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QUATERNARY NEWSLETTER

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Editor: Dr B J Taylor
British Geological Survey
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Quaternary Newsletter is issued in February, June and November. Contributions comprising articles, reviews, notices of forthcoming meetings, news of personal and joint research projects, etc. are invited. They should be sent to the Quaternary Research Association Newsletter Editor. Closing dates for submission of copy for the relevant numbers are 1 January, 1 May and 1 October.

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EDITORIAL

Colleagues

My editorial in the previous edition of the *Newsletter* produced some interesting correspondence, notably from Professor F W Shotton, now aged 82, who said he was pleased to see an 'old FIDS man' as editor, and Alan Morgan, President of the Canadian Quaternary Association who was also reminded of *his* days at the University of Birmingham and our subsequent meeting at Keele. Alan also suggested that our 'stacks of respective sins were so huge that it would take a pile of indulgencies to clear the backlog'!

In addition, Alan suggested that we should start a "News from Overseas" section in both our respective newsletters. He would be willing to provide a summary of Canadian Quaternary news for our newsletter if either myself or someone else (preferably someone else!) would provide a summary of the more interesting events for the Canqua Newsletter/Bulletin—whose editor is John Driver, an archaeologist at Simon Fraser University. Therefore any volunteers/conscripts please?

I also received an interesting letter from Dr Richard Clark of Parcey House, Cumbria, another ex-member of the Falkland Islands Dependencies Survey, who was interested in my work (with Russell Coope) on Quaternary arthropods. Richard (with others) intends making a study of the Quaternary landforms and ecology of the Falkland Islands (one of my old stamping grounds) including the Coleoptera. Hopefully, we shall hear of Richard's exploits on his return.

My thanks to all contributors for submitting copy on time and for complying with my request for illustrative material. Together, you have produced a 'bumper-bundle' pre-Christmas edition and a fitting last issue in the 25th Anniversary Series.

Finally, may I take this opportunity to wish all my colleagues a somewhat premature Happy Christmas and a prosperous New Year.

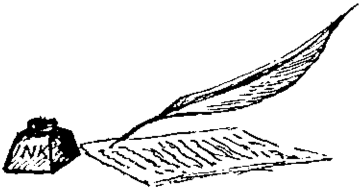
The Cover

The cartoon on the front cover is reproduced from a Christmas Card that formed part of a series of such Christmas Cards for the British Geological Survey in 1985. Based on an original idea by Brian Taylor, the card was designed by Noel Ford, a member of the Cartoonist Club of Great Britain and the Federation of European Cartoonists Organisations.

Noel, who is freelance, is a frequent contributor to *Punch*, *Private Eye* and *The Spectator*, and is resident cartoonist for the *Church Times*. He is also the author of two books of cartoons, namely "Golf Widows", published by Angus & Robertson in 1988 and available in paperback at £3.50 and "Cricket Widows", published in May 1989 and also available in paperback at the same price. A third publication on "Business Widows" is in the first draft stage and should be available in the Autumn of 1990.

Other 'vignettes' in the text by Linda Wahl, BGS

ARTICLES



INVESTIGATIONS AT GADDESDEN ROW BRICKPIT, HERTFORDSHIRE

D R Bridgland and P Harding

Introduction

A small pit at Gaddesden Row (TL 039136), on the Chilterns' dipslope in Hertfordshire, was exploited for brick making during the late nineteenth and early twentieth centuries. Known as Butterfield's Pit, or Gaddesden Row brick pit, this working provided exposures in Pleistocene silts ('brickearth') within which Palaeolithic artefacts were recovered at certain levels. These discoveries were made by the archaeologist Worthington G Smith, who concluded that the principal concentration of artefacts, at a depth of ca.6 m within the 'brickearth' sequence, represented a working site in primary context. This was supported by the excellent condition of the material and the fact that several pieces could be refitted (Smith, 1916; Roe, 1981). The collections from the 'working floor' at Gaddesdon Row comprise 50 hand axes, 11 cores and 88 other artefacts, mainly flakes (Roe, 1968). Some of the latter are retouched and a few have been interpreted as flake implements (Roe, 1968, 1981). The site also yielded a great many unstratified finds. Further discoveries were probably made but have since been lost.

On the strength of the established collections of unabraded artefacts, the degraded pit was designated as a Site of Special Scientific Interest by the Nature Conservancy Council. In 1975 an attempt was made (Wymer, 1980) to locate the archaeological level within the Gaddesden Row sediments by manually excavating a section in the old workings (Fig. 1). This revealed a sequence of silts and silty gravels above Clay-with-flints "at a steep angle" (Wymer, 1980, p.4). A few flint artefacts were recorded, including a crude hand axe, but none were from a primary context and no trace of Smith's working floor was found. A detailed analysis of the sediments in this section was reported by Avery et al. (1982).

The Gaddesden Row site is now covered with well-developed trees and much of the old pit has been infilled with tipped material, which obscures any potential exposures in its north-western and western parts. However, degraded faces exist on the southern and eastern sides of the old working. In 1988 the position of the 1975 excavation was clearly visible, although largely infilled with slumped material (Fig. 1). Two new sections were opened in April 1988, in an attempt to determine whether the Pleistocene silts remained intact in any available part of the site (Figs. 1 and 2).

Description of the 1988 investigation

Both of the 1988 sections revealed traces of bedded silts banked against a steeply rising wall of compact brown clay with flint nodules, the clay-with-flints recorded by Wymer (1980). Section 1, on the south-eastern side of the pit, was a combination of separate higher and lower level excavations, there being a step in the side of the pit at this point ca.1.5 m below the land surface (Fig. 2). This combined section provided an exposure from the land surface to a depth of 6 m. Beneath the platform separating the two parts of the section a remnant of bedded silts survives (Fig. 2). However, these sediments are steeply inclined towards the centre of the pit and clearly represent only the 'feather edge' of a worked-out resource.

In section 2, to the north of the 1975 section, little trace of any 'brickearth' remained, being restricted to thin remnants plastered against a concave wall of clay-with-flints. The top of this section truncated an infilled hollow containing silty topsoil with scattered pebbles. Three flint flakes were encountered in this hollow, together with brick fragments and a piece of clay pipe. It is likely that this feature is broadly contemporary with the operation of the brick pit.

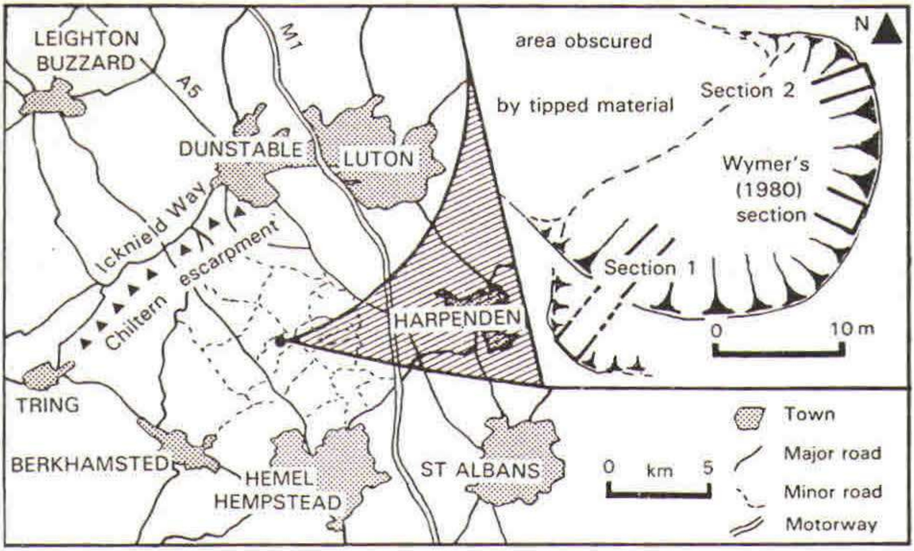


Fig. 1 Location of the Gaddesden Row site and (inset) the 1988 sections.

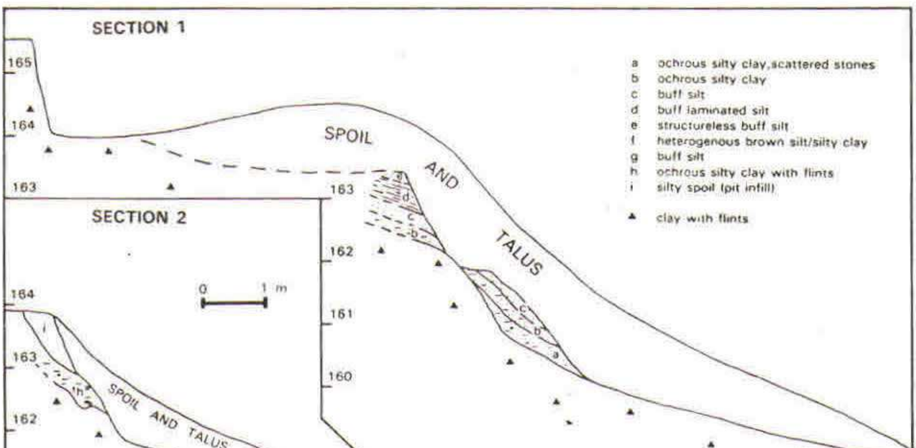


Fig. 2 Transverse sections through the edge of the old pit at the positions of Sections 1 and 2.

Conclusions

Both attempts to re-expose the Pleistocene silts at Gaddesden Row in 1988 failed to locate substantial remnants of these deposits. On the contrary, the occurrence of remnants of silty beds banked against rising slopes in clay-with-flints suggest that the former were restricted to a steep sided hollow within the latter and are essentially worked out. Wymer (1980) also recorded steeply rising clay-with-flints, implying that his section was also close to the edge of the hollow.

It seems likely that the brick pit was limited by the extent of the silt-filled hollow, working ceasing when the resource was exhausted. In this case the shape of the old working probably reflected the outline of the hollow. This appears to have been approximately circular. The form of the feature is suggestive of a 'doline', formed by solution of the underlying chalk bedrock. The Gaddesden Row 'brickearth' has previously been interpreted as a doline infill by Catt (1977), who considered it as a possible pre-Devensian loessic deposit. Catt suggested a similar interpretation for a comparable Chiltern dipslope 'brickearth' locality at Caddington, Bedfordshire, where Worthington Smith discovered another Palaeolithic working site (Smith, 1894; Sampson, 1978). Avery et al. (1982) found no mineralogical evidence for a loessic component in the 'brickearth' at Gaddesden Row, however, and concluded that the material was derived by fluvial or colluvial processes from the local Reading Beds.

Acknowledgements

The authors would like to thank the owner of the Gaddesden Row site, Mr D Simon, for granting permission for the investigation. John Wymer kindly supplied details of his earlier excavation and John Catt visited and commented on the exposures while they were open. The work was carried out by the authors on behalf of the Nature Conservancy Council.

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A PRELIMINARY REPORT ON THE LATE DEVENSIAN GLACIOMARINE DEPOSITS AROUND ST FERGUS, GRAMPIAN REGION

A M Hall and J Jarvis

Jamieson (1858; 1906) recorded the occurrence of an apparently in situ arctic marine fauna in a stoneless grey clay exposed near present sea level in a former brick pit near Annachie (NK 104 532), 7 km north of Peterhead (Fig. 1). A recent borehole survey (McMillan and Aitken, 1981) has shown that dark grey clays at least 14 m thick occur extensively east of the nearby village of St Fergus. These sediments were interpreted as lake alluvium, following Ritchie, Smith and Rose (1978), despite their apparent association with a marine fauna. Construction works at the St Fergus gas terminal in 1988, together with a shallow pit survey (Fig. 1) to a maximum depth of 6 m of the ground around Annachie, has allowed further examination of these sediments which has revealed that a substantial body of glaciomarine silts of Late Weichselian age occurs in the St Fergus area.

The sediments are dominantly massive very dark grey (2.5Y N3) to very dark greyish brown (2.5Y 3/2) calcareous silts which are here formally named the St Fergus Silts. In places the silts show crude lamination, with sand laminae, but other bedding structures are not apparent in small exposures. Median grain sizes are between 8 and 20 microns and generally coarsen with depth, with size fractions greater than 1 mm diameter normally accounting for less than 1% of the material. Locally present, however, are matrix-supported granules, pebbles and cobbles, both as isolated clasts and forming small lenses or clusters of clasts, and these are interpreted as dropstones. Occasional clasts carry striations. Clast lithologies are mainly of Cretaceous chalk, quartzite and gneiss, similar to the Inzie Head Gneiss, together with quartz psammite, pelite, semi-pelite, felsite, basic igneous rocks and red sandstone. Shell fragments occur in variable concentrations throughout the silts. Occasionally, however, concentrations of whole shells are found apparently in situ. The shells comprise mainly unabraded paired valves of *Hiatella arctica* (Fig. 2) and occur in association with worm casts as thin shell beds or lenses within bioturbated silts. Samples of silt both rich and poor in shell have yielded low concentrations (less than 5 tests per gram) of foraminifera dominated by unabraded tests of *Elphidium clavatum*. Ostracoda appear to be absent. Although much work has still to be carried out on the fauna, the presence of *Hiatella arctica* and the monospecific nature and low concentrations of the microfauna are consistent with a shallow, cold water environment for deposition of the silts. This faunal evidence, together with the occurrence of dropstones, leaves little doubt that these silts are of glaciomarine origin.

The silts reach a known maximum elevation of +16 m OD and extend below present sea level to a known minimum elevation of c. −10 m OD. The silts rest on a dark grey diamict with chalk erratics derived from the Moray Firth. East of the gas terminal, the silts extend seawards beneath postglacial beach deposits and blown sand whilst to the west the silts terminate against a steep break of slope (Fig. 1) developed in earlier interbedded red and grey clays, silts and diamicts previously interpreted as Late Weichselian glaciolacustrine deposits (McMillan and Aitken, 1981). Within the gas terminal site, the silts extend virtually to the present land surface and have a rather uniform maximum elevation of c.7 m OD. This surface is terminated to the east by a ridge which reaches an elevation of 16 m OD and which is cut into on its seaward side by the postglacial cliffline. Exposures in the ridge showed faulted and deformed beds of silt and sand. This disturbance may be due to glaciotectonics and the prominent ridge, which extends for 4 km north of the gas terminal, is provisionally interpreted as a large moraine formed by a readvance of ice from the east or north-east over part of the glaciomarine silt body.

A single radiocarbon date of 15320 ± 200 BP (Lu-3028) has been obtained for *Hiatella arctica* from the silts. This date indicates that the silts are of Late Weichselian age and provides the first absolute age estimate of the timing of the final retreat of ice from the North Sea coast of Buchan.

Further age estimations of shells by amino acid analysis and accelerator radiocarbon dating are in hand. Detailed work on the litho-, bio- and morphostratigraphy of deposits continues. A further phase of major construction work at the gas terminal is planned for Spring 1990 and it is hoped to arrange an informal trip to the site for interested QRA members through the Hutton Club in Edinburgh.

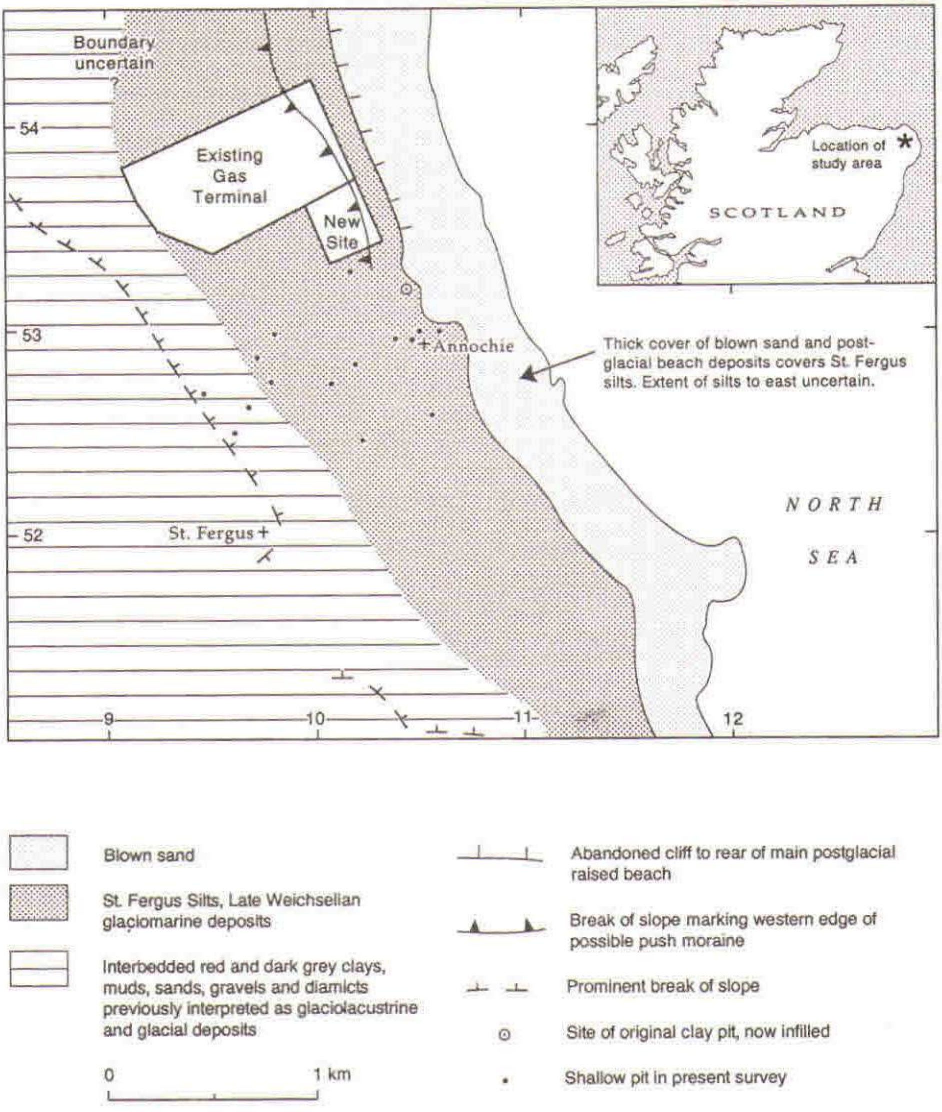
Boundary uncertain
?
54
53
52
9
10
11
12
Existing Gas Terminal
New Site
Annochie
St. Fergus
Location of study area
SCOTLAND
Thick cover of blown sand and post-glacial beach deposits covers St. Fergus silts. Extent of silts to east uncertain.
NORTH SEA
Blown sand
St. Fergus Silts, Late Weichselian glaciomarine deposits
Interbedded red and dark grey clays, muds, sands, gravels and diamicts previously interpreted as glaciolacustrine and glacial deposits
0
1 km
Abandoned cliff to rear of main postglacial raised beach
Break of slope marking western edge of possible push moraine
Prominent break of slope
Site of original clay pit, now infilled
Shallow pit in present survey

Figure 1

Figure 2

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A M Hall
Dept. of Geography
University of Edinburgh
Drummond Street
Edinburgh EH8 9XP

J Jarvis
Dept. of Geography and Geology
University of St Andrews
St Andrews
Fife KY16 9AL

A UNIFIED APPROACH TO THE STRATIGRAPHY OF PLEISTOCENE RIVER BASIN SEDIMENTS

D Maddy and C P Green

The recent paper entitled "Problems in the application of lithostratigraphic classification to Pliestocene terrace deposits" (Dr D R Bridgland, *Quaternary Newsletter*, 55) outlined some of the problems which may be encountered when an attempt is made to describe detailed Pleistocene fluvial sedimentary sequences using the recommended stratigraphical nomenclature (Hedberg, 1976; Holland et al., 1978). While undertaking research into the Pleistocene fluvial deposits of the Severn/Avon and Thames Basins, it has become apparent that there is a need to re-evaluate accepted classification schemes, as none of those currently available is totally satisfactory.

A recent trend has been to avoid stratigraphic schemes based entirely upon terrace morphology, and to focus instead on the lithological composition of the underlying deposits (Green & McGregor, 1978; Green et al., 1980; Gibbard, 1985; Hey, 1980, 1986 etc.). Composition is often a more appropriate basis for stratigraphic separation, as many fluvial deposits are not obviously related to terrace forms, while others underlie terraces which owe their form to periglacial slope processes and not to deposition.

The lithological composition of fluvial sediments laid down during the same time interval in a single river basin can be highly diverse and thus does not readily conform to the basic requirement of internal homogeneity needed for formal lithostratigraphic identification. Furthermore, sediments laid down at different times, in different river basins may show very similar compositions, and therefore inhibit formal lithostratigraphic separation, although the grouping of certain of these sedimentary units may fulfil lithostratigraphic classification requirements.

Dr Bridgland admits that the lithostratigraphic classification outlined in the various stratigraphic codes is designed "principally for geologists working on Pre-Quaternary (solid) deposits" and thus the approach is "somewhat ambiguous about procedure necessary for applying this type of classification to superficial deposits". The code itself, however, is far from ambiguous, but is simply not sufficiently comprehensive in its scope to deal with most superficial geological deposits at an appropriate scale of statigraphic resolution.

Sources of lithological variability

The problem to be overcome in the application of the existing formal lithostratigraphic schemes to Quaternary sequences, is the inherent variability of lithological composition within individual stratigraphic units. This problem is not unique to Quaternary sequences, but such variability is often the result of relatively short timescale processes and as such offers a resolution of events which is rarely the focus of interest in hard rock studies. However, within Quaternary sequences, this level of resolution of events is critical.

Variability within Quaternary fluvial sequences tends to be expressed in terms of relative compositional changes rather than absolute lithological type changes. Most systems have remained essentially closed throughout the recent past and thus only large scale events such as glaciation of the basin or major catchment change, have introduced distinctive new lithologies.

This relative compositional variability stems from, amongst other things, downstream and cross-stream process-related changes—for example comminution leading to relative dilution and enrichment, or variable flow hydraulics leading to differential sorting, and changes in composition due to downstream variation in the underlying basin geology. Since exotic inputs are relatively rare and in any case do not necessarily coincide with distinct sedimentary units, it is apparent that the natural variability within individual units may mask, between-unit changes. Alternatively, lithological change between units may not occur at all.

Sometimes, however, lithology alone is sufficiently distinctive to allow clear separation. For example the Kesgrave Formation of East Anglia can be clearly distinguished from post-Anglian gravels on lithological grounds (Rose and Allen, 1976). However, are the individual members of the Kesgrave Formation lithologically distinct in the field? Composition rarely, if ever, allows total separation of units at the level of stratigraphic resolution suggested by the dispositon of the sediments and the unconformities within them.

Perhaps the largest source of potential variability, and thus a major problem, relates to the dramatic lithological changes that can occur at tributary confluences. Tributaries often have distinctly different compositions from those of the main valley. For example, the Avon valley sediments of Midland England are radically different in composition from those of the adjoining Severn valley, upstream from the confluence; similarly, more minor tributaries of the Avon such as the Warwickshire Stour and the Arrow have different gross lithological composition, both from each other, and from the main Avon valley sediment. If we are to follow the scheme suggested by Dr Bridgland, are we therefore supposed to name the gravels of each of the tributaries as separate Formations/Members? If so what happens when they join, a further Formation? In the case of the Avon, this would lead to sediments within the main valley comprising five or more different Formations/Members at any "terrace" level.

This, we believe, would lead to a confusing and totally unnecessary amount of new nomenclature. Such internal variation, whilst of interest, should not lead to a multiplication of units of the same hierarchical status.

The application of formal lithostratigraphy

Such conditions of lithological variability, where within-unit changes equal or surpass between-unit changes, appear to be the norm rather than the exception. A quick visual scan of the mean composition of the **MEMBERS** of the Thames Valley **FORMATION** (Gibbard, 1985) will soon lead one to realise that lithological distinction between the Members is not entirely satisfactory for their separation. Furthermore, the majority of the Gravel **FORMATIONS** cited as examples by Dr Bridgland from Essex, have internal variability on the same scale as the between-unit variability (Bridgland, 1983) and rarely do distinctive new lithologies enter the system, allowing clear separation.

Dr Bridgland recognises that the usual application of the code does not convey the detail of information required and so simply suggests that we emphasize the basic 'mappable unit' aspect of a Formation, while seemingly pushing aside stringent lithological requirements, and classify each separate unit as a Formation. Dr Bridgland further argues that successive aggradations are separated by unconformities and thus according to his interpretation of the American Stratigraphic Code can be afforded separate lithostratigraphic status. However, we would argue that a minor break in preservable sedimentation without changes in composition should not lead to formal lithostratigraphic separation. After all, the nature of the boundary between separate lithostratigraphic units is not important in their definition, since lithostratigraphic units can be either conformable or non-conformable.

What then have most authors used to separate their stratigraphic units? The answer is simple, downstream profiles and altitudinal differences, with due attention to lithological variation. Unfortunately the admission of this clearly causes some distress. After all, this is primarily a **GEOMORPHOLOGIC** classification! Furthermore, if supposed river profiles are used, is this not inferring a mode of genesis and thus breaking yet another rule (from Hedberg, 1976, p.31). How then can Dr Bridgland assert that using lithostratigraphy leads to the units being more "precisely defined"?

We argue therefore that the use of formal lithostratigraphy, when correctly applied, will invariably lead only to a coarse stratigraphic subdivision. Surely then, to obtain stratigraphic subdivision at a greater resolution, would it not be better to design a classification procedure specifically for the job? It appears to us that a sensible procedure would attempt to use all the available information, both geomorphological and geological, in a unified approach to the classification of Pleistocene fluvial sedimentary sequences. Such a scheme is not intended to replace formal lithostratigraphy but can be viewed as an extension of the existing scheme developed in order to extract the maximum stratigraphic resolution.

Towards a unified approach

The proposed scheme (shown in Fig. 1 and described below) is not intended to be a rigid framework for classification procedure, but rather is intended only as the starting point for sensible discussion.

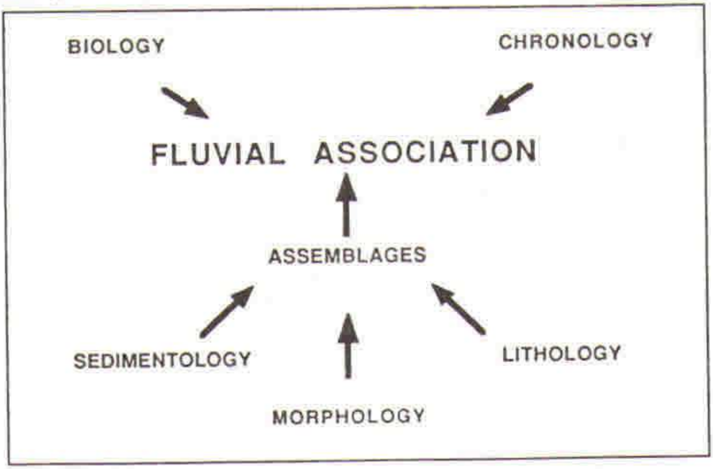

Figure 1

The use and abuse of the term River Terrace has made it desirable to seek an alternative terminology. However, the concept of the River Terrace, as 'a continuous/discontinuous body of sediment, lying upon a reasonable river gradient, and apparently the product of aggradation within the same river' is widely recognised in practice and is obviously useful. It is suggested here that the term River Terrace used in this sense be replaced by the term **FLUVIAL ASSOCIATION**. The term River Terrace should be retained purely for the geomorphological form.

A Fluvial Association is defined as a grouping of river sediments which can be shown to be stratigraphically closely related. The term refers specifically and exclusively to river sediments and can only be applied where such sediments are present. The grouping together of sediment bodies to form a Fluvial Association can be based on one or more criteria, which may reflect position, lithology, or biological or chronometric evidence.

In differentiating a body or bodies of sediment as a Fluvial Association, or in correlating together bodies of sediment within an Association, spatial position is of primary importance. Sediment bodies may be correlated within a Fluvial Association only if their positions are consistent with their former continuity along a realistic river gradient.

A Fluvial Association may be differentiated or correlated on the basis of the position of the sediment alone, but normally, wherever possible, additional means of correlation will be employed. In situations where the spatial position of two or more Fluvial Associations overlap, the use of additional means of differentiation and correlation is essential.

As defined, the term implies no specific geomorphological form nor specific lithological character, and thus has no direct link with terrace form or formal lithostratigraphy. Clearly the separation of Fluvial Associations may result from the application of one or more of several criteria and furthermore, where lithology permits the use of formal lithostratigraphic nomenclature, may be applied to the sediments of the Association or groupings of Fluvial Associations. The Association should be applicable basin wide, thus incorporating upstream and tributary gravels related to the same period of sedimentation (although not necessarily contemporaneous such deposits can be considered as such within the likely bounds of the available timescale resolution).

The Association can be, but need not be, composed of **ASSEMBLAGES**. An Assemblage may be defined by whatever aspect of the available information seems reasonable. It is suggested here that sedimentology and lithology often form the basis for Assemblages within the Association.

Lithological Assemblages may reflect the natural within-unit variability, that is, they consist of Lithological Facies. Such distinctions can be useful not only in achieving a more refined stratigraphic resolution than the Association, but also in interpreting geomorphological context. Similarly, Sedimentological Assemblages comprise groups of lithofacies (essentially the concept of Sedimentary Architecture—see Miall, 1985) and thus, again, are related to geomorphological process and may be useful stratigraphically.

Application

The suggested classification of units into Fluvial Associations, as with formal lithostratigraphic subdivisions, does not necessarily represent subdivision into chronostratigraphic units. River Basin development can be very complex and thus the simple altitudinal staircase approach may not be appropriate. Unless biostratigraphic or direct chronological control via geochronology is available, Associations cannot, and should not, be correlated temporally.

Fig. 2 shows a possible use of the procedure outlined above in the classification of the Warwickshire Avon "Terrace No. 4" (Tomlinson, 1925) and its equivalent Severn counterpart, the "Kidderminster Terrace" (Wills, 1938) along with all the related tributary "terraces" of the same level. Neither "terrace" level has a lithology distinct from the other terraces in the basin and each displays highly diverse lithological composition and thus cannot be assigned a unique formal lithostratigraphic term. However, the stratigraphic separation of the unit as a whole is clearly demonstrable in the field and the grouping of the related fragments is reasonable. Thus, this stratigraphic unit is defined as a Fluvial Association. Since the main basin river is the River Severn, the Association is named from the Severn valley term set by precedent, that is The Kidderminster Fluvial Association.

The sediments of the Fluvial Association show distinctive lithological and sedimentological Assemblages. For instance, an Assemblage dominated by sandy bedform facies lies at the base of this Association in the Stour tributary at Ailstone (Maddy, 1989), whereas generally the Association is characterised by a gravel dominated Assemblage made up primarily of facies Gm (massive to crudely horizontally bedded gravels). Using additional biological information, this Assemblage change can be shown to correspond to distinct, longer term, stratigraphic events, although more usually the facies change may reflect only minor changes in reach-dependent flow dynamics. Furthermore, lithological Assemblage changes within the Association reflect the input of Cotswold tributary fan gravels (Jurassic Facies) and other distinctive tributary inputs e.g. Worcestershire Stour Assemblage (Permian Facies) reflecting the distinctive input into the Worcestershire Stour valley of sediment derived from the Permian Clent Breccia.

This example, as portrayed, is very much simplified. In reality, several lithological/lithofacies assemblages exist. The example, therefore, is meant only as a guide to possible usage.

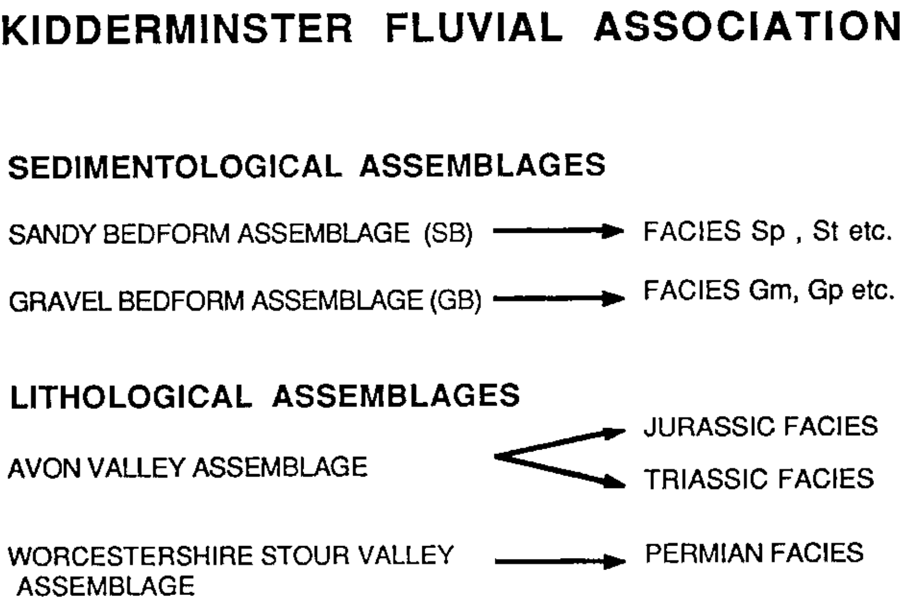

Figure 2

Discussion

The proposed methodology has distinct advantages over previously proposed schemes in that it provides a framework, however informally, for classification with no preconceived assumptions other than that the deposits are fluvial and that the Association is the basis of stratigraphic division. The exact nature of stratigraphic links between bodies and the grounds for distinguishing units are left formally undefined. The means of separation should, however, conform to a standard geological/geomorphological procedure or a combination of procedures. The emphasis of the scheme must be on common sense. Stratigraphic groupings **MUST** be geomorphologically reasonable.

What is required is the identification of a sensible procedure with which to approach the classification of Quaternary river deposits and to outline a standard terminology which aids both communication between workers and sensible interpretation. As stated above, the proposed scheme is suggested as the starting point for discussion and no doubt experience in the field will dictate what, if any, part of the procedure is sensible. As to improvement of this limited proposal, how about suggestions?

Acknowledgements

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Dr D Maddy and Dr C P Green
London Quaternary Research Centre
Department of Geography
Royal Holloway and Bedford New College
Egham Hill
Egham
Surrey TW20 0EX

LATE GLACIAL AND HOLOCENE ENVIRONMENTAL CHANGE IN THE GOWER PENINSULA, SOUTH WALES: EVIDENCE FROM THE ALLUVIAL VALLEY FILL OF THE ILSTON RIVER.

G E Saunders, S J Wood and P J Burrin

Introduction

It has long been appreciated that most, if not all, of the major river systems of South Wales flow over extensive and thick sequences of sedimentary deposits infilling deeply scoured bedrock channels, particularly in their lower reaches (Codrington, 1898; Strahan, 1899; Strahan and Cantrill, 1912). However, in spite of the early recognition of these infill deposits, the geological literature contains relatively few studies concerning the Quaternary stratigraphy and sedimentological characteristics of these valley fills and their implications for landform evolution and environmental conditions in the Holocene Period. Studies in the lower Usk (Williams, 1968), the lower Taff (Anderson and Blundell, 1965), and in the Swansea Bay Region (George and Griffith, 1938; Godwin, 1940; Al-Saadi and Brooks, 1973; and Anderson and Owen, 1979) have been largely concerned with the establishment of the depth and morphological characteristics of the buried rock channels and, to a lesser degree, with the stratigraphy and character of the sedimentary infill. Moreover, the sedimentary sequences described have been predominantly sub-littoral/estuarine facies associated with the inundation of these lower valley reaches consequent upon the Flandrian Transgression, although a restricted development of lacustrine sediments has been reported in the Lower Swansea Valley and Swansea Bay area (Culver and Bull, 1979, 1980). In consequence, surprisingly little is known of the nature and character of the valley fills away from the coastal or near coastal sites where alluviation has been primarily in response to fluvial and mass movement processes in changing floodplain environments.

The purpose of this paper is, therefore, to present the results of preliminary investigations into the litho-stratigraphy of sediments comprising the valley fill deposits of the Ilston Cwm river in the Gower Peninsula of South Wales. Attention will be focused upon the inter-relationships between the contemporary channel-floodplain system and the older alluvial fill materials, the apparent variations that can be identified therein, and some suggestions ventured as to why such differences are evident.

The Ilston Valley

The Ilston river drains a catchment area of some 25–30 km^2 on the south-eastern margins of the South Wales Coalfield where it crosses central Gower. North of Ilston village (SS 557904), the catchment (Figure 1) is floored predominantly by shales with intercalations of sandstone and grits typical of the Lower Coal Measures. The bedrock in the southern part of the catchment is the more massive Carboniferous Limestone, into which the valley, now occupied by the Ilston river, has been incised.

The catchment appears to have experienced a short, but relatively complex evolution. Much of the basin lies on a remnant of the 60 m (200′) erosion surface (Goskar and Trueman, 1934; Driscoll, 1958), which has been subsequently modified by a range of factors, including glacial and periglacial processes during the Pleistocene. The main valley is manifestly composite in origin. From its source to Cartersford Bridge (SS 552914), the river flows in a shallow, open moorland-type valley with upwardly convex, low-gradient slopes and a wide floodplain, and is clearly post-glacial in age and origin. Downstream from this point, however, the valley becomes rapidly incised and markedly asymmetrical in cross section, exhibiting many of the features characteristic of a typical glacial meltwater channel. Although the extent of the Devensian glaciation in the Gower remains unclear, Bowen's (1974, 1977) limits indicate that the ice front crossed the catchment from east to west somewhere between Ilston and Kilvrough (SS 561892). Meltwater from this ice-front is considered to have initiated the valley south of Ilston church (557903). Hence, the middle and lower valley reaches almost certainly have a fluvio-glacial origin. Subsequently, fluvial processes, much modified by the complex oscillations of sea-level changes in the lowermost valley reaches, appear to have been largely responsible for the Holocene development of the valley and its associated deposits.

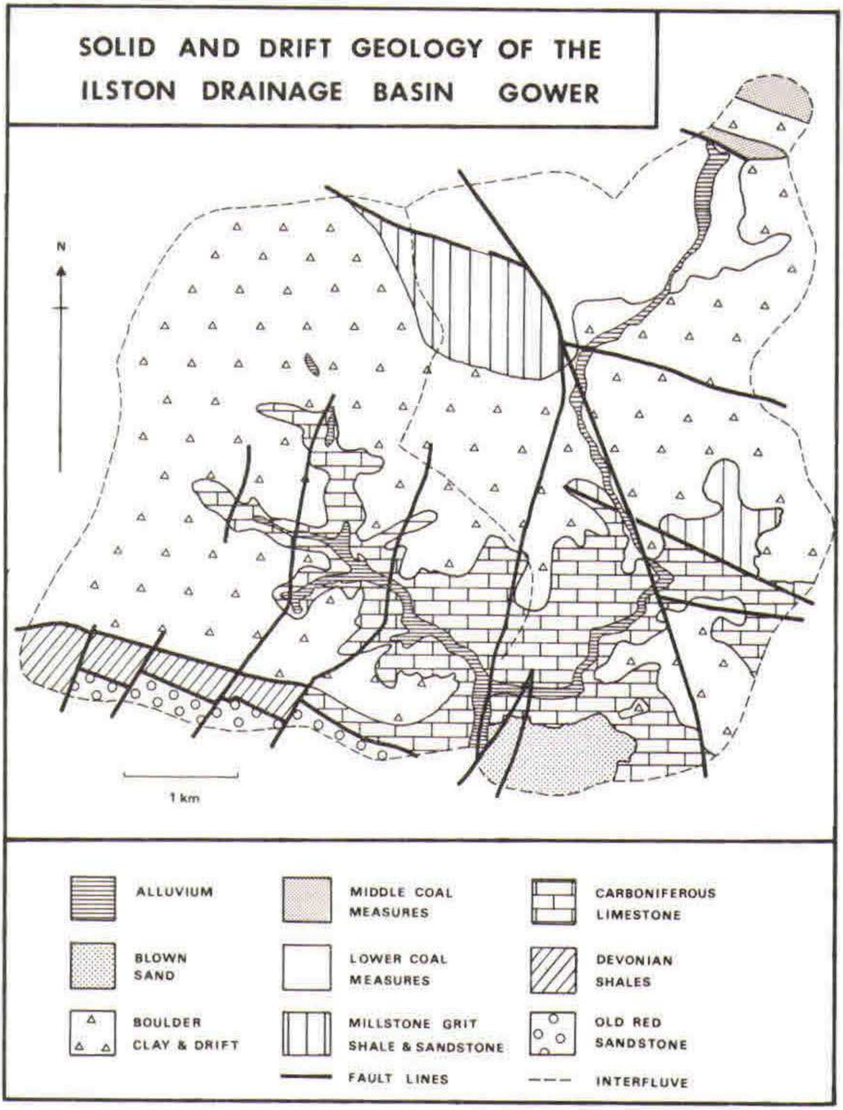

Figure 1 The solid and drift geology of the Ilston drainage basin, Gower.

Sedimentology of valley fill

Sub-surface investigation of the sedimentary sequence infilling the Ilston valley away from the coastal zone, has enabled five major lithostratigraphical facies to be recognised (Figure 2). These include:

5. The clastic bedload of the present stream channel.
4. Brown silts and clays.
3. Blue-grey sandy silt with clays and peat.
2. Brown silts and clays with very fine gravels and grits.
1. Blocky boulder glides.

The blocky boulder glides, such as that seen at Kilvrough Wood (557897), testify to local hillslope instability along the valley sides within the Carboniferous Limestone tracts. These products of mass movement are also found in the neighbouring Green Cwm Valley and interestingly, appear coarser than those presently found along the Gower coastline. Individual blocks range between 0.5 m to 1.0 m in diameter, with many being blanketed in moss or other vegetation. Limited and localised contemporary instability is evidenced by the occasional block lying on the floodplain surface or in the channel where it abuts close to or against the valley sides. Although the precise stratigraphical relationship of these glides to other fill deposits is unclear, it seems likely that they were developed immediately after the excavation of the valley as a result of oversteepening of the valley walls, by processes including frost shattering. If so a Devensian or Late Glacial age seems most likely.

The remaining facies identified are almost certainly of Late Glacial or Holocene age. Boreholes through the valley floor have enabled 4 major alluvial facies to be recognised (Figure 2). The oldest element of the alluvial fill sequence (Unit 1) appears to be intimately associated with the limestone outcrop and within this reach of the valley not only forms the basal alluvial fill but also constitutes the material in the river terrace remnants which occur intermittently between Parkmill (553892) and Ilston Church. Sedimentologically, this unit is an almost structureless, stiff, very fine gravelly, silt with a maximum proven thickness of ca.5.0 m. Weathered clasts of up to 10 mm in diameter are interbedded within the matrix, together with occasional inclusions of charcoal, the latter being restricted to the top few centimetres. This facies, which forms the more significant of the two components of the alluvial fill sequence, can be traced laterally into fine-grained alluvial fans and colluvial splays which debouch from small tributary dry valleys or locally fringe the floodplain-valley side margins.

Prior to the formation of the second fill unit a phase of erosion or channel incision occurred, dissecting the surface of Unit one and giving rise to the series of small fragmented terrace remnants, best developed at Kilvrough Wood (SS 557897) and to the south of Trinity Well (SS 552893), which stand some 1.5 m above the level of the present channel and floodplain.

Between Cartersford Bridge and Bryn Afel (554909), the eroded surface of Unit 1 is locally overlain by a band of blue-grey sandy silts containing frequent laminae of clay with intermittent 'fining upwards' sequences (Unit 2). This unit has a unimodal particle size distribution reflecting preferential sorting indicative of fluvial deposition, although the range of mean grain sizes suggests shallow, variable flow with perhaps a seasonal component. It has a high H_2O_2 oxidisable organic content of 10–15% and is characteristic of deposits from waterlogged, anaerobic environments with slow rates of sedimentation. Similar organic sediments have been identified by Bell (1981) and appear to be associated with sedimentation under woodland environmental conditions. Included within Unit 2 is a layer of well humified, detritus peat, whose history of accumulation has been C^{14} dated and represents a period from the early Iron Age up to ca.1000 A.D.

The youngest component of the alluvial infill sequence (Unit 3) consists essentially of soft to stiff, brown to dark brown, silt which has a higher sand content in the immediate vicinity of the present river channel. This unit is significant in that it is ubiquitous throughout the drainage basin, its uppermost surface consistently forming the contemporary floodplain surface of the River Ilston. The deposit is demonstrably different from Unit 2, containing less organic material (2–3%) and is generally less well sorted. Unit 3 is considered to represent a fluvially derived, overbank facies as it exhibits a general fining away from the channel. The present day channel of the River Ilston is incised into Unit 3 to a depth in excess of 1.5 m. Throughout the fill sequence there is no evidence of coarse material comparable to that active within the present channel.

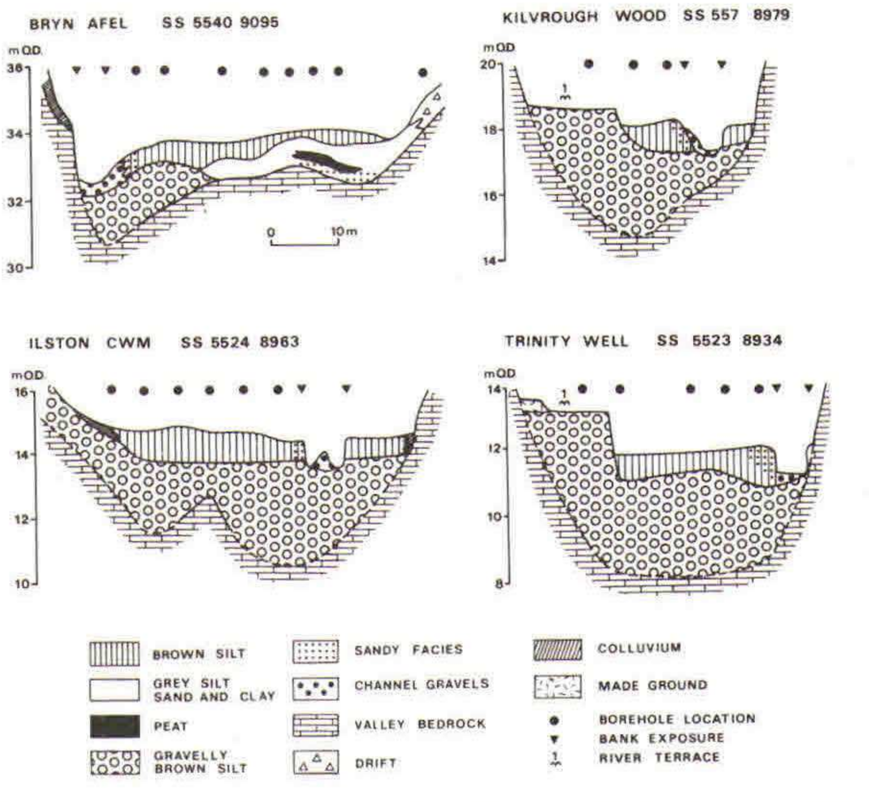

Figure 2 Selected cross profiles of valley fill sediments in the Middle and Upper reaches of the Ilston valley.

Sedimentation within the contemporary river channel stands in marked contrast to the fine-grained nature of most of the materials which constitute the alluvial fill. The channel floor is unevenly veneered by a bedload of coarse, clastic deposits, fashioned into a variety of point-, mid-, and side-bar features. These deposits range in calibre from coarse sands through cobbles to boulders, are angular to subrounded in shape and do not appear to exhibit any preferential longitudinal sorting. The bedload material presents something of a geomorphic enigma with respect to its provenance and mode of entry into the present channel. No materials comparable to the main bedload calibres (ranging between 1–35 cm) have been found in either the fine-grained silts of the alluvial fill or replicated within the block glides of the valley walls. The most obvious provenance for the bedload clasts would appear to be the erratics in the boulder clay mantling the catchment interfluves. However, the manner in which these reach the valley floor remains a matter of conjecture. Furthermore, the sharp differentiation between the contemporary channel sediments and those comprising the bulk of the valley alluvium is an interesting occurrence and merits further discussion.

Discussion

Detailed sedimentological and other analyses of these fill deposits are still in progress and these results will be published in full subsequently. However, it is of interest to note here some initial observations. A tentative chronostratigraphical sequence of events recorded by the alluvial infill sediments of the Ilston valley is presented in Table 1.

The incision of the valley into bedrock is almost certainly a legacy from the Pleistocene period. The bedrock channel may be polyphase in origin but undoubtedly received its final form as a result of erosion by meltwater issuing from the Late Devensian ice-front (18 000 to 20 000 years BP) at a time when sea levels were considerably lower that at present (ca. −90 to −100 m OD). During the ensuing Late Glacial and Holocene periods the erosional bedrock valley has witnessed several phases of aggradation separated by phases of incision. The vegetated coarse blocky, boulder glides which locally mantle the limestone walls of the valley may be confidently ascribed to the cold, tundra-like environmental conditions of the Devensian Late Glacial (14 500 to 10 000 years BP).

Locally exceeding 5.0 m in thickness, Unit 1 forms the bulk of the valley infill sequence, and represents not only a major aggradational phase but also substantial environmental disturbance within the catchment. The silt component of the fine-grained litho-facies bears a strong resemblance to aeolian or loessal deposits found elsewhere in the British Isles, although the occurrence of grits and small pebbles therein indicates that this facies cannot be interpreted as a wholly wind-blown deposit. It is considered to represent the contemporaneous reworking of colluvial materials, which appear to include a loessal component, brought down into the valley by mass movement processes operating on superficial deposits mantling the interfluves. This interpretation is supported by the lateral interdigitation of this litho-facies into fine-grained colluvial splays on the valley sides and into alluvial fans where dry valley tributaries enter the main valley. Some of the component materials of Unit 1 may have had their provenance in former local spreads of the 'upper silty loam' which has been described capping the Pleistocene succession in many coastal localities in Gower (George, 1932, 1933; Bowen, 1977) and elsewhere in South Wales (John, 1970).

The marked geomorphological activity in the catchment attested to by the extent and thickness of this deposit almost certainly implies a restricted vegetation cover under which mass colluvial wasting could operate unhindered. Such processes are likely to have occurred either prior to the establishment of, or as a result of the subsequent disturbance of, the vegetation cover. In the case of the former a Late Glacial age is likely, whilst the latter requires evidence of a prehistoric presence in this region. Although the evidence is not unequivocal, a Late Glacial Age is preferred for this deposit for the following reasons:

(1) Conventionally, the pre-Boreal and Boreal periods are considered to be times of improving climate and a transition to more continental conditions; vegetation cover was being increasingly established, and drainage basin runoff and groundwater levels may have been reduced in limestone environments as a consequence of drier conditions and the lower sea level. Base flow contributions to contemporary river discharge are important and it is tentatively suggested that early Holocene river flow may have been considerably lower if not absent.

(2) The permafrost conditions of the Late Glacial would have not only offset to some extent limestone permeability but also provided a surface over which solifluction could operate. Moreover, vegetation cover would be sparse and discontinuous.

(3) The occurrence of charcoal fragments within the sediments, while they are conventionally interpreted as evidence of anthropogenic activity, may be equally attributed to natural, lightning-induced fires (which are common to periglacial environments during the summer) or to contemporary contamination.

Table 1 A tentative chrono-stratigraphy of the valley fill sediments of the Ilston River

	Lithostratigraphy	Environment	Years BP	B.C./A.D.	Sea Level
HOLOCENE	Contemporary Channel Processes/ Channel Incision	Post-mining re-adjustment			O.D.
	Floodplain Surface	Mining disturbance			
			post	1640–1660 A.D.	
	Aggradation Unit 3	Agricultural disturbance			
			440(?)	1410–1610 A.D.(?)	
	Aggradation	complex cut and fill response to clearance			
			940 ± 100	910–1110 A.D.	
	Peat	oak/hazel/birch			
			2670 ± 70	650–790 B.C.	
	Unit 2				+4 m O.D. (Flandrian)
			3170 ± 70(?)	1150–1290 B.C.	
	2 m Incision/ Ilston Terrace				Rising Sea Level
		Parc le Breos tomb	5200/4800	3250–2850 B.C.	
			10 000		
LATE DEVENSIAN	Aggradation Alluvial Splays/ Unit 1	Rapid Mass-Movement			−20 m O.D.
	Block glide Formation	Periglacial			Rising Sea Level
			14 500		
	Excavation Ilston Melt-water channel	Fluvioglacial			−90/−100 m O.D.
	Late Devensian Glaciation				

N.B. The dating of the upper and lower boundaries of Unit 2 has been somewhat crudely extrapolated based on the thickness of silt accumulating during the deposition of the peat.

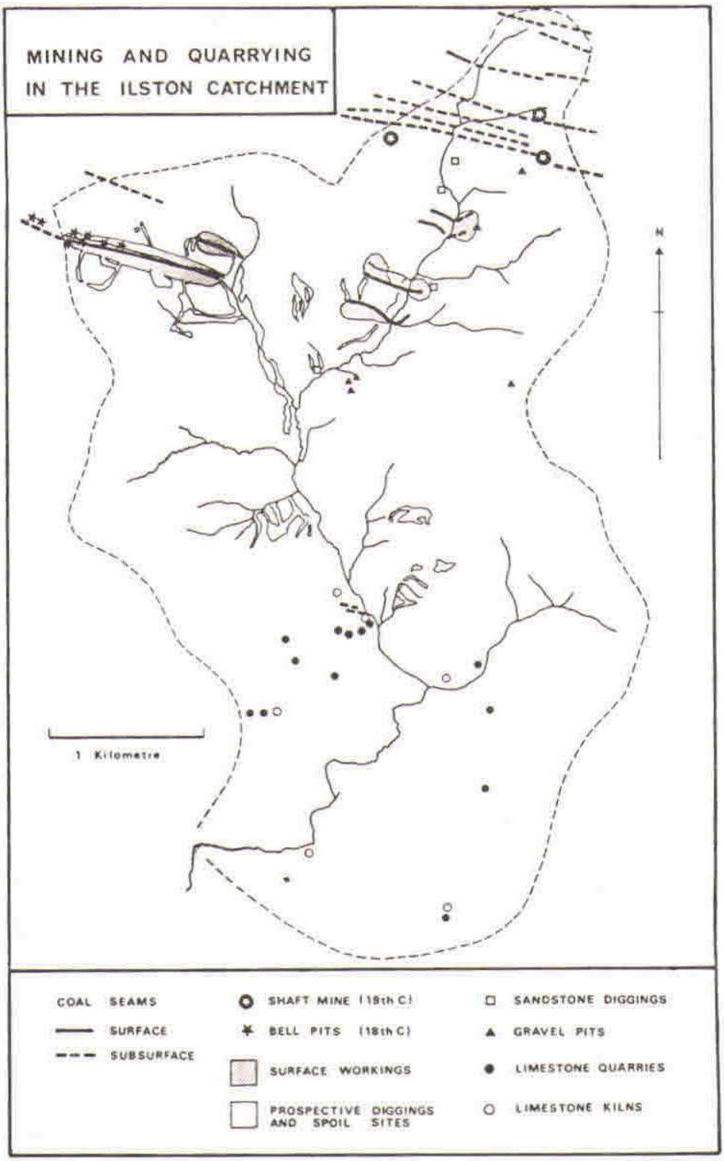

Figure 3 Mining and quarrying in the Ilston catchment.

Precise dating for the commencement and termination of this first phase of valley alluviation has so far proved difficult in the Ilston valley but, in the neighbouring valley of Green Cwm (Parc le Breos), Lynch (1976) has assigned the Neolithic chambered tomb which stands on the upper surface of Unit 1, to the period 5200–4800 BP. These dates may be considered to mark the absolute minimum age for this deposit, since the construction of the tomb post-dates the cessation of sedimentation by a phase of non-deposition and/or erosion of unknown duration.

The first episode of colluviation and valley aggradation was followed by a phase of stream incision and lateral erosion into the fill (Unit 1). Downstream of Ilston village the maximum amount of incision was in excess of 2.0 m and was responsible for the abandonment of the former floodplain surface, thereby creating a series of well developed terrace fragments. Interestingly, the amount of incision decreases as the terrace is traced up-stream. This incision, occurring as it does during a time of rising sea-level culminating in the Flandrian Transgression, must be attributed to local adjustments occurring within the basin fluvial-hydrological system.

The blue-grey silts and sands with interbedded peat lenses which overlie the eroded surface of Unit 1 between Cartersford Bridge and Bryn Afel represent a phase of localised, but protracted, aggradation within this reach of the valley during a period when geomorphological activity appears to have been relatively limited elsewhere in the catchment. C^{14} dating has shown that this phase of aggradation commenced sometime before 2670 ± 70 years BP (650–790 BC) during the Late Bronze Age—Early Iron Age transition, and continued well after 940 ± 100 BP (910–1110 AD) into Early Medieval times. The pollen content of the peat indicates the existence of two distinct vegetation communities: the interfluves carried a mixed (oak-hazel-birch) thermophilous woodland, while the moister conditions of the valley floor was dominated by a marshy alder carr vegetation (R Scaife pers comm). The progressive decline of arboreal pollens upwards through the sequence coupled with the general increase in flowering plants and gramineae as well as the occurrence of cereal type pollens and the pollens of weeds associated with cultivation all point convincingly to a progressive increase in the period from the Bronze/Iron Age transition up to early Medieval times.

The third episode of valley alluviation, represented by the more homogeneous brown silts of Unit 3, is attributed to a renewed phase of valley side instability coupled with fluvial reworking of the surficial horizons of the first fill unit. The onset of this phase of aggradation is uncertain but may be tentatively placed around 550–350 BP (1400–1600 AD), and is possibly a response to enclosure and increased agricultural activity in the catchment. The present surface of the Ilston floodplain had apparently been attained by the 17th century for the chapel at Trinity Well was constructed on this surface and dates from ca.1649–1660 AD.

The sequence of geomorphological events is completed by the establishment of new conditions of equilibrium following further channel incision associated with the introduction into the contemporary channel system of coarse calibre sediments, chiefly gravels, pebbles and cobbles. The marked difference between the coarse, clastic, bedload of the modern stream and the fine-grained Holocene silts of the valley fill strongly suggests that the contemporary channel-floodplain environment is significantly different from the floodplain systems whereby the valley fills were created. Whilst there is good evidence (Lawler and Bull, 1977) that the river is now meandering actively across its floodplain (much of it formed of Unit 2 and is, therefore, by implication essentially relict) the confinement of the gravel/cobble bedload within the boundaries of the present channel suggests that the introduction of this coarse fraction is a relatively recent event, and may well be associated with anthropogenic disturbance of the environment caused by the prospecting and working of coal seams at some time between the 17th and 19th century, within the catchment.

Information concerning the location of coal seams and associated diggings within the Ilston catchment have been obtained from the field notes on W Logan (quoted in Strahan, 1907) and the six inch 'County' series sheets of the Geological Survey (Figure 3). Areas of disturbed ground adjacent to known seam locations are apparent from six inch OS maps of the region, and analysis of first edition maps indicate that the diggings were well wooded prior to 1870. Establishing the period of active extraction is, however, problematic without recourse to parish records, but they have all the characteristics of 16th and 17th century excavations. Cooper (1986) has documented the history of mining in the Penclawdd area north of the catchment and exemplifies the nature of early coal extraction. Initial exploitation was often by a local farmer or land owner, and tended to concentrate on surficial deposits in better drained locations on higher ground. These were generally free from drift cover and, consequently, easy to locate. Knowledge of geological structure was limited at this time, particularly in relation to faulting and fracturing of seams, and early excavations are often characterised by extensive tracts of orthogonal prospective disturbance. Limitations of transportation restricted exploitation of coal seams in less accessible areas and this may have extended the active life of small reserves.

Many of these factors apply to the coal seams present in the upper Ilston and it would appear that surface disturbance far exceeded that merited by the magnitude of the coal reserves. What is clearly demonstrable is that all known coal seams in the area were located adjacent to tributary streams in the upper basin and consequently, sediments resulting from disturbance were readily entrained in overland or stream runoff. Furthermore, it is possible that specific efforts were made to facilitate efficient drainage of groundwater from the worked coal seams, inevitably exacerbating sediment removal.

Within the Ilston catchment, post-Medieval anthropogenic disturbance thus appears to have induced considerable changes in the fluvial regime. Evidence of localised, contemporary floodplain erosion and planimetric instability may be partly related to increasing recreational pressures (Lawler and Bull, op. cit.) but, more generally, it is intimately associated with the intermittent transportation and storage of coarse channel sediments. The introduction of these sediments appears to have been a relatively recent event in terms of the chronostratigraphy presented here, and a consequence of direct anthropogenic disturbance and the incision into, and destabilisation of, coarse boulder clay materials in the upper catchment. The contemporary re-adjustment of the Ilston river may be a lagged response to environmental disturbance similar to that identified by Lewis et al. (1983) in Mid-Wales rivers.

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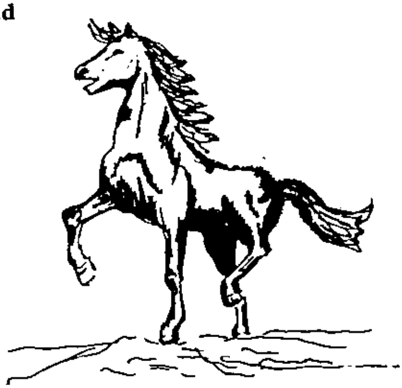
Drs Paul Burrin and Gordon Saunders
Department of Resource and Environmental Management
University of London Goldsmiths' College
Lewisham Way
New Cross
SE14 6NW

Simon Wood
Department of Geography
Portsmouth Polytechnic
Lion Terrace
Portsmouth PO1 3HE

A WILD HORSE BONE FROM BREDON HILL, WORCESTERSHIRE

P F Whitehead



In August 1985, Mr M Wojczynski of Redditch brought to me a collection of vertebrate bones for naming. One of these was a left calcaneum of a horse (*Equus* sp.) with the *tuber calcis* worn away by attritional processes. From its condition and my experience of vertebrate fossils in the area, I concluded that the bone was likely to be either Devensian or early Flandrian. It was picked up by Mr Wojczynski in 1982, some 17 cms below the modern land surface in limestone rubble (scree) on Bredon Hill at SO/97004045 at about 220 m OD in the parish of Elmley Castle. It had been revealed during the construction of a cattle trough.

The bone was submitted to the Radiocarbon Dating Laboratory at the University of Birmingham School of Earth Sciences for dating. Whilst every effort was made to combust the small amount of collagen yielded by the bone, this ultimately proved to be an impossible task (R E G Williams, personal communication).

The plateau-like summit of Breden Hill is capped by Inferior Oolitic Limestone, forming a well-marked feature 80 m above the find-site, which is within a zone of shattered landslip blocks from that formation, likely to be of Devensian age. This surface find of a wild horse bone supports the view that the Cotswold and its outlying plateaux provided ecological refugia for wild horses in Britain prior to their extinction. There is a surface find of a wild horse tooth from Broadway, Worcestershire (Whitehead, 1979a) and other pre-Flandrian vertebrate fossils are known from the scarp-slope of the Cotswold Hills (Whitehead, 1979b).

I wish to express my gratitude to the School of Earth Sciences University of Birmingham, and the staff of its sadly defunct Radiocarbon Dating Laboratory.

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P F Whitehead
Moor Leys
Little Comberton
Pershore
Worc
WR10 3EP

NOTE ON THE FROG HALL GRAVELS DESCRIBED AND DISCUSSED BY M G SUMBLER

F W Shotton

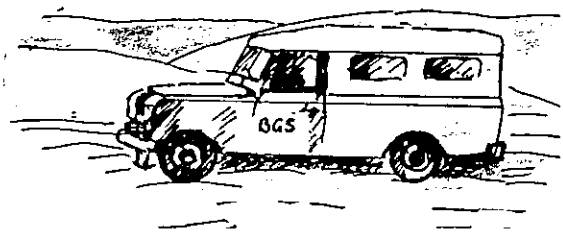
I welcome the paper by Sumbler on the Frog Hall Sand and Gravel recently published in the *Quaternary Newsletter* (No. 58, June 1989), even if I am not wholly convinced by it. I wish I could have seen the details of the auger holes which are cited to the east of the pit's workings, and their laminated clays and silts which are accredited to the Wolston Clay. I am, of course, aware that gravels are being worked near to Frog Hall and I ascribed them on my map (Shotton, 1953) to the Dunsmore Gravel which had been worked in the now abandoned pit marked B in Sumbler's Fig.2. I still feel inclined to this classification. Sumbler's map (Fig.2) and section (Fig.3) look convincing enough until one realises the great vertical exaggeration of scale. We cannot cite other examples of the working of coarse gravels in the position where I am inclined to think the "Frog Hall Beds" are supposed to lie, because they do not exist. Stratigraphically lower, the Wolston Series provides many examples of where gravels have been or are being exploited and their base is often very channeled. This was so at Baginton, and Cornets End and at Waverley Wood Farm, to name a few examples. Sumbler's Fig.3 looks at first glance very convincing, but if one assumes as I did that the postulated channel is filled with Dunsmore Gravel, the slope of the channel's sides only works out at around 1¼° to the horizontal, which is not abnormal in what must surely have been a very high energy deposit.

I find no reason to change the capping of hill-top gravel between Fosse Farm (419746) and Lammas Hill (419752) from my original classification as Dunsmore Gravel.

Incidentally there were unexpected flint/quartzite gravels which are shown on my map near to Ryton-on-Dunsmore. From their shape and extent, I ascribed them to No.4 Terrace near the head waters of the River Leam.

F W Shotton
111 Dorridge Road
Dorridge
Solihull
West Midlands B93 8BP

FIELD REPORTS



REPORT ON THE SHORT FIELD MEETING TO GLEN ROY 12–15 MAY, 1989

The QRA field meeting to the Glen Roy area, near Fort William, was attended by 22 participants. The trip was based at the Spean Bridge Hotel which provided excellent accommodation for the duration of the meeting, although some hardy souls braved the elements at a nearby campsite.

The aim of the excursion was to examine the Late Quaternary history of three valleys (Glen Roy, Glen Gloy and Glen Spean) lying adjacent to the Great Glen. The area is famous for the occurrence of ancient lake shorelines, known as the Parallel Roads of Lochaber, which have excited the interest of researchers for more than two centuries. Although much was known about the Roads in the Nineteenth Century, their recognition as lake shorelines rested ultimately with the acceptance of the glacial theory, first proposed for the area by Agassiz in 1840. Since then, the extent and elevation of the shorelines, their relationship to the cols through which the lakes drained and to landslips that both predate and postdate the formation of the Roads, have been the subjects of intensive study.

Recently, controversial evidence of palaeoseismicity from both the landslips and lake sediments has been correlated with two distinct seismic events, one of which may relate to the catastrophic drainage of several of the lakes. Dating of sediments infilling small lake basins within the cols has provided a chronology for the pattern of drainage during the deglaciation of the area, whereas sedimentological studies of the Quaternary sequence, and in particular the nature and significance of fans and deltas in Glen Roy and Glen Spean, have been particular sources of controversy.

The party assembled at Spean Bridge at lunchtime on May 12 and set off in the afternoon to examine a major landslip in Glen Fintaig and proposed ice-limits for the Loch Lomond Readvance in Glen Fintaig and Glen Gloy. Unfortunately, the weather, which had been changeable during the morning, deteriorated during the afternoon to incessant rain and mist, not unusual in the NW Highlands. This meant that the expected views of the Parallel Roads were often obscured, but the drift limits in Glen Fintaig and Glen Gloy were convincingly demonstrated. The contact between the shorelines and the landslip in Glen Fintaig was impressive, as were the recent landslips and debris flows that had destroyed the road in Glen Gloy during the previous winter.

The group reassembled in the hotel in the evening when Doug Peacock gave an introductory talk on the areas that we were to visit during the next three days. This was most appreciated by those members of the party like myself, who had never visited the area before.

The Saturday dawned bright and clear, with a light powdering of snow on the tops of the surrounding mountains. The party, which had now been joined by Jim Rose who arrived by overnight train from London in time for breakfast, embarked in three BGS Landrovers for a full day's excursion to view the spectacular features in Lower and Middle Glen Roy. The first stop at Glen Roy Viewpoint provided panoramic views of the Parallel Roads and the drift marking the limit of the Loch Lomond Readvance. The party then walked into the glen, across the drift limit and into Caol Lairig where the limit is partially covered by the lake deposits associated with the 350, 325 and 297 m Roads. We then descended into Middle Glen Roy to view sequences of deformed lake sediments exposed in a series of road-cuttings. The successive deformation events identified by Ringrose and interpreted by him as evidence for palaeoseismicity led to a vigorous debate as to whether the liquifaction and slumping phenomena observed could not simply be explained by recurrent loading.

The remainder of the day was spent examining the Brunachan Landslip and associated 'earthquake features' and the Reinich and Brunachan Fans, before a belated return to the hotel for a well-earned late evening meal. For me, the abiding impression of the second day was of the views from 300 m above the floor of Glen Roy, looking down the glen to see the lake shorelines bathed in sunshine and stretching for miles towards Roybridge and the snow-capped Grey Corries beyond.

On the third day of the excursion we again travelled along the narrow serpentine road through Glen Roy to reach the outwash fan and associated moraines at the mouth of Glen Turret. Here we examined the Turret Fan Gravels, which are known to rest on laminated silt and clay. Lively debate took place on the conflicting views on the mode of formation of the fan (subaerial or subaqueous) and its implications for the history of Late Glacial drainage in Glen Roy. The significance of a pollen spectrum from organic silts at Turret Bank, close to the fan and its bearing on the likely presence or absence of ice occupying the Glen Turret col during the Loch Lomond Readvance, was discussed at some length. The party then made its way up to the col between Glen Roy and Glen Gloy and examined the evidence for and against the passage of ice over the col during the Loch Lomond Readvance before returning to the Landrovers for the trip back to Spean Bridge.

The final day of the meeting was spent examining glacial and fluvial landforms in Glen Spean. Highlights included the kame and kettle topography in the River Treig area, and the Treig glaciolacustrine delta. Sand and gravel workings in the glaciofluvial delta at Brackletter provided spectacular sections through cross-bedded shingle. Giant potholes were seen, preserved in the vertical right bank of a gorge now occupied by a small tributary of the River Spean (the Allt Mhill Dhuibh). They are thought to be evidence of the catastrophic drainage of the lake that occupied Glen Spean.

By the end of the meeting all of the participants agreed that it had been a well organised, fascinating and thoroughly enjoyable four days. Overall the trip was filled with intriguing geology, beautiful scenery and much lively and good natured debate. The enthusiasm and stamina of Doug Peacock, who was responsible for what was a fairly strenuous schedule, meant that we visited most of the sites described in the field guide; to have fitted them all in would have taken at least a week!

Clive Auton
British Geological Survey
Murchison House
West Mains Road
Edinburgh
EH9 3LA

ABSTRACTS

LATE CENOZOIC ICE AGE SYMPOSIUM

Thanks to Geoffrey Boulton, I have been able to repreduce a set of abstracts of talks delivered at the symposium on the Late Cenozoic Ice Age, held at The Royal Society of Edinburgh in July. The symposium, organised by the Royal Society of Edinburgh and sponsored by the QRA, discussed a number of new and exciting ideas, a number of which are in precis form. (Ed)

ODP SITE 677, A NEW STANDARD OXYGEN ISOTOPE SEQUENCE FOR THE PLEISTOCENE

N. J. Shackleton

ODP Site 677 (1°12'N, 83°44'W, 3461 m water depth) was recovered close to DSDP Site 504 in the Panama Basin. Using material from ODP677A, ODP677B and DSDP504 is should be possible to generate complete oxygen and carbon isotope records for both planktic and benthic species. Our record has a sampling interval of 10 cm which represents about 2500 years. The clear 40 ka cycles recognised by Ruddiman, Raymo and McIntyre (1986) in DSDP607 are equally well marked here but in addition the record contains evidence of the 22 ka precession cycle.

Tuning the record to assumed orbital forcing has been attempted in two ways. Correlating the record to the DSDP607 timescale results in a switch in the observed phase of the climate response to precessionally forcing at about 900 ka. On the other hand tuning to yield a consistent relationship with assumed precessional forcing yields excellent coherencies but implies that the accepted K/AR ages for the magnetic reversals of the Pleistocene require upward revision by about 5 per cent.

FORCING OF LATE CENOZOIC NORTHERN HEMISPHERE CLIMATE BY PLATEAU UPLIFT IN ASIA AND AMERICA

W F Ruddiman and J E Kutzbach

Geologic evidence indicated that net vertical uplift occurred on a large (km) scale and at accelerating rates during the middle and late Cenozoic in plateaus of southeast Asia and the American southwest. Based on this evidence, we ran General Circulation Model sensitivity tests to isolate the unique effects of plateau uplift on climate. The experiments predicted significant climatic changes in many places, many quite remote from the uplift regions. To a remarkable degree, these predictions are borne out by changes found in the geologic record: winter cooling of North America, northern Europe, northern Asia, and the Arctic Ocean; summer drying of the North American west coast, the Eurasian interior, and the Mediterranean; winter drying of the North American northern Plains and the interior of Asia; and changes over the North Atlantic Ocean conducive to increased formation of deep water. The modelled changes result from increased orographic diversion of westerly winds, from cyclonic and anticyclonic flow induced by summer heating and winter cooling of the uplifted plateaus, and from widespread subtropical subsidence in compensation for the enhanced monsoonal rising motion near the plateaus.

Taken together, these observed regional trends comprise most of the Northern hemisphere pattern of 'late Cenozoic climatic deterioration' that culminated in the Plio-Pleistocene ice ages. The success of the uplift experiment in predicting the direction of virtually all of these regional climatic responses points to uplift as a key function of late-Cenozoic climatic change in the Northern Hemisphere at time scales longer than orbital variations.

MODELS OF THE MID-PLEISTOCENE CLIMATE TRANSITION

W R Peltier

On the basis of $\delta^{18}O$ data from deep sea sedimentary cores that are sufficiently long to extend beyond mid-Pleistocene time, it is clear that a marked transition in global climate took place near 9 Ma. The history of continental ice volume fluctuations through the earlier Pleistocene was characterised by negligible power at the period of 10^5 Ma. Subsequent to this time the dominant source of variance in these records consists of an intense quasi-periodic oscillation at this period. Since the conventional Milankovitch theory provides no insight into the origin of the 10^5 year oscillation it is much more successful in reconciling data from the early Pleistocene than from the more recent part of the record which appears to require the operation of strong nonlinearity. In this paper I will describe a new one dimensional climate model with coupled ice physics and earth physics (glacial isostatic adjustment) that we have been developing at Toronto in an attempt to understand what the cause might be of the mid-Pleistocene transition. As observational control on the theory we are employing the very high resolution record from ODP site 677 in the Panama Basin (Shackleton, personal communication). A standard digital sonogram of this record has revealed interesting spectral characteristics of the way in which the climate transition occurs.

THE PLEISTOCENE GLACIATION OF TIBET AND THE ONSET OF ICE AGES—AN AUTOCYCLE HYPOTHESIS

Matthias Kuhle

During six expeditions new data were obtained on the maximum extent of glaciation in Tibet and the surrounding mountains. Evidence was found of moraines at altitudes as low as 1100 m on the southern flank of the Himalayas and 2300 m on the northern slope of the Tibetan Plateau, in the Qilian Shan. On the northern slopes of the Karakorum, Aghil and Kun Luyn. moraines occurred as far down as 1900 m. In southern Tibet radiographic analyses of erratics document former ice thicknesses of at least 1200 m. Glacial polishing and knobs in the Himalayas, Karakorum etc. are proof of glaciers as thick as 1200–1600 m. On the basis of this evidence, a 1100–1600 m lower equilibrium (ELA) line was reconstructed for the Ice Age, which would mean 2–2.4 million km^2. Because of the subtropical latitude and the high altitude, solar radiation in Tibet is 3–4 times greater than the energy intercepted between 60 and 70°N or S.

With an area of 2–2.4 million km^2 and an albedo of 90%, the Tibetian ice sheet caused the same heat loss on the earth as a 6–9.6 million km^2 sized ice sheet at 60–70°N. Because of its proximity to the present-day equilibrium line Tibet must have undergone large-scale glaciation earlier than other areas. Being subject to intensive radiation, the Tibetan ice must have performed an amplifying function during the onset of the Ice Age.

This amplifying function is linked to an initial 400–500 m fall in the equilibrium line due to the Milankovic insolation anomalies. This drop in temperature led to the glaciation of Tibet which in turn caused a further global lowering of the equilibrium line to approximately 700 m. Now, other mountain glaciers as well as those in Tibet flowed into the respective mountain forelands, also creating large reflection surfaces. In this way the subtropical glaciers, especially effective in reducing temperatures, increased in size to about 3.5 million km². But also the higher latitude mountain forelands like those in Alaska and Scandinavia were increasingly glaciated until ice sheets were formed in the Nordic lowlands. The feedback effect of this self-amplifying cooling process on its subtropical source area, Tibet, caused the maximum extent of ice sheet cover. It corresponded to a drop in summer temperature of 7.1–9.4°C, whereas the initial cooling caused by isolation anomalies had only been about 3.5°C.

At the maximum stage of the last ice age the cooling effect of the newly formed, about 26 million km² sized ice sheets of the higher latitudes was about three times that of the Tibetan ice. Nevertheless, without the initial impulse of the Tibetan ice such an extensive glaciation would never have occurred.

The end of the Ice Age was triggered by the return to preglacial radiation conditions of the Nordic lowland ice. Whilst the rise of the equilibrium line by several hundred metres can only have reduced the steep marginal outlet glaciers, it diminished the area of the lowland ice considerably.

THE PALEOCLIMATIC RECORD IN THE LOESS SEQUENCES OF ASIA AND EUROPE

George Kukla

Layers of calcareous wind blown dust alternate with soils in loess sequences up to 300 m thick, which formed in Asia and Europe during the last 2.5 million years. Numerous proxy indicators point to a dry and cold climate of the loess as opposed to the humid climate of the soil-forming intervals.

Low field magnetic susceptibility in the loess deposits of north central China and central Europe fluctuates in inverse relation to climate. It is low in the loess and high in the soils.

In the inner part of the Chinese Loess Plateau, the deposition rate of magnetic minerals carrying the susceptibility signal fluctuates only little with time and can be used for the refinement of chronostratigraphic models. This is not the case with the slope deposits in the foothills surrounding the Plateau and in the central European sites.

Principal features of the loess deposits in Europe and Asia are as follows:

1 Dominant pedogenesis and suppressed eolian sedimentation during the interglacials and early glacials.
2 A relatively sudden shift to the dominant hillwash and eolian sedimentation at the early glacial/pleniglacial boundary. Last such shift correlates with the oxygen isotope stage boundary 4/5. It is represented by a conspicuous 'marker' bed in central Europe.
3 Warming of the loess deposition near the glacial/interglacial boundary.
4 Four well expressed glacial cycles in the upper half of Brunhes.
5 A major polygenetic paleosoil or soil group about 500 to 600 millenia old.
6 Thick loess units correlating with the oxygen isotope stages 2 + 4, 6, 12, 16 and 22.
7 At least 44 soil-loess couplets of a glacial/interglacial rank.
8 A pronounced shift toward drier and older climate in the loess belt of Europe and Asia at about 2.3 million years ago, representing by far the sharpest environmental change of the last 5 million years.

A 400 KY HISTORY OF THE INDIAN SW MONSOON—EVIDENCE FROM ODP LEG 117, NW ARABIAN SEA

Graham Shimmield, Stephen Mowbray and the Leg 117 Scientific Party

The Indian summer SW Monsoon plays an important part in influencing, and regulating, the marine response (biomass productivity) of the NW Arabian Sea. This is achieved by affecting coastal upwelling and hence nutrient supply to the euphotic zone waters. The resulting productivity has been shown to leave a permanent record in deep-sea sediments from the Arabian Sea. Interpretation of this palaeoproductivity record enables the history of the SW Monsoon to be traced, and allows the possibility of quantifying the effect of glacial and interglacial episodes on this major climatic system. Core 722B was raised from the Owen Ridge (16°37.3'N, 59°47.8'E, 2028 m depth) during Leg 117 of the Ocean Drilling Program and has been subjected to 150 multi-element analyses for the upper 15 m representing 400 ky of sediment accumulation. The chronostratigrphy of this core has been modelled using $CaCO_3$ records available for this area. Over this period mass accumulation rates have varied by a factor of 8 reflecting variable aeolian and fluvial terrigenous input. In addition, markers of palaeoproductivity (biogenic Si, Ba ^{230}Th) indicate that important productivity episodes have occurred. These episodes display strong coherence with interglacial periods, suggesting that at these times the SW Monsoon was stronger, resulting in greater upwelling and surface productivity. This finding is in accord with previous results using pollen and foraminiferal upwelling faunas (Prell and Van Campo, 1986). Using chemical data from Hole 723 on the Oman Margin, and radioisotope measurements, we present a possible means of quantifying this upwelling record to obtain a unique history of the SW Monsoon through Late Cenozoic time.

VARIATIONS IN THE TROPICAL MONSOONS AND THE ASSOCIATED HYDROLOGICAL FLUXES

F A Street-Perrott

This paper will focus on the palaeohydrological evidence for long-term variations in the African and Asian monsoons, and on the role of orbital forcing as an explanation for these changes. Analyses of lake-level data from the northern tropics show that periods with stronger summer monsoons occurred during or just after three of the insolation maxima during the last 130 000 years. Data for the others are lacking. Modelling experiments for 9000 yr BP carried out with both the NCAR and UK Meteorological Office GCMs suggest that hydrological variations of opposite sign should have occurred in the southern tropics; a conclusion only partially consistent with the available geological data.

For the early Holocene period of enhanced Northern Hemisphere monsoons, the changes in hydrological fluxes simulated by the two GCMs will be compared with published reconstructions of the water budgets of individual lake basins, and with areal estimates based on the palaeogeographical information shown on the recently published map 'Le Sahara a l' Holocene: Mali by N Petit-Marie *et al.* (1988).

OCEANIC AND ATMOSPHERIC FEEDBACK BETWEEN MID- AND HIGH-LATITUDE ICE SHEETS

Scott J Lehman and Glenn A Jones

We have radiocarbon dated records of isotopic and faunal change during the last deglaciation in four sediment cores from Fram Strait (PS-21295), the west Spitsbergen continental shelf (L87-136), the central Norwegian Sea (V27-60), and Denmark Strait (V28-14). A light oxygen isotope anomaly in each of these cores indicates that glacial melt-water discharge into the Norwegian Sea began 15 ka BP, a time when subtropical North Atlantic cores (Keigwin and Jones, in press) still exhibited the heaviest isotope values of the last 20 ka BP. We infer from this pattern that the deglaciation of the Barents Shelf Ice Sheet and the continental shelf-based portions of the Fennoscandian Ice Sheet were responsible for the first notable transfer of water from the full glacial ice sheets to the oceans, and hence the onset of eustatic sea-level rise.

Productivity in Denmark Strait began to increase at 13.5 ka BP, and in Fram Strait by 13 ka BP. This change was associated with incipient flow of Atlantic water into the Norwegian Sea basin and was synchronous with the initial melting of the western terminae of the Spitsbergen Ice Sheet complex. The transition from a polar to a Fram Strait, documenting an advance of the polar front through the Norwegian Sea at a rate of approximately 150 km/100 years. A large increase in the rate of sediment accumulation on the West Spitzbergen Shelf indicates that the west coast of the island was being rapidly deglaciated by the time the polar front advanced into the southern Norwegian Sea. Climatic optimum conditions were experienced throughout the Norwegian Sea region from 9.5–4.0 ka BP during which time Equilibrium Line Altitudes in western Norway were elevated, glaciers on Spitsbergen were behind their present margins, and the increased activity of the West Spitsbergen Current was winnowing the shelf.

One plausible explanation for the timing of these events is that the early deglaciation of portions of the Barents Shelf and Fennoscandian Ice Sheets may have promoted the decay of the Laurentide Ice Sheet via eustatic sea level rise. Atmospheric changes associated with the subsequent lowering of the Laurentide Ice Sheet may have then allowed the first incipient, and then, exaggerated meriodional advection of Atlantic water toward Fram Strait. These changes would have contributed to the further decay of the Fennoscandian, Barents and Spitsbergen ice masses, thereby bringing full circle the deglacial cycle begun in the Norwegian Sea.

DECAY OF THE SVALBARD AND BARENTS SHELF ICE SHEETS DEDUCED FROM ACCELERATOR MASS SPECTROMETER C-14 DATED SEDIMENT CORES FROM FRAM STRAIT AND THE SPITSBERGEN SHELF

Scott J Lehman and Glenn A Jones

While the maximum extent of the Svalbard Ice Sheet during the last glaciation is still poorly constrained, most investigators agree on a minimum model that was confluent to the south and east with a Barents Shelf Ice Sheet, forming a complex, multidomed ice sheet system (Mangerud et al., 1987). Here we compare radiocarbon dated records of the last deglaciation in sediment cores from Fram Strait (PS21295) and the west Spitsbergen continental shelf (Lance 87-136) in order to examine the degree of diachroneity between the decay of the west Spitsbergen and Barents Shelf components of this ice sheet complex. An earlier study of the isotope record from PS21295 (Jones and Keigwin, 1988) inferred an early break-up of the Barents Shelf Ice Sheet, and possibly the marine based portions of the northern Fennoscandian Ice Sheet, which liberated a large quantity of meltwater to the Norwegian-Greenland Sea basin at 15 ka BP. 'Lance' core 87-136 provides a record of large changes in terrigenous and biogenic sediment flux, and oxygen isotope anomalies, that are indicative of a later local deglaciation on western Spitsbergen. The diachroneity between the two different parts of the ice sheet complex reflects their differing sensitivity to such variables as glacio-isostatically induced changes in relative sea level, oceanic heat flux and insolation.

Because the deglaciation of the Barents Shelf Ice sheet may have promoted the decay of the Laurentide Ice Sheet via eustatic sea level effects (Jones and Keigwin, 1988) a complete telemetric feedback loop may have been set in motion which eventually determined sea surface conditions in the Norwegian Sea via Laurentide Ice Sheet size modulation of the intensity of the jet stream and westerly surface winds. Changes in sea surface conditions in Fram Strait, deduced from paleo-oceanographic indicators in the two cores, support General Circulation Model results for the full glacial, late glacial and early Holocene (Manabe and Broccoli, 1985; Kutzbach and Guetter, 1986; DOHMAP, 1988) showing the effect of Laurentide Ice Sheet size on sea surface temperature and sea-ice extent in the Norwegian-Greenland Sea. As the Laurentide Ice Sheet lowered, and SST's began to rise, the west Spitsbergen Ice Sheet began to recede. The increasing SST's bolstered by changes in orbital seasonality, eventually promoted an early Holocene optimum (Kutzbach and Gallimore, 1988) that is well documented in our cores and on the adjacent land mass (Forman et al., 1987).

GLACIAL/INTERGLACIAL CHANGES IN OCEAN CIRCULATION AND ATMOSPHERIC pCO_2

L D Labeyrie, J C Duplessy, E Michel and F Maitre

The foraminiferal $\delta^{18}O$ and $\delta^{13}OC$ may be related to the physico-chemical characteristics of sea water at the time of deposit the difference between the foraminiferal $\delta^{18}O$ and water $\delta^{18}O$ is a thermodynamic function of the water temperature, once corrected from specific fractionation. Vertical density profiles may be estimated from the vertical benthic foraminifera $\delta^{18}O$ gradient, using sediment cored at different depths along continental slopes and sea-mounts. Such reconstruction, in the Atlantic and the Indian Oceans for the Last Glacial Maximum indicate strong changes in the vertical water structure, with decreased mixing between intermediate and deep water. The foraminiferal $\delta^{13}C$ is related (for the benthic foraminifera species *Cibicides wuellerstorfi*) to the $\delta^{13}C$ of the total dissolved CO_2. This parameter is correlated, in the ocean, with the amount of dissolved oxygen and to the amount of dissolved CO_2, and thus depends directly on the ventilation, circulation and aging of the water masses.

Application of these relations to the isotopic measurements of fossil foraminifera living during the last glacial maximum allows the reconstruction of the 2-D vertical circulation patterns of the ocean during that period: intermediate and deep waters above 2000–2500 m were significantly more oxygenated than at present in the Atlantic, Indian and Pacific oceans. The turn-over was faster, a probable result of more active winter convection along polar fronts and in marginal seas. In contrast, deeper waters were depleted in oxygen and enriched in dissolved CO_2. A deep thermocline limited the exchanges, around 2000–2500 m depth, between both types of water masses. Exchange of the deep waters with polar surface waters was probably still active, to dissipate the bottom geothermal flux, but ventilation was limited by the ice cover, and an insufficient flow from North Atlantic deep water.

Estimation of the atmospheric pCO_2 is obtained using a steady state 14 box model which simulates the hydrography, the biogenic cycle and the dissolved CO_2 $\delta^{13}C$ in the different oceanic basins, calibrated on the GEOSECS data base for the modern ocean. The glacial simulation, based upon our global reconstruction, indicates a decrease of the atmospheric pCO-2 to approximately 220 ppm, thus still higher than the changes observed in Dome C and Vostok ice cores (180 ppm). However, as observed by Boyle (Nature, 1988), the calculated atmospheric pCO_2 depends strongly upon the estimated mean alkalinity of the glacial ocean, which is poorly constrained.

PALAEOCLIMATIC INFORMATION FROM ICE CORES

J Jouzel, J R Petit and D Raynaud

Ice deposits from Greenland and Antarctic ice sheets have stored over long periods of time information about the climate and environment of our planet. Attention will be focussed on the 2083 m Vostok Antarctic ice core which represents an unusually long record (160 000 ky) due to the low accumulation rate (~ 2 g cm^{-2} a^{-1}) and the rather uniform conditions of ice flow. This ice core provides a unique opportunity to obtain several paleo data such as temperature, accumulation (precipitation), aerosol loading, CO_2 and trace gases over a full glacial to interglacial climatic cycle.

The Vostok temperature, deduced from the interpretation of the deuterium content and the CO_2 records, show a large 100 ky signal with a change of the order of 10°C and 700 ppmv, respectively. The two records are closely correlated and both display shorter periodicities characteristic of the earth orbital parameters. CH_4 concentrations also show variations from about 0.35 to about 0.65 ppmv linked with the glacial-interglacial warming. These features suggest a fundamental role of radiatively active gases in climatic changes.

The accumulation (precipitation) record appears to be governed by temperature with values during the coldest stages reduced by a factor of 2 with respect to the present rate. Ice deposited during these coldest stages is also characterised by high concentration of marine and terrestrial aerosols; these peaks likely reflect strengthened sources and meridional transport during full glacial conditions, linked to hither wind speed, more extensive arid areas on the surrounding continent and a greater exposure of continental shelves.

THE LONGMANS LECTURE
MODEL PROJECTIONS OF GREENHOUSE-GAS-INDUCED CLIMATE CHANGE

Michael E Schlesinger

Since the dawn of the Industrial Age the concentration of CO_2 in the Earth's atmosphere has increased, predominantly due to the burning of fossil fuels. Projections of the future consumption of fossil fuels show that sometime in the next century the concentration of atmospheric CO_2 will likely be twice its pre-industrial value. More recently, other gases also have been anthropogenically produced which are even more effective greenhouse gases than CO_2, their addition to the Earth's atmosphere thus hastening the time of an effective CO_2 doubling.

Our expectations of what a greenhouse-gas-induced climatic change should look like are based on supercomputer simulations performed with mathematical models of the atmosphere-ocean-sea ice system. Simulations of the changes in the equilibrium climate have been conducted with atmospheric general circulation models (GCMs) coupled to simplified models of the ocean. In the earliest simulations, the ocean was treated as being equivalent to perpetually wet land with zero heat capacity, this to economize on computer time. Simulations with these so-called swamp ocean models showed significant changes in the 'annual-mean' equilibrium climate induced by a CO_2 doubling. Subsequently, atmospheric GCMs were coupled to models of the upper well-mixed layer of the ocean in which the oceanic heat transport convergence was prescribed, often as zero.

Simulations of the annual cycle of CO_2-induced equilibrium climatic change have been performed with five such coupled atmospheric GCM/mixed-layer ocean models. These simulations reveal a cooling of the stratosphere, which increases with altitude; a warming of the troposphere, which also increases with altitude in the tropics; a surface warming which increases with latitude toward the winter pole; an increase in the global-mean precipitation and evaporation rates; large increases and decreases in precipitation between 30°S and 30°N latitudes, with smaller increases in the high latitudes of both hemispheres, and a dessication of the northern hemisphere continents during summer. However, the results of these models are questionable owing to the absence of predicted heat transport in the ocean. Futhermore, such models cannot be used to simulate the correct temporal response of the climate system induced by increased greenhouse gas concentrations.

Simple models of the climate-ocean system have been used to estimate the response time of the system to greenhouse forcing, with results of 10–100 years in terms of e-folding time. If the smaller timescale is correct, then the greenhouse-gas-induced global-mean warming should be twice as large as the actual warming observed from 1850 to 1980, this implying that our climate models are twice as sensitive as nature. If the larger timescale is correct, then the observed warming is not inconsistent with the increases in greenhouse gas concentrations. To determine the timescale accurately, however, requires a comprehensive model of the ocean. Such oceanic general circulation models have been coupled to their atmospheric counterparts, and the joint atmosphere-ocean-sea ice models have been used to simulate the response time of the climate system. These models give results of 25 to 60 years.

Recently, simulations of the non-equilibium climate change induced by increasing concentrations of greenhouse gases have been performed. These non-equilibrium simulations indicate that the expectations of what greenhouse-gas-induced climate changes should look like based on the antecedent equilibrium climate change simulations may not be completely correct. However, these non-equilibrium simulations have either been idealised in terms of the increases in the concentrations of greenhouse gases, or they have been initiated only late in the actual history of such increases. Therefore, there is a need to perform realistic non-equilibrium climate change simulations which begin early in the history of the observed greenhouse gas increases, and which extend into the next century. However, before such simulations are performed, it is necessary to enhance the physical completeness of the oceanic component of the coupled model, this by the inclusion of the deep-water-formation mechanism caused by brine rejection.

A FIRST-ORDER GENERALIZED MODEL OF TERTIARY AND QUATERNARY CLIMATIC CHANGE

Barry Saltzman and Kirk A Maasch

The theory of the Quaternary climate will be incomplete unless it is embedded in a more general theory for the entire Cenozoic that can account for the onset of the ice-age fluctuations. Here we construct a simple mathematical model for the Cenozoic climatic change based on the hypothesis that forced and free variations of the concentration of atmospheric greenhouse gases (notably CO_2, methane, and water vapour) is a primary determinant of the climatic state over this period. Our goal is to illustrate how a single model, governing both very long term variations and higher frequency oscillatory variations in the Pleistocene, can be formulated. Although the details of this model are speculative, it is hoped that the formalism may be relevant for developing improved models in the future as our knowledge of the past climatic variations improves.

FLUXES BETWEEN THE DIFFERENT PARTS OF THE CLIMATE SYSTEM SIMULATED BY A COUPLED ATMOSPHERE-OCEAN-ICE SHEET MODEL OVER THE LAST GLACIAL-INTERGLACIAL CYCLE

A Berger, T H Fichefet, H Gallée, I Marsiat and C H Tricot

A 2.5-D seasonal model has been developed for simulating the transient response of the climate system to the astronomical forcing. The atmosphere is represented by a zonally averaged quasigeostrophic model which includes accurate treatment of the radiative transfer. The atmospheric model interacts with the other components of the climate system (ocean, sea ice and land surface covered or not by snow and ice) through vertical fluxes of momentum, heat and humidity. The model explicitly incorporates surface energy balances and has snow and sea-ice mass budgets. The vertical profile of the upper-ocean temperature is computed by an interactive mixed-layer model which takes into account the meridional advection and turbulent diffusion of heat. This model is asynchronously coupled to a model which simulates the dynamics of the Greenland, northern American and Eurasian ice sheets.

Over the last glacial-interglacial cycle, the model simulates climatic changes in general agreement with the low frequency part of the deep-sea, ice and sea-level records. In this experiment, the following physical processes play a particularly important role: the albedo-temperature feedback, the precipitation — altitude feedback over the ice sheets, the albedo of the aging snow and the ablation rate of the southern edge of the ice sheets.

This paper will focus on the sequence of events involved in the transient response of the climate model to the astronomical forcing. Specifically, the long-term evolution of the seasonal cycle of the solar forcing and of the surface heat fluxes will be emphasised. Analysis of the cycle of the energy fluxes within the coupled climate system will help to diagnose the most important physical processes and feedbacks operating in the modelled climate system. Their comparison with proxy data will contribute to the validation of the model.

THE FORM OF MID-LATITUDE ICE SHEETS THROUGH GLACIAL CYCLES

G S Boulton and C Clark

Geological evidence which permits us to reconstruct the changes in form and flow of former ice sheets has generally been restricted to evidence of change in location of the margin. Flow-parallel features such as drumlins and striae have been variously interpreted as evidence of the pattern of flow during the maximum of glaciation or a reflection of the successive patterns of flow in the sub-marginal zone during final retreat of the ice sheet.

We have established that sets of major drift lineations often occur with a cross-cutting relationship, for the areas occupied by mid-latitude ice sheets. These have been mapped over the whole area of mainland Canada from satellite images. Conventional areal photographs have been used to determine the relative ages of these lineation sets.

We believe that each lineation set reflects the pattern of flow within the ice sheet during periods when the pattern of flow and the location of the divides was relatively stable. Assuming this, the successive patterns of lineations demonstrate the location of successive ice divides, and that these ice divides and the associated patterns of flow shifted dramatically through time.

Although dating of these changes is as yet insecure, existing stratigraphies around Hudsons Bay suggest that several major shifts of ice sheet geometry have occurred during the Wisconsinan.

We suggest that the inferred changes in ice sheet mass and the locations of the divides reflect both changes in insolation and circulation, and periods of strong marine drawdown.

TIME-SCALES IN THE EVOLUTION OF CONTINENTAL ICE-SHEETS

Richard C A Hindmarsh

Dimensionless models of ice-sheets provide a basis for rigorous and systematic derivations of the reduced equations describing their mechanical behaviour. They also illustrate and illuminate the essentials of ice-sheet behaviour. The height and velocity scales are set by the atmosphere, and the other scales follow from the rheological properties of ice.

Thermo-mechanically coupled ice-sheets operate according to five time-scales; two kinematical and three thermal. The kinematical timescales relate to spreading processes and advance processes, and are strongly modulated by the atmosphere. Typically marginal kinematical processes are of the order of thousands of years, while central, spreading time-scales are of the order of tens of thousands of years.

Thermal processes are dissipation, advection and conduction. These have time-scales one thousand years, ten thousand years and one hundred thousand years each. The dissipation time-scale is closely linked to the central, spreading kinematical time-scale. It does not seem possible for thermal processes to act very much faster than kinematical time-scales, implying that thermally induced viscous collapse is unlikely.

A wide variety of similarity solutions for viscous spreading of Stokes' bodies (i.e. without surficial mass-exchange) exist which incorporate descriptions of a wide variety of those processes occurring in the spreading of ice-sheets. The solution form is an invariant profile whose vertical and horizontal dimensions scale differently with time. Viscous bodies not in invariant profiles relax into such profiles very quickly. Ice-sheets in advance or in retreat adopt a normalised profile that is very near constant, and can be quite close to the invariant Stokes' body profile. This suggests that the growth and decay of ice-sheets may be a 'low-dimensional' system. Numerical ice-sheet models are fitted to a systems of few ordinary differential equations.

SEA-ICE MODELLING AND CLIMATIC CHANGE

Douglas G Martinson

Numerical and analytical models have been developed to describe the nature of ocean/sea-ice interaction in the climatically sensitive Southern Ocean. The models accurately simulate the sparse modern observations and describe the ice-ocean structure and temporal evolution. The numerical model provides an indication of the interannual sensitivities of the system while the analytical model explicitly resolves sensitivities through a single winter season. These allow a detailed assessment of the relative roles and importance of the controlling processes and system variables. Consequently, the response of the system to climatically expected changes as well as the impact and magnitude of change resulting from a perturbation to a single system component can be evaluated.

The Southern Ocean influences and responds to long term climate change predominantly through (1) temporal and spatial variations in the sea-ice cover and (2) its ability to produce deep and bottom water and store/ventilate climatically active gases through deep convection. Both of these are dependent upon the vertical stability of the water column. Open ocean convection is controlled by 3 system variables: (1) depth of the pycnocline; (2) atmospheric radiation relative to the strength of the halocline. The first is related to the vigour of the circulation, ultimately related to the strength of the subpolar atmospheric low pressure cell. The last two are critical and intimately related to the temperature and salinity characteristics of the NADW (or whatever water may replace it during glacial periods). Therefore, the Southern Ocean response to a cutoff of NADW is strictly dependent upon the ratio of temperature to salt in the replacement deep water. Seasonality of the sea-ice cover is controlled by similar conditions.

EVOLUTION OF THE INDIAN OCEAN SUMMER MONSOON OVER THE PAST 2–3 MILLION YEARS AND SEDIMENT FLUXES TO THE INDIAN OCEAN

W L Prell

The strength or intensity of the Indian Ocean summer monsoon reflects changes in solar insolation, tectonic, and ice-age boundary conditions. The primary driving force for the monsoon is the variation in summer insolation over the Asian continent and the development of a low pressure cell over Asia and the resultant pressure gradient between the Asian interior and the Indian Ocean. The insolation changes are related to the Milankovitch mechanism and are cyclical at periods of 100 Ky, 41 Ky and 23 and 19 Ky. Superimposed on these orbital patterns are responses due to uplift of the Tibet-Himalayan complex, which strengthens the monsoon, and changes in ice-age conditions, which weaken the monsoon during ice-ages. The evolution of the monsoon represents a complex combination of these processes.

Cores collected on Leg 117 of the Ocean Drilling Project contain a 10 My history of sedimentation under an evolving monsoonal system. Although deposition rates and silica accumulation began about 10 My ago, clear upwelling plankton assemblages were established later. During the past 3.5 My, the western Arabian Sea sediments are marked by variation of terrigenous components that are transported by monsoon-related winds. Maximum flux occurs at Milankovitch frequences and represents aridity cycles in Arabia and Africa. Grain size data indicates stronger winds at 23 and 100 Ky periods but not necessary at 41 Ky. The apparent emergence of the 41 Ky cycle at about 2.5 My may represent a tectonic (uplift of Tibet) and ice-age (high latitude cooling) amplification obliquity related aridity cycles in the source area. Long term trends in the plankton data suggest that the upwelling ecosystem has also evolved over the past one million years.

BOOK REVIEWS

For the reviews in this issue, I am indebted to David Keen, Department of Geography, Coventry Polytechnic, and Mike Bishop, County Archaeologist for Nottinghamshire, both of whom have assured me that there is some more compulsive reading to be done! (Ed.).

The Viking World by James Graham-Campbell. Published by Windward/Francis Lincoln, London 1989, paperback 220 pp. Priced at £9.95.

The Vikings were irresistibly attracted to British monasteries and churches. They saw them as sources of loot and slaves. Not surprisingly, the Church saw the Vikings as black-hearted pagans, ruthless destroyers and "wolves". Since the Church was the principal author of the chronicles of the period, its view stuck. 19th and early 20th Century studies of Icelandic Sagas, and the romantic retelling of them, have added another dimension. Thus, the popular idea of the Vikings invokes images of fierce warriors, demigods, longships, fire, rape and pillage. So universally understood is this concept that it can underpin the long running cartoon, "Hagar the Horrible", which appears in the *Sun*.

The Viking World shows this to be a one-sided picture. The Vikings were a European phenomenon, an outflowing of Scandinavian adventurers, merchants and colonists who left their mark on Russia and Byzantium in the East, on Newfoundland in the West, and nearly everywhere else between. Vikings were not simply brutish bandits preying upon others but were the product of a complex and sophisticated society. There were kings seeking power and empire, princes and nobles seeking wealth and status, merchants seeking new markets and farmers seeking land and a new life. If some of these were cruel, violent pirates and oppressors, if others were rumbustious and proud adventurers, they were no different in that to other contemporary figures of European history. But the Vikings stand out, for they came from outside of Christian European society and were possessed of a drive and vigour which significantly altered the course of history in the west of Europe. In Britain, their legacy is still with us, in our language, our place-names and at the root of the concepts of our society.

This is the subject matter of this book. In ten sections, it presents an overview of the whole of Viking history and culture, from tribal groupings and kingdoms in Scandinavia, through their raiding, trading and colonising activities in western and eastern Europe, Greenland, Iceland and Vinland, to their domestic life, art, literature and religion. It is a comprehensive review of the Vikings and their achievements, but do not expect to find exhaustive accounts of them in any one particular country. The key facts and interpretations are here, with selected detail, scattered through the book, but if real depth is required then the reader should turn to other sources.

The arrangement by thematic sections betrays the origin of the volume. It was first published in 1980 to parallel the very successful Viking Exhibition at the British Museum. That publication has been revised for this new edition. Thematic arrangements work very well in exhibitions but can present problems of continuity and cohesion in writing. This is the case here. Overall, the whole hangs together well enough, but there is a disjointed feel about some parts. This is particularly so in the last section on Nation States, which embraces a number of short passages which are inadequately linked. With this exception however, each section has its own integrity and stands up as an individual discourse.

Three specialist contributions are of particular value. Sean McGrail provides one of the most coherent overviews of Viking ships and seamanship available. His presentation of the lineal development of ship architecture and of the skills involved in their construction must impress even the most rooted land-lubber. Equally impressive was the Viking ability to navigate open water with no greater instrumentation than know-how and the fingers of an outstretched hand sighted against the horizon.

Religion, both pagan and Christian, is dealt with by Christine Fell in a sensible and balanced manner. She brings home just how important the pagan cults were in Viking society and that the adoption of Christianity was no light matter. It could bring real problems when the ethics of the new belief came into conflict with social conventions based on the old ways. The common sense and social concern displayed by the Vikings in the course of conversion is striking. The decision of the heathen Lawspeaker of Iceland in 1000 AD, who declared that for the sake of unity all should be baptised and become Christian but that those who were genuinely believers in the pagan gods might worship them in private, was pragmatic and practical.

The third specialist is Professor Page, who is responsible for the section on runes and poetry. In this he demystifies and illuminates the Viking arts of writing and literature. His lucid exposition of the conventions behind the metre and rhyme of skaldic verse show us a people of great intellectual dexterity, especially when one realises that these verses were composed and received without being written down.

The material presented in these sections is hard to come by at the popular level and this alone makes the book worthwhile. The same may be said of another section, by the principal author, James Graham-Campbell, on Viking art. This gives a good introduction to the various decorative styles and their "family" relationships. It is important to understand these styles in order to fully appreciate the art-work of this period. Further, they are a principal guide to the dates of many sites. Although there are copious photographs, comprehension might have been better assisted by more line drawings dissecting the elements of the artistic compositions. When the eye is presented with tangled knots of sinuous, stylised animal bodies, legs and curlicues, verbal description alone is inadequate.

In other respects the standard of illustration is superb. The maps are clear and the line drawings are precise, although the pedant might wish for the inclusion of explicit indications of scale. The photographs are excellent; they make the book. There are lots of them, and at least half are in colour. Well lit and composed, they bring out the detail and beauty of both objects and landscapes with compelling intensity.

The publishers and author(s) must be given full marks for the presentation and content of *The Viking World*. As a book it is perhaps best seen as a collection of essays around the Vikings, to be dipped into individually. In this way it imparts both knowledge and pleasure.

Mike Bishop

Drawings to illustrate this review have been taken from Gwyn Jones' book 'A History of the Vikings'.

Gadd, Nelson R. (editor). 1988. *The Late Quaternary Development of the Champlain Sea Basin.* Geological Association of Canada Special Paper 35. Published by the Geological Association of Canada, St Johns, Newfoundland.
ISBN 0-919216-35-8. Price $60.00, plus $5.00 postage.

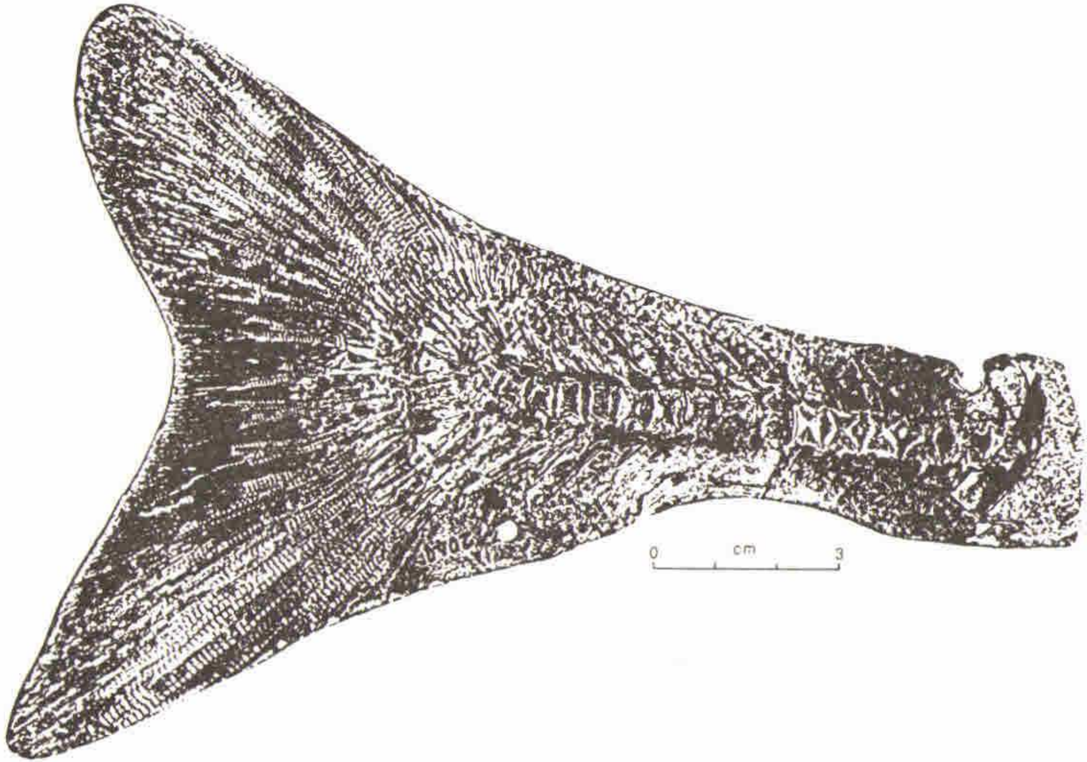
The Champlain Sea was the body of marine water that covered the isostatically depressed St Lawrence Lowlands of Ontario, Quebec, New York and Vermont during the retreat of the Laurentide Ice from eastern North America. The sea existed for c.2000 years between 12 000 and 10 000 bp, at the end of which isostatic uplift in the east closed off the basin from the sea. This volume is a collection of 21 papers given on the various aspects of the Champlain Sea at a symposium in Ottawa on the 21 May 1986. Although the Champlain Sea deposits were first recognised as marine as early as 1825, and considerable contributions on aspects of the geology of the basin were published in the 19th century, some 55% of all work has been published since 1951. The aim of the symposium was to summarise the current state of knowledge and highlight the point of disagreement between the various workers.

Because of this long history of research, the outlines of study in the area are relatively uncontroversial, although the paper by Pair, Karrow and Clark puts forward some local revisions of the marine limit in New York State, so the papers presented are largely detailed accounts of specific problems. The major themes that emerge from the volume are the types of environment which controlled deposition, the exact types of palaeoenvironment represented by the various faunal remains present, and perhaps most problematic of all the dating of the various stages and aspects of deposition.

The arrangement of the volume broadly follows these three themes. After an introduction by the editor, Nelson Gadd, Elson provides a review of the literature and a "selected bibliography" which however contains 377 individual references. A further introductory paper by Gadd gives an outline of the limits of the Champlain Sea and includes a series of stage-by-stage maps of the development and waning of the transgression. Following these two papers are 4 (by Barnett; Rust; Burbidge and Rust and Sharpe) which describe various aspects of the sedimentology of the Champlain Sea deposits. The concentration is largely on the sands and gravels associated with glacio-marine sedimentation, and the interpretation of these deposits benefits fully from studies conducted in modern glacio-marine environments. This group of papers is well illustrated by numerous photographs and diagrams of the various facies types described, and also by reconstructions of the types of environments occasioned by sedimentation from sub-ice conduits and in submarine fans. High sedimentation rates are apparent in virtually all sequences examined, with for example, Burbidge and Rust indicating from varve counts that the 14 m thick and 6 km long St Lazare fan was deposited in 47 years. In such situations deformation and slumping of the sediments are usual and such rare features as submarine kettle in-fills also occur. All this sedimentological variation is well described by the authors.

The other major themes of the volume, the dating and types of palaeoenvironment of the deposits, form the subject matter of the next eleven papers. The two themes are closely interlinked as the main indicators of the palaeoenvironments, faunal and floral remains, also provide the raw materials for the dates. The main points of controversy are whether the Champlain Sea had a wholely freshwater precursor, and what the dates of the transgression were. Both of these questions are difficult to answer satisfactorily given the nature of conditions in the basin. The major influxes of marine water from the north east and melt water from the north and west, made salinities in the basin very varied and constantly changing and thus difficult for any but the most tolerant faunal groups to withstand. The high energy conditions also allow almost infinite possibilities of the mixing of different faunal associations and thus the indications of particular conditions. However, faunas comprising ostracods, foraminifera and molluscs (Prichonnet; Cronin; Hunt and Rathburn; Rodrigues), fish (McAllister, Harington, Cumbaa and Renaud) and marine mammals (Harington) are described. The faunal remains are also used by Hillaire-Marcel and Wassenaar, Brand and Terasmae via stable isotope geochemistry, to indicate palaeotemperature and palaeosalinity.

These studies are of interest not only from a palaeoenvironmental view point, but also from the question of radiocarbon dating the deposits by dating their included marine shells. The major problem is that the influx of melt-water into the basin carried a high solution load of "old" carbonate derived from



Lake charr, Salvelinus namaycush, *caudal fin and caudal peduncle, from Besserer's Wharf, Ottawa area, Ontario (NMC 2040B).*

the Palaeozoic bedrock. Thus dates obtained from shells living in the less saline waters in the west of the basin and around its edges are likely to be less reliable than those derived from faunas in the east and the centre of the basin where deeper, more saline and carbonate-poor water prevailed. This general distribution of palaeoenvironments and their control over the dates obtained is well illustrated by the data provided by Rodrigues who links micro-fossil evidence for shallow, brackish water with anomalous dates. Even in individual profiles, dates may become "older" up sections as water depth and salinity falls. Rodrigues links these anomalous dates to hard water effects by way of the evidence from the marine faunas for decreased salinity. Hillaire-Marcel's work on the isotopic composition of shell carbonate also allows for this sort of interpretation with shells formed in water of low salinity giving dates which are anomalously "old".

Whatever the dating problems, the various lines of evidence confirm a general environment of sub-arctic character. The fish fauna from the Green Creek nodules with its spectacular preservation illustrated by some fine photographs, suggests an environment equivalent to that of the Labrador coast today (McAllister et al.). Considerable amounts of sea ice are indicated by the mammals, particularly by the seals (harp, bearded and ringed) which breed on ice (Harington), while although Cronin can find no direct current analogue for the micro-fauna, the general indications fit with the other evidence. Conditions around the sea are handled by Anderson, with a consideration of the pollen floras of small lake basins at the limit of the marine incursion, and by David, who reviews the extent of aeolian deposition of sand blown from the lake shore. Both these papers, as well as adding to the sum of data about the general environment, add details of their own, with Anderson providing radiocarbon dates on plant material to compare with those obtained from shell, and David the reconstruction of two different palaeowind patterns, pre- and post- the collapse of the ice sheet, along the north shore of the basin.

The final two papers, by Torrance and Teller, address other specific problems of the Champlain Sea which are more loosely tied to the theme than the major part of the volume. Tellers' paper takes a wider view of the de-glaciation of eastern North America than just the St Lawrence lowland, and speculates that the ultimate replacement of the marine conditions of the Champlain Sea with freshwater owes as much to the catastrophic influx of melt water from Lake Agassiz 1500 km to the east along the ice front, as to the isostatic uplift of the narrows at Quebec. Torrance brings the papers up to the present with consideration of the geotechnical behaviour, mineralogy and pore-water chemistry of the Champlain Sea sediments.

The volume is very well produced in an A4 format which allows good reproduction of the drawings, photos and maps. It is provided with a subject index and is virtually free of typographical errors. Although perhaps rather high, its' price is not out of line with that of volumes of a similar quality. It will be of great relevance to anyone interested in the last phases of glaciation in North America and also has many lessons for those whose fields of study are in other parts of the world, but which touch on the subject material here.

Finally no review of this volume could be complete without mention of the paper which is absent. This should have been by Serge-Henri Richard and detailed the extensive mapping of the areas around Ottawa which had occupied him for so many years (see the citations in Elsons' bibliography) and which he demonstrated so enthusiastically to the participants in the Ottawa Valley field trips of the 1987 INQUA. His untimely death has left a considerable gap in an otherwise satisfyingly complete book.

David H Keen

ABSTRACTS

APPLICATIONS OF QUATERNARY RESEARCH

On 3 and 4 January, 1990, the QRA discussion meeting will be held at Manchester Polytechnic when the topic will be "Application of Quaternary Research". I am indebted to Murray Gray of the Department of Geography, Queen Mary and Westfield College, London for sending me all the available abstracts (arranged below in 'running order') and for his help in editing some of the submissions (Ed.).

QUATERNARY ENVIRONMENTAL CHANGE AND THE DEVELOPMENT OF PLACER DEPOSITS

D G Sutherland (Placer Analysis Ltd.)

Four principal factors govern the development of placer deposits. First, there must be a source rock for the mineral concerned; secondly, that source should undergo a period of subaerial weathering leading to an in place concentration and/or alteration of the mineral; thirdly, sufficient quantities of the mineral must be liberated from the source rock by erosion; and fourthly, the liberated mineral must be transported, reworked and concentrated by slope, fluvial or marine processes. Quaternary environmental change has its greatest impact on the last two factors. The most important aspect of Quaternary environmental change for placer formation is the *alternation* of periods characterised by distinct geomorphological and sedimentological processes. Such alternation results in periods of increased erosion being succeeded by periods of lower erosion and sediment reworking on timescales of 10^3 to 10^4 years. Repeated cycles have led to high sediment fluxes in fluvial systems during the Quaternary and this, together with the natural tendency of heavy minerals to be retained within the system, has resulted in the formation of rich Quaternary placer deposits in many parts of the world.

THE APPLICATION OF GLACIAL GEOLOGY TO MINERAL EXPLORATION

M P Brown (Queen Mary & Westfield College, London)

Mineral exploration in glaciated terrain is often hampered by glacial drift covering the bedrock. In addition, processes of glacial dispersal displace bedrock signatures within overlying drift away from the mineralized source. This is often considered a further hindrance to exploration. In many cases the subcropping target is small and easily missed, but glacial dispersal increases the target size and can be useful in tracing the source. Glacial dispersal appears to take the form of a negative exponential curve consisting of a "head" and a "tail". The head represents a peak in concentration of minerals close to their source, followed by a rapid decline in the direction of transport. The tail represents a more gradual decline in concentration to background levels at greater distances from the source. At the reconnaissance scale of exploration a sampling programme should aim to intersect the head of a dispersal train. It is important to evaluate the probable distance and direction of sediment transport, and therefore the style of glaciation in an area, prior to the implementation of a sampling programme. At the detailed scale, dispersal trains in lodgement till tend to be ribbon-shaped, appearing as a plume of till that is enriched in debris from the source relative to the till surrounding the train. As such, the train should be regarded as a three-dimensional body, its configuration and extent determined mainly by the thickness of till. Consequently, profile sampling in areas of thick till is very important to establish the three-dimensional geometry and map the anomaly to its source. Such a scientific approach is rarely adopted by exploration companies in the British Isles. Usually, only one sample is collected at each site, and once there is a whiff of the source, the less subtle approach of trenching through the drift anomaly to bedrock is adopted. This makes it difficult to apply more than elementary knowledge of glacial geology to a current exploration project.

AN INTRODUCTION TO MARINE AGGREGATES

I Selby (United Marine Aggregates Ltd.)

Nationally, marine aggregate contributes about 15% to the total aggregate production. Locally this contribution is significantly greater and it is predicted that its market share will increase in the future.

The majority of sand and gravel is dredged off East Anglia and the South Coast from licences in depths < -30 m. These deposits largely consist of marine reworked fluvial sediments. The sand dredged in the British Channel and the sands and gravels of the eastern Irish Sea and the Humber region are derived from glacigenic sediments. Increasing efforts are being made by the industry and the Crown Estate using highly accurate, high resolution seismic and sampling surveys and licence management techniques to ensure the supply of high quality aggregate in the future.

QUATERNARY GEOLOGY, SOILS AND AGRICULTURE

J A Catt (Rothamsted Experimental Station)

Through their almost ubiquitous influence on soil properties, Quaternary processes of deposition, erosion and pedogenesis under various past climates have a considerable influence on modern agriculture and forestry. Some agriculturally important soil properties (e.g. nutrient status) are easily modified by the farmer, but most of those relating to Quaternary events are usually difficult to improve without expensive engineering procedures. In many upland areas of hard bedrock, the depth of soil which can be exploited by plant roots is determined simply by the thickness of unconsolidated glacial or periglacial sediments; elsewhere it may be limited by fragipans (loamy subsoil horizons compacted by ground ice in the last cold stage) or even by subglacially compacted lodgement till. The particle size distribution of soils in mid-latitude regions such as Britain is determined mainly by that of their parent materials, as it is little modified by pedogenetic processes such as weathering. It is often the single most important soil property, as it determines the retention and release of water and plant nutrients, and the strength, trafficability and ease of cultivation of the soil. Patterns of short-range soil variation resulting from various Quaternary processes (ice wedge polygons or stripes, pingos, karstic disturbance, irregular deposition of colluvium, river floodplain sedimentation, gulls, archaeological features) may cause considerable variation in crop yields. Relict interglacial soils are often greatly enriched in alluvial clay, which would normally make them less permeable and more easily waterlogged than their parent materials. However, in Britain these soils were also periglacially disturbed during cold Quaternary stages, and this seems to have improved their structure and permeability. Periglacial disturbance and deposition of loess also chemically rejuvenated the soils which had been strongly weathered and leached by interglacial pedogenesis. The agricultural performance of relict interglacial soils is therefore better in regions subject to periglacial activity in the last cold stage than in lower latitudes.

ENGINEERING IN QUATERNARY SEDIMENTS

Edward Derbyshire (University of Leicester)

Over extensive areas of the northern continents and epicontinental marine basins, optimal foundation design and aggregate and core material supply are dependent on sound knowledge of the types of Quaternary sediments and the sources of variation within them. Formerly glaciated terrain contains perhaps the most complex of all sedimentary associations, with variable amounts of glacial, glaciofluvial, glaciolacustrine and glaciomarine deposits, together in certain environments with periglacial, paraglacial and aeolian components. For engineering site purposes, such complex associations are a source of variations in geotechnical properties, and they are best presented in terms of three-dimensional process models, to which should be added evidence of secondary processes such as erosion, deformation and diagenesis. The efficiency with which site engineering works proceed is influenced more by the nature and location of the site data and the theoretical framework in which it is set than by the data volume. Examples from some major site investigations suggest that the presence and accurate diagnosis of constructional landforms materially influences sampling and theoretical understanding in terrestrial glacial situations, and that sites underlain by glaciomarine, paraglacial, periglacial, and aeolian sediments, with and without neotectonic and diagenetic modifications, continue to pose sampling and modelling problems in site development work for dams, highways, pipelines and oil and gas platforms.

THE ENGINEERING GEOLOGY OF LATE AND POST GLACIAL SEDIMENTS IN THE EAST COAST ESTUARIES OF SCOTLAND

T P Gostelow (British Geological Survey)

A common sequence of Quaternary deposits in Scottish estuaries is stiff glacial till or dense sands overlain by soft clays and loose silts and sands. The latter were laid down during the Flandrian rise in sea level and their upper levels have since become raised above present sea level by isostatic uplift. These areas are low lying, flat, and are comparatively easy to use for agricultural purposes and as sites for human settlement. However, this Quaternary sequence can give rise to engineering problems and requires careful investigation prior to development. This paper broadly reviews the engineering geology of the east coast estuaries and relates geotechnical properties to the Quaternary history of the region.

THE GEOLOGY OF DUTCH HOLOCENE SEDIMENTS AND CIVIL ENGINEERING: EXPERIENCES WITH WORLD WIDE VALIDITY

B P Hageman (Dutch Geological Survey)

With respect to civil engineering, the vertical and horizontal distribution of Quaternary sediments are of vital importance. This statement will be supported by the following arguments.

- The generally unconsolidated nature of the Quaternary sediments means that various important parameters such as bearing capacity, compressibility and permeability, show extreme differences over the variety of lithogenetic units. This is in contrast to many of the older, consolidated rocks.
- The distribution patterns of such lithogenetic units and their composing subunits are often of a very complicated nature, e.g. those of a terrestrial or shallow coastal origin where the dominating sedimentological conditions can rapidly change in time and place.

Moreover, many areas with thick Quaternary cover are of paramount economic significance because of a level topography, natural waterways, agricultural potential, groundwater supply, etc.

The Dutch coastal zone, and its Holocene topcover in particular, provides a good example of how the quality and cost of civil engineering schemes can profit on large as well as small scales, from detailed knowledge of the anatomy of this Holocene cover. Specific examples will comprise roadbuilding, coastal engineering, foundation problems, supply of raw materials, planning and environmental protection.

IDENTIFYING THE SEDIMENTARY ARCHITECTURE OF GLACIATED VALLEY SEDIMENTS: AN IMPORTANT OBJECTIVE IN SITE INVESTIGATION STUDIES

J F Raper (Birkbeck College, London)

An improved knowledge of the processes and products of glacial deposition in valleys, based on work in actively glaciated environments and Quaternary stratigraphy, has led to the development of general models of glaciated valley landform-sediment relationships, for example by Eyles (1983). Such models can be of considerable use to engineers planning construction projects in formerly glaciated valleys, if they can be used to predict sediment facies from landform descriptions and to indicate their distribution from preliminary borehole logs. However, typically local conditions at a site differ from the general circumstances of the model, reducing the value of the model to an engineer. This study critically reviews existing landform-sediment models, and proposes a new approach based on the identification of landform associations and the site sedimentary architecture, illustrated with reference to a case study in the Taff Valley, S Wales.

PROBLEMS OF PERMAFROST ENGINEERING

Peter Worsley (PRIS, University of Reading)

Permafrost is a product of a specific kind of heat balance at the earth's surface. Currently it underlies about 20% of the terrestrial realm and during parts of the glacial stages its extent was up to twice this value. Formation of almost all of the present day permafrost is due to palaeoclimate and some may be at least a million years old. Permafrost persistence or stability is consequent upon either (a) the maintenance of a thermal quasi equilibrium or (b) a negative heat balance which will induce aggradation. If the heat balance becomes positive, then the degradation of permafrost commences and will be progressive so long as the positive balance is maintained. Areas of Quaternary sediments are particularly prone to ground instability if the permafrost is decaying but this also applies to older fine-grained sediments even though they may be lithified. So-called 'terrain sensitivity' is largely determined by the ground ice content and frequently the upper part of permafrost has an ice content greatly in excess of 'normal' pore volume. High sensitivity values pose serious problems for urbanisation and allied activities. Successful construction, mining, transportation, water supply and waste disposal practices must adapt to the special circumstances imposed by the presence of permafrost. Failure to make accommodation for these can be both costly and environmentally disastrous. Drawing upon examples from several communities in the western Canadian arctic, the engineering methods designed to ensure the stability of permafrost will be discussed ranging from simple low cost types to expensive sophisication.

ENGINEERING IN QUATERNARY PERIGLACIAL AREAS

J N Hutchinson (Imperial College, London)

The main civil engineering problems arising in Britain through the effects of Quaternary periglacial processes are briefly reviewed under the following headings:

1 Weathering and solution.

2 Loess.

3 Periglacial solifluction
  - granular debris
  - till
  - clayey debris.

4 Thermokarst.

5 Pingos and diapirs.

6 Cambering and valley bulging.

Areas requiring further research are identified.

QUATERNARY DEPOSITS AND GROUNDWATER POLLUTION

D Daly (Geological Survey of Ireland)

In Ireland, Quaternary deposits are arguably the single most important natural feature in influencing groundwater vulnerability and groundwater pollution prevention. This situation is also likely to apply to most glaciated areas in Britain, particularly those underlain by bedrock older than the Permian Period. The Quaternary deposits are the first line of natural defence against pollution. Where a significant thickness of low to medium permeability materials overlie groundwater, they act either as a barrier to the vertical movement of pollutants or as a filtering, purifying medium. Where they are absent, very thin or very permeable, the groundwater is vulnerable to pollution and polluted wells are common. It follows that Quaternary geology maps and Quaternary scientists should have a major role to play in this area of environmental protection.

The paper will outline, with examples, firstly the influence of Quaternary deposits on the movement of pollutants from point sources—septic tank systems, farmyards, waste disposal sites, leakages and spillages, and secondly the use of Quaternary geology information in groundwater vulnerability mapping and groundwater protection schemes. Vulnerability mapping can serve as an effective and useful preliminary tool for the policy and operational levels of decision-making concerning the location of potentially polluting developments and groundwater protection. The paper will argue that Quaternary geologists should play a greater role in land-use planning and environmental protection.

HOLOCENE PALAEOLIMNOLOGY AND 'ACID RAIN'

R W Battarbee, (University College London)

The last twenty years have seen an energetic international debate between politicians and scientists on 'acid rain' and its effects. By and large, countries which are and were not exporters of sulphur (as SO_2 and SO_4-), such as the UK, argued that surface water acidification and associated problems with fish populations were caused not by acid deposition but by natural processes (long-term leaching and soil palurification) or by land-use changes. Palaeolimnological research over the last 10 years involving a whole range of analytical techniques (especially diatom, chrysophyte, pollen, carbonaceous particle, trace metal analysis) on securely dated (210 Pb, 241 Am) sediment cores has shown the overriding importance of acid deposition as the cause of lake acidification over the last 150 years. Long-term acidification has taken place at some sites but the rate of "natural" acidification is imperceptible when compared to the rate of post-1800 AD changes. And changing land-use patterns have little effect on acidity, except where afforestation has taken place in areas of high acid deposition. In these cases enhanced scavenging of atmospheric pollutants by the forest canopy can exacerbate acidification.

POLLEN-CLIMATE RESPONSE SURFACES AND THE HOLOCENE CLIMATE OF EUROPE

B Huntley (University of Durham)

Pollen-climate response surfaces describe the quantitative relationship between pollen abundance and the modern climate for individual pollen taxa. Response surfaces have been constructed for all major European pollen taxa with respect to mean temperatures for July and January and the mean annual precipitation. These surfaces can be used to make palaeoclimate reconstructions as well as to evaluate the palaeoclimate simulations produced using General Circulation Models (GCM's) of the atmosphere. Response surfaces can also be used to investigate the implications for the potential natural vegetation of climate scenarios predicted for the future using GCM's. Such quantitative models that relate Quaternary palynological data to climate give Quaternary palynology a key position in current research into the problems of 'Global Change' and especially in relation to the research program focussed upon global changes of the past.

SEA-LEVEL CHANGES: PAST, PRESENT AND FUTURE APPLICATIONS

R W G Carter (University of Ulster)

The spectre of rapid rises in world sea-levels has been with us now for over a decade. However, while there is an emerging scientific concensus that such sea-level changes are one consequence of global warming (i.e. the Greenhouse Effect), there is still much debate over the exact nature of the coastal response to such climatic variations. While Quaternary sea-level workers have been able to establish numerous local frameworks for examining relative water level variations, the construction of regional syntheses in the British Isles has only just begun (e.g. Shennan, 1987; Carter et al., 1989). These studies reveal time-space gradients of Holocene sea-level trends, not only between the extremes of the isostatically-controlled north and the eustatically-controlled southeast, but within smaller zones associated with variations in tectonics, sediment supply, wave and tide ranges and diverse human impacts. Hopefully, this more recent regional approach will lead to the development of shoreline evolution models. At present, very little is known about the sensitivity of the British and Irish shorelines (and their adjacent shelves) to differences in Holocene sea-level signature. It would appear that even short-lived sea-level tendencies—perhaps restricted to single events—may have a major bearing on coastal expression. One important challenge facing sea-level research is to effect a coherent match between the known sea-level history and the evolution of the shoreline. Recent work in eastern Canada, where sea-level is rising quickly, suggests that a simple linear association between changing water level position and shoreline erosion (or inundation) is unlikely, and that response may be decidedly non-uniform even within single embayments and over periods as short as 10 to 20 years.

If recent sea-level rise predictions are confirmed, then the anticipated rates of rise (up to 40 mm/year by 2100 AD) will be far higher than any hitherto experienced in the last 15 000 years. To offset the impact of such dramatic changes will require a major interdisciplinary effort, with the Quaternary sea-level expert occupying a central role in the proceedings.

QUATERNARY PERSPECTIVES ON JOKULHLAUP PREDICTION

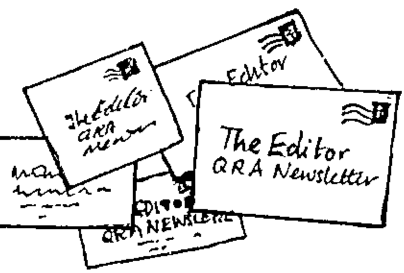
Judith Maizels (University of Aberdeen)

This paper reviews the ways in which palaeohydrologic analysis of Quaternary jokulhlaup events (glacier burst floods) can help in prediction of modern jokuhlaups in present-day ice-marginal terrain. Unpredicted jokulhlaups can cause major and costly destruction of industrial plant, transport links and settlements. At particular risk, for example, are hydro-electric plants constructed (or planned for construction) on meltwater rivers in parts of Alaska, northern Canada, Greenland and Iceland. Reliable prediction of jokulhlaup events should contribute to the reduction or avoidance of major damage from these floods.

The paper proposes a simple model to indicate the relationships between the characteristics of Quaternary jokulhlaups and the likely geomorphic controls on these characteristics, as the basis for jokulhlaup prediction. Prediction of modern jokulhlaups involves not only prediction of the likely magnitude and frequency of the events, but also the timing of the flood and the nature of the hydrograph, the flood pathways, sediment concentrations and flow dynamics. Understanding of flow dynamics forms an important element in prediction of flood power and erosional capacity, the mechanisms of erosion, entrainment and sedimentation, the changes of flow conditions through time and space, and the geomorphic impact of the jokulhlaup on the flood routeway.

The paper explores the model in relation to a number of examples (both from the literature and from field work) from the northern hemisphere, focussing particularly on the Icelandic jokulhlaup record. The paper concludes that analysis of the longer term Quaternary jokulhlaup record provides a valuable means of predicting infrequent, high magnitude jokulhlaup events. However, relatively frequent jokulhlaups (occurring every 1–10 years) can best be predicted from recent or historic records. In both cases, however, the long-term record can provide a useful indication of any longer term trends in flood characteristics, and of the larger scale geomorphic significance of different populations of jokulhlaup events.

POST BAG



XIII INQUA Congress, Beijing, People's Republic of China, 1991

Given the reaction of the Chinese government to recent events in the People's Republic, would it perhaps be correct for the QRA to boycott the next INQUA congress, if it still goes ahead in Beijing as planned? Also, should it be suggested to the international steering committee that official recognition of the proposed meeting be withdrawn and that an alternative venue be selected for 1992? *Some* official condemnation of the inhumane behaviour of the present Chinese leadership does seem to be called for. Should such a corrupt regime benefit either from the recognition that such international meetings confer or the hard currency congressistes would contribute to governmental coffers?

QRA members need to consider the moral implications of their attendance in Beijing very carefully.

Esmée Webb
Department of Archaeology
University of Western Australia
Nedlands WA 6009

ANNOUNCEMENTS

Discussion meeting on: 'Radiocarbon dating—recent applications and future applications'

A one-day discussion meeting, organised by John Lowe (Royal Holloway and Bedford New College) and Peter Worsley (Reading University), on the aforementioned topic will take place in the Lecture Theatre of the Geological Society of London on Wednesday, 7 February 1990. For further details on specific objectives, topics and call for papers, please see November's *Circular.*

Ed.

GLOBAL ENVIRONMENTAL CHANGE

Announcement and Call for Papers

INTERNATIONAL SEDIMENTOLOGICAL CONGRESS 1990

26–30 August 1990, in Nottingham

This meeting will have several themes, one of which is **GLOBAL ENVIRONMENTAL CHANGE.** This theme will be addressed by five separate symposia, for which papers will be needed. The symposia and their convenors are listed below:

Obital Forcing and Cyclic Sequences: convenors Dr D G Smith, BP Research Centre, Chertsey Road, Sunbury-on-Thames, Middx TW16 7LN and Dr P L De Boer, Div. of Comparative Sedimentology, State University of Utrecht, Budapestlaan, 4, PO Box 80.021, 3508 TA Utrecht, The Netherlands.

Sedimentology, Sealevel and Seismic Stratigraphy: convenors Dr C P Summerhayes, IOS Deacon Laboratory, Brook Road, Wormley, Surrey GU8 5UB and Dr B U Haq, NSF Ocean Sciences Division, Room 609, 1800 G Street NW, Washington DC 20550, USA.

Glacial Sediments Through Time: convenors Prof. L A Frakes, Dept. of Geology & Geophysics, University of Adelaide, GPO Box 498, Adelaide, South Australia and Dr M J Hambrey, Scott Polar Research Institute, Lensfield Road, Cambridge CB2 1TN.

Weathering Changes and Sedimentation: convenors Dr K Myers, BP Research Centre, Chertsey Road, Sunbury-on-Thames, Middx TW16 7LN and Dr J T Parrish, Dept. of Geosciences, University of Arizona, Tucson, AZ 85721, USA.

Man's Influence on Sedimentation: convenors Prof. T H van Andel, Dept. Earth Sciences, University of Cambridge, Downing Street, Cambridge CB2 3EQ and Dr D Eisma, Nederlands Instituut ver het Onderzoek van de Zee, PO Box 59, 1790 A6 Texel, Nederlands.

If you are interested in presenting a paper, please contact one of the appropriate convenors with a title and an abstract of no more than 100 words. It is intended to publish the papers from the first two of these symposia together in a book on new approaches to stratigraphy. For general information about this theme, contact the theme coordinator Dr C P Summerhayes at the Institute of Oceanographic Sciences Deacon Laboratory, Brook Road, Wormley, Godalming, Survey GU8 5UB.

ANNOUNCEMENT

Extraordinary circumstances have occurred that necessitate the rescheduling of the Lubbock Lake 50th Anniversary Celebration Week to approximately 14 October 1990. This rescheduling provides us the opportunity to have the grand opening of the new facilities and public exhibits, in addition to the dedication ceremonies, as part of the Celebration Week. Furthermore, we can now plan a year-long anniversary celebration with a series of special events beginning on the local level this October and culminating with the international focus for October, 1990. A circular outlining the expanded plans and schedule will be forthcoming.

(From Museum of Texas Tech University, P.O. Box 4499, Lubbock, Texas)

PRELIMINARY ANNOUNCEMENT

PALAEOCLIMATOLOGY SPECIAL TOPIC

A meeting to discuss the background to the Special Topic on the Palaeoclimate of the Last Glacial/ Interglacial Cycle will be held on:

Thursday, 8 February 1990

At the Linnean Society, Burlington House, Piccadilly, London.

Accommodation is limited and the meeting will be ticketed; all are invited to apply.

International speakers have been invited to make contributions on the following scientific themes; proxy data, modelling, geochronology, international research programmes.

An important component of the meeting will be an open forum to discuss the future development of this initiative.

Further details will be circulated later. If you hope to attend, and for further information, please contact: Dr R L F Kay, Earth Sciences Directorate, NERC, Polaris House, Swindon SN2 1EU. Telephone: 0793 411521; fax: 0793 411501.

QUATERNARY RESEARCH ASSOCIATION

The Quaternary Research Association is an organisation comprising geologists, geographers, botanists, zoologists, archaeologists, soil scientists, civil engineers and others interested in research into the problems of the Quaternary. Most members reside in Great Britain, but membership also extends to most European countries, North America, Africa and Australia. Current membership stands at c.1000. Membership is open to all interested in the objects of the Association. The annual subscription of £5.00 is due on 1 January for each calendar year.

The main meetings of the Association are the annual field meeting, usually lasting 3–4 days, held in April, and a 1–2 day discussion meeting held at the beginning of January. Additionally, short field meetings may be held in May or September and occasionally these visit overseas locations. Study courses on the techniques used in Quaternary work are also occasionally held. The publications of the Association are the *Quaternary Newsletter* issued with the Associations' *Circular* in February, June and November, the *Journal of Quaternary Science* published in association with Longmans and with three issues a year, the field guides series and the technical guides series.

The Association is run by an executive committee elected at an annual general meeting held during the course of the April field meeting. The current officers of the Association are:

President	Professor J Rose, Department of Geography, Royal Holloway and Bedford New College, Egham, Surrey
Vice-President	Professor P Worsley, Department of Geography, University of Reading
Secretary	Dr D H Keen, Department of Geography, Coventry Polytechnic
Assistant Secretary (Publications)	Dr R V Dackombe, School of Applied Sciences, Wolverhampton Polytechnic
Treasurer	C A Whiteman, Botany School, University of Cambridge
Editor, *Quaternary Newsletter*	Dr B J Taylor, British Geological Survey, Keyworth, Nottingham NG12 5GG
Editor, *Journal of Quaternary Science*	Dr J J Lowe, Department of Geography, City of London Polytechnic

All questions regarding membership are dealt with by the Secretary, the Associations publications are sold by the Assistant Secretary (Publications) and all subscription matters are dealt with by the Treasurer.

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