, W.B., Gordon, J.E., Gellatly, A.F. and Hansom, J.G. (1995). Plateau and valley glaciers in north Norway: responses to climate change over the last 100 years. *Zeitschrift Für Gletscherkunde und Glazialgeologie*, 31, 115-124.

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REVIEW

GEOLOGY OF THE ISLE OF MAN AND ITS OFFSHORE AREA

Research Report (RR/01/06) 143 pp.[1]

R.A Chadwick, D.I. Jackson, R.P. Barnes, G.S. Kimbell, H. Johnson, R.C. Chiverrell, G.S.P. Thomas, N.S. Jones, N.J. Riley, E.A. Pickett, B. Young, D.W. Holliday, D.F. Ball, S.G. Molyneux, D. Long, G.M. Power and D.H. Roberts

Isle of Man: solid and drift geology 1:50,000 scale [2]

Isle of Man - foundations of a landscape: 48 pp Booklet [3]

E.A. Pickett

Published by British Geological Survey 2001

ISBN 0 85272 395 4 [1]

ISBN 0 7518 3325 8 flat 0 7518 3326 6 folded [2]

ISBN 0 85272 396 2 [3]

Research Report £30, 1:50,000 map £9·95 (folded copies supplied in a tough clear plastic wallet) and Booklet £5, with 25% academic discount when ordered from: Sales Desk, British Geological Survey, Keyworth, Nottingham NG12 5GG Tel. 0115 - 936 3100 Fax. 0115 - 936 3200 (prices exclusive of post and packing).

The Isle of Man - home to the Tynwald, the oldest parliament in continuous existence - is a roughly 45-km long and up to 16-km wide part of a horst block in the middle of the Irish Sea, 572 km^2 in area, with Snaefell (621 m a.s.l.) the highest point and a population of around 70,000. As it is a self-governing Crown dependency and not part of the United Kingdom these are not standard BGS publications, but produced in collaboration with the Manx government along with a customised GIS package for use on the island. The report thus incorporates the Manx designated area which extends up to 12 nautical miles (22·22 km) from the coast and includes the results of recent offshore hydrocarbon exploration along with targeted geological mapping sponsored by these exploration companies to revise the island's 1:50,000 sheet. Considering the commercial bias of this publication, which includes five seismic sections incorporating a company logo, the solid pre-Quaternary geology of the island is covered by a comprehensive and well illustrated account with small but crystal clear photographs and extensive figures often also in full colour. The text is succinctly written and incorporates the results of the reconnaissance mapping with numerous academic studies and the offshore data that are often relevant to its interpretation.

The chapter dealing with the Quaternary deposits is up-to-date and revises the information provided in Bowen (1999) by Thomas, one of the authors. It clearly describes not only the many and varied Late Devensian and post-glacial formations exposed at the surface, but also older more deeply buried material and offshore deposits, besides discussing the past environments in which they were deposited. The northern end of the island has an exceptional sequence of mainly glacial material up to around 250 m thick in places. Boreholes show this contains towards its base deposits from two earlier glacial stages when northern ice sheets impinged upon the Manx uplands and from an intervening interglacial (Oxygen Isotope Stages 9, 7 or 5). Surface exposures include material deposited during the last glacial maximum and in places highly deformed by a later glacial re-advance which deposited further moraines and ice-marginal material before the ice sheet finally decayed to leaving a complex post-glacial landscape. This is superbly illustrated by a perspective cartoon of this ice-marginal environment and a couple of schematic cross sections through these formations. In addition there is a magnificent full-page map show the distribution of the island's Quaternary deposits and features such as the localised erratic trains away from granitic intrusions, alluvial fans and drumlins.

The account of the offshore area around the island draws heavily on an earlier and much more extensive report (Jackson *et al.*, 1995) and the associated Sea Bed Sediments and Quaternary 1:250,000 sheets Isle of Man and Anglesey without referring to their informative cross sections or closing the gaps in coverage between deeper waters and inshore areas. As a hybrid publication with slightly longer pages than a standard memoir it does not deal with geotechnical ground conditions, potential hazards, soil types, planning and (amazingly) coastal erosion. This material could have been incorporated into the economic geology chapter about mineral resources and groundwater and would have helped demonstrate the relevance of local geology. In addition, the report lacks the usual information sources section listing the various unpublished maps, technical reports and data bases that can normally be consulted in libraries along with relevant BGS publications. Refreshingly, it is clearly stated that radiocarbon dates are quoted as calibrated years BP, even if this is not defined in the text as 1950, unlike the Ulverston memoir (Johnson *et al.*, 2001). However, both publications simply declare that the Quaternary only extends back to 1·8 Ma, rather than 2·6 Ma (see *Quaternary Newsletter*, 93, 56-8).

The accompanying 1:50,000 map is presented in a plastic slip case when folded without a hard cover, but even if the offshore area is left blank it appears to have undergone a more extensive revision and partial resurvey at 1:25,000 than most provisional editions. While the sheet is well drafted and clearly shows the extensive drift deposits that blanket much of the island's solid geology, these Quaternary deposits are not directly labelled. This can be confusing in places, and is compounded by the conventional geological symbols being rather too small even if this may have been to stop adjacent symbols clashing and overcrowding the map in a few places. Unfortunately, while this includes geomorphological symbols for roche moutonnée and glacial striae, nearby pairs of these two symbols (such as at SC 397 879) contradict each other. In addition, these glacial striae directions appear to be roughly at right angles to those shown both on the report's excellent Quaternary map and the original 1898 one-inch (1:63,360) edition. Areas of soliflucted till are also shown with pecked diagonal stripes over the underlying colour, which normally allows the 20 m contours and spot heights quoted to within 0·1 m on the Manx base map to be seen clearly.

To complement these more formal publications an illustrated booklet in a similar style to the BGS Earthwise series has been produced to educate the public and introduce them to the geological history of the island. The well-illustrated text engages the reader and refers to familiar building stones and local archaeology and with this emphasis a high proportion of the pages are devoted to the ice age, the Irish Elk and the post-glacial period, including the arrival of people, the evolving landscape and coastal erosion. Considering the corporate sponsorship and additional funding from the Manx government this BGS collaboration could have resulted in better coverage of the Quaternary. Around the coast it would have been possible to include at least a km or two of the offshore area (see *Quaternary Newsletter*, 95, 47-48) on the larger than normal sheet by simply rotating the map by 90°. The report would have benefited from the inclusion of a satellite image of the island and a series of maps reconstructing the changing Devensian and post-glacial geography of the Irish Sea. As it is, the Quaternary chapter appears rather dull compared to the rest of the report, even though it is thoroughly researched and compares well with accounts in 1:50,000 memoirs.

References

Bowen, D.Q. (1999). *A revised correlation of Quaternary deposits in the British Isles.* Geological Society Special Report, No. 23.

Jackson, D.I., Jackson, A.A., Evans, D., Wingfield, R.T.R., Barnes, R.P. and Arthur, M.J. (1995). *The geology of the Irish Sea. United Kingdom offshore regional report,* HMSO, London, for the British Geological Survey.

Johnson, E.W., Soper, N.J. and Burgess, I.C. (2001). *Geology of the country around Ulverston.* Memoir of the British Geological Survey, Sheet 48 (England and Wales).

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ABSTRACTS

SEDIMENT-SOURCE-LINKAGES IN THE GWENDRAETH ESTUARY, SOUTH WALES, BASED ON MINERAL MAGNETIC ANALYSES

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The nature and possible causes of spatial differences in the mineral magnetic and textural properties of sediments in the Gwendraeth Estuary are examined together with those of Carmarthen Bay and the rivers Gwendraeth Fach and Gwendraeth Fawr, for the purpose of creating a sediment source apportionment-mixing model to infer information about the sediment dynamics of the estuarine system. The stability of many estuaries and other low-lying coastal areas are threatened by the predicted accelerations in climatic change and sea-level rise. It is thus imperative that because of their social, economic and environmental significance, coastal and estuarine sediment dynamics are fully explored and understood, for inclusion in the strategies of coastal engineers, commercial activities, and conservation management plans. Therefore, the modelling adopted in this work allows the nature and causes of any variations in natural surface processes to be investigated.

The physical characteristics of contemporary sediment sources for the Gwendraeth Estuary, namely Carmarthen Bay and the rivers Gwendraeth Fach and Fawr, are explored and the usefulness of their datasets for inclusion in a sediment source apportionment-mixing model are evaluated by qualitative, statistical, bivariate and multivariate approaches. Results show the sediment sources to be significantly distinguishable in terms of both the magnitude of the variables and the relationship between textural and mineral magnetic variables, and therefore, are appropriate to be combined with the estuarine dataset and assessed for inclusion in a sediment source apportionment-mixing model.

A diagenetic 'redox-effect' and/or the presence of 'bacterial magnetite' are identified as causing the modelling assessment to fail. However, the estuarine and sediment source datasets are re-assessed without the variables influenced by these effects and reveal the sediment source datasets to now be appropriate for inclusion in a sediment source apportionment-mixing model for unmixing both contemporary and temporal sediment samples in the Gwendraeth Estuary.

A linear programming algorithm is employed to determine sediment source apportionments of contemporary and Late Holocene core samples. Both sets of results show the Carmarthen Bay sediment source to supply the most significant contribution and both of the river sources to supply similar quantities as each other. With the aid of a geographical information system, the unmixed sediment source proportions for the contemporary sediment samples are displayed and analysed spatially. These reveal the Carmarthen Bay and Gwendraeth Fach River sediment sources to be thoroughly mixed throughout the estuary and the Gwendraeth Fawr River sediment source to be mainly mixed on the southern shore of the estuary. All these data are then combined with field evidence to infer realistic information about the estuarine sediment dynamics. The unmixed sediment source proportions for the temporal sediment samples are displayed in down-core profiles. Historically, these data indicate variations in shoreline movement and vertical textural patterns of the saltmarsh, with a possible overprint of information pertaining to an environmental shift in sediment source contributions.

LATE PLEISTOCENE SEA-LEVEL CHANGE IN THE CELTIC SEA: RADIOCARBON DATED MACROFAUNA AS PALAEO-WATER-DEPTH INDICATORS

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The Northwest European continental shelf has been subjected to repeated transgressive-regressive cycles as a function of fluctuating glacio-eustatic sea-level throughout the Quaternary. Numerical models incorporating both global eustatic and regional glacio-hydro-isostatic sea-level signals for the latest transgressive phase (20–5 ka BP) suggest extensive early subaerial shelf exposure, particularly in the Celtic Sea, with impounding of shallow freshwater bodies north of a terrestrial land-linkage between southwest Britain and southern Ireland. Whilst such models are well constrained by ^{14}C-calibrated index-points peripheral to the region, critical offshore evidence from the Celtic Sea constraining the early phases of transgression is lacking.

In this study, macrofossil-derived ^{14}C-calibrated sea-level index-points from vibrocores between the shelf edge and St George's Channel are used to critically assess the accuracy of such models and to develop sea-level curves and palaeocoastline maps spanning the period of inundation. In addition, lithoand bio-stratigraphic techniques are employed to further elucidate the nature and timing of transgression across the shelf.

An extensive gravel lag possessing intertidal and subtidal taxa, representing initial inundation of subaerially exposed shelf and subsequent subtidal reworking is identified throughout the region. Evidence for the existence of a palaeolacustrine system within the present Celtic Deep basin subjected to marine incursion from the south is also described lending credence to published numerical models.

The accuracy of faunal-based index-points and resultant sea-level curves is, however, considered questionable, given the extensive taphonomic modification, time-averaging and condensation experienced by shell accumulations in such transgressive environments. Palaeo-water-depth estimates derived using sedimentological principles, whilst suggestive, do not provide the acuity necessary to confidently determine sea-level behaviour.

Whilst sea-level index-points are questioned, stratigraphic evidence for marine incursion into the Celtic Deep represents a critical constraint on palaeo-water-depth, exhibiting good agreement with published numerical models. High deglacial sea-level models, however, are not supported by the stratigraphic evidence.

FORAMINIFERAL ECOLOGY OF CONTEMPORARY ISOLATION BASINS IN NORTHWEST SCOTLAND

Damien Laidler (Doctor of Philosophy)
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Isolation basins contain high-resolution records of environmental change relating to RSL and climate since the last glacial maximum, and provide valuable data in constraining regional and global ice sheet and earth rheology models. A key weakness in current research is a lack of information regarding the identification of the reference tide level of different stages of basin isolation, and the role of factors such as freshwater input in controlling palaeosalinity. To address these issues, this thesis reports data collected from modern isolation basins from twenty sites in northwest Scotland.

The basins range in size and elevation of their sill within the tidal cycle. Surface sediment samples were analysed for their foraminiferal composition, and other analyses of water chemistry and sedimentology were completed. Statistical analyses show a poor correlation between sill altitude and fauna. A transfer

function was therefore produced based on average salinity, but calibration of this using fossil data was unsuccessful. This research demonstrates that the modern training set lacks adequate analogues for many of the fossil foraminiferal assemblages recorded in previous work. Likely causes for this include differences in the relative abundance of foraminiferal species between the modern and fossil data-sets, and the fact that no modern basin was found which has the water depth and salinity required for reconstruction of the fully marine stage.

Because of these factors, foraminiferal data should be used with care in the definition of the indicative meaning of isolation basin sea-level index points. The statistical methods do, however, yield the first detailed understanding of the distributions of foraminifera in contemporary shallow water isolation basins, particularly with reference to their optimum and tolerance values for environmental variables. Variable salinity species such as *Miliammina fusca* are dominant in the training set, displaying their broad tolerance of environmental conditions.

GEOMORPHOLOGICAL EVIDENCE FOR THE PATTERN OF DEGLACIATION AROUND THE DRUMOCHTER PASS, CENTRAL GRAMPIAN HIGHLANDS, SCOTLAND

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Geomorphological mapping and sedimentological logging was employed to reconstruct the pattern of deglaciation and to test existing reconstructions in the study area around the Drumochter Pass, central Grampian Highlands, Scotland. Distinct groups of landforms are confined to (a) the upper reaches of slopes on the eastern side of the study area and (b) to the valley floors. A third group is located at an intermediate level. Those in (a) are interpreted as representing successive positions of a former ice-sheet margin. Geomorphological and sedimentological evidence documents the synchronous development of an ice-dammed lake in Coire Mhic-sith that probably drained non-catastrophically along an ice-sheet margin that retreated south-westwards. The landforms in (b) include *inter alia* "hummocky moraine" which consists of chains of moraine ridges and mounds that are interpreted as recessional moraines formed by valley glaciers that retreated towards the southwest and west. Another ice-

dammed lake developed in the present basin of Loch Garry during this later phase of deglaciation.

This interpretation differs significantly from that of Sissons (1974), who proposed an ice cap of Loch Lomond Stadial (LLS) age sourced on the Gaick Plateau northeast of the study area that extended towards the West via Coire Mhic-sith and joins ice from the south-west (Sissons *et al.*, 1973). As the evidence for the ice-dammed lakes is undisturbed, this could not have been the case. The deviations can be explained by the recent reinterpretation of hummocky moraine and the failure to present important sedimentological information, e.g. for the existence of ice-dammed lakes. Consequently, the two former reconstructions have to be regarded as too simplistic and the existence of a Gaick Plateau ice cap must be strongly questioned, an interpretation that is supported by hitherto unpublished results of geological mapping carried out by the British Geological Survey (BGS) on the Gaick Plateau and in the northwest of the study area.

The ice sheet probably dates to the Main Late Devensian Glaciation (MLDG) as evidence of older glaciations has not survived on such a large scale. The activity of the valley glaciers is tentatively attributed to a later phase of the MLDG due to the presence of landforms at an intermediate level (c) that suggests a *continuous south-westward retreat*. A readvance for example of LLS age is tentatively refuted due to the enormous size of an accumulation area required in the SW and other indicators. However, the timing of deglaciation remains speculative as dating techniques could not yet be applied.

References

Sissons, J.B. (1974). A Late-Glacial ice cap in the central Grampians, Scotland. *Transactions of the Institute of British Geographers*, 62, 95-114.

Sissons, J.B., Lowe, J.J., Thompson, K.S.R. and Walker, M.J.C. (1973). Loch Lomond Readvance in the Grampian Highlands of Scotland. *Nature Physical Science*, 244, 75-77.

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LATE HOLOCENE INTERTIDAL SEDIMENTATION: A LITHOSTRATIGRAPHIC APPROACH TO PALAEOENVIRONMENTAL RECONSTRUCTION IN THE WAINWAY CHANNEL, ROMNEY MARSH, SOUTHEAST ENGLAND

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The Manchester Metropolitan University

Our understanding of intertidal environments is based primarily on studies that focus on the extremes of the temporal and spatial resolution spectrum. A gap exists relating to the processes and controls that influence temporal and spatial evolution of intertidal environments over periods of decades to centuries.

The Wainway channel, part of the Romney Marsh complex in southeast England, developed over only about 200-300 years during the late Holocene, from a significant tidal inlet, to a minor tidal creek tightly constrained by extensive and mature salt marsh. A lithostratigraphic approach was adopted to interpret the Wainway's depositional history. This combined high-resolution temporal and spatial analysis of the texture, structure and magnetic properties of the subsurface sediments, with mapping of the relict topography of the Wainway, absolute dating of shell remains, and relative dating based on the well-preserved documentary records covering the period leading to final reclamation during the 17th century.

Two distinctive periods of sedimentation have been identified along a 2 km length of the Wainway on East Guldeford Level. Firstly, the high-energy, rapid (0.5 m/y) infill of the tidal inlet with a suite of tidal rhythmites, which clearly record tidal deposition over periods of days to years, and isolated storm layers. Deposition was initiated by alterations to hydraulic boundary conditions driven by salt marsh progradation and land-claim some distance from the study site around the head of the inlet. After infill of the major tidal inlet a period of increasingly low-energy tidal flat and salt marsh sedimentation commenced. This saw much localised variability in patterns of sedimentation controlled by proximity to channels and creeks, but no well-developed spatial trends across the study site.

Models derived from a series of lithostratigraphic and morphosedimentary units describe the evolution of the Wainway and successfully relate the sedimentary evidence to the historical records. A more general model depicts the episodic mesoscale (decades to centuries) response of a back-barrier tidal channel to marsh progradation and land-claim, and identifies key thresholds which control distinct phases of sedimentation and morphology.

NOTICES

ERRATUM

Part of the report on the QRA Annual Field Meeting to West Wales (*Quaternary Newsletter* 97, 40-45) was written by Amanda Williams, University College Chester.

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4. **Climate Change: cryospheric responses**
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   Frederick Nelson (University of Delaware)
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3. JOURNAL OF QUATERNARY SCIENCE

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Research Papers

McCarroll. Amino acid geochronology and the British Pleistocene: secure stratigraphic framework or a case of circular reasoning?

Wilmshurst *et al.* Holocene vegetation and climate change in southern New Zealand: linkages between forest composition and quantitative surface moisture reconstruction from an ombrogenous bog

Berrio *et al.* Lateglacial and Holocene history of the dry forest area in the south Columbian Cauca Valley from sites Quilichao and La Teta

Smith *et al.* Stable carbon and oxygen isotopic evidence for late Pleistocene to middle Holocene climatic fluctuations in the interior of southern Africa

Hall *et al.* Glacial Lake Victoria, a high-level Antarctic lake inferred from lacustrine deposits in Victoria Valley

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QUATERNARY RESEARCH ASSOCIATION

The Quaternary Research Association is an organisation comprising archaeologists, botanists, civil engineers, geographers, geologists, soil scientists, zoologists and others interested in research into the problems of the Quaternary. The majority of members reside in Great Britain, but membership also extends to most European countries, North America, Africa, Asia and Australasia. Membership (currently *c.* 1,000) is open to all interested in the objectives of the Association. The annual subscription is £15 with reduced rates (£5) for students and unwaged members and an institutional rate of £25.

The main meetings of the Association are the Annual Field Meeting, usually lasting 3-4 days, in April, and a 1- or 2-day Discussion Meeting at the beginning of January. Additionally, there are Short Field Meetings in May and/or September, while Short Study Courses on techniques used in Quaternary work are also occasionally held. The publications of the Association are the *Quaternary Newsletter* issued with the Association's *Circular* in February, June and October; the *Journal of Quaternary Science* published in association with Wiley, incorporating *Quaternary Proceedings*, with eight issues per year, the Field Guide Series and the Technical Guide Series.

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

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October 2002 No. 98

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ISSN 0 143-2826