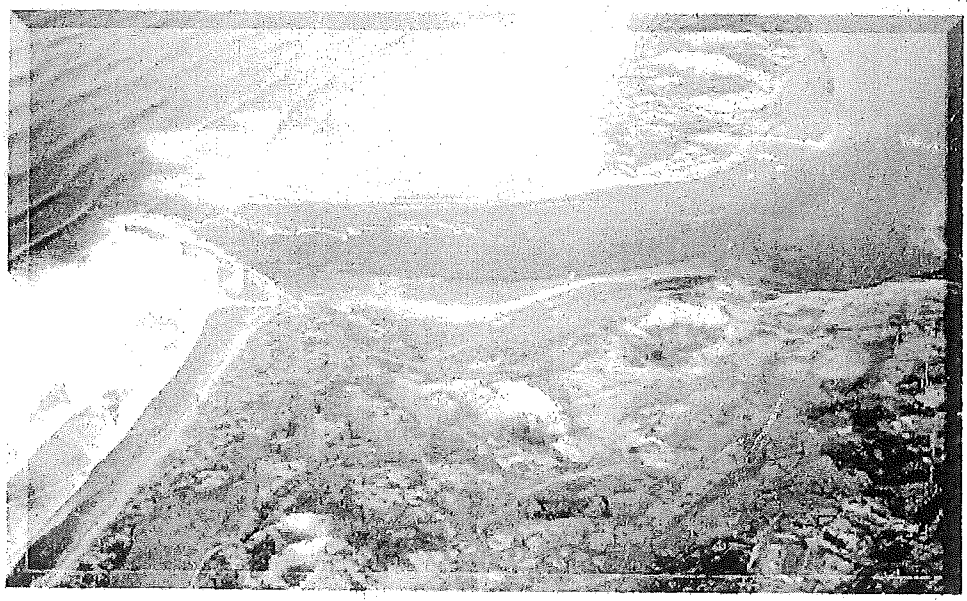
Irish Association for Quaternary Studies

Lower Bann and adjacent areas



IQUA

Edited by:

Jasper Knight

Field Guide No. 23
1999

Front cover: Oblique aerial view looking eastwards across the Bann mouth at the sand dunes at Grangemore (foreground) and Portstewart (background) (Photo: Nigel McDowell, University of Ulster)

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PREFACE

This guide complements the Annual Field Meeting of the Irish Association for Quaternary Studies (IQUA) held in the Lower Bann region, Northern Ireland, 1st-3rd October 1999. Some coastal parts of this region have been visited in a previous IQUA meeting (*North Antrim and Londonderry*, P. Wilson, ed., 1990). As a 'pre-millennium' field meeting, it is appropriate to focus on the Lower Bann region because of the close and intriguing relationship between human activity and Holocene landscape development. The River Bann, linking Lough Neagh to the sea, has along its course some of the earliest evidence for human activity in Ireland (Woodman 1981), which appears to broadly coincide in age with the initiation of coastal sand dunes at the Bann mouth (Wilson and McKenna 1996). Additionally, changes in relative sea-level (at the coast) and lake level (in Lough Neagh) have allowed for detailed sediment stratigraphic records of environmental change to be built up. Therefore the Lower Bann region is important in assessing landscape development and environmental change on a range of spatial and temporal scales, and it is hoped that this field guide will generate discussion and future research in these areas.

Maps recommended for use with this guide are OSNI 1:50,000 Discoverer Series sheets 4 (Coleraine), 5 (Ballycastle), 8 (Garvagh) and 14 (Magherafelt).

Jasper Knight
Coleraine, September 1999

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I am very grateful for the advice and help received from Peter Wilson, Michael Philcox, Michael Simms and Valerie Hall during the preparation of this guide and the accompanying field meeting. However, all omissions and mistakes are entirely the responsibility of the Editor.

List of figures

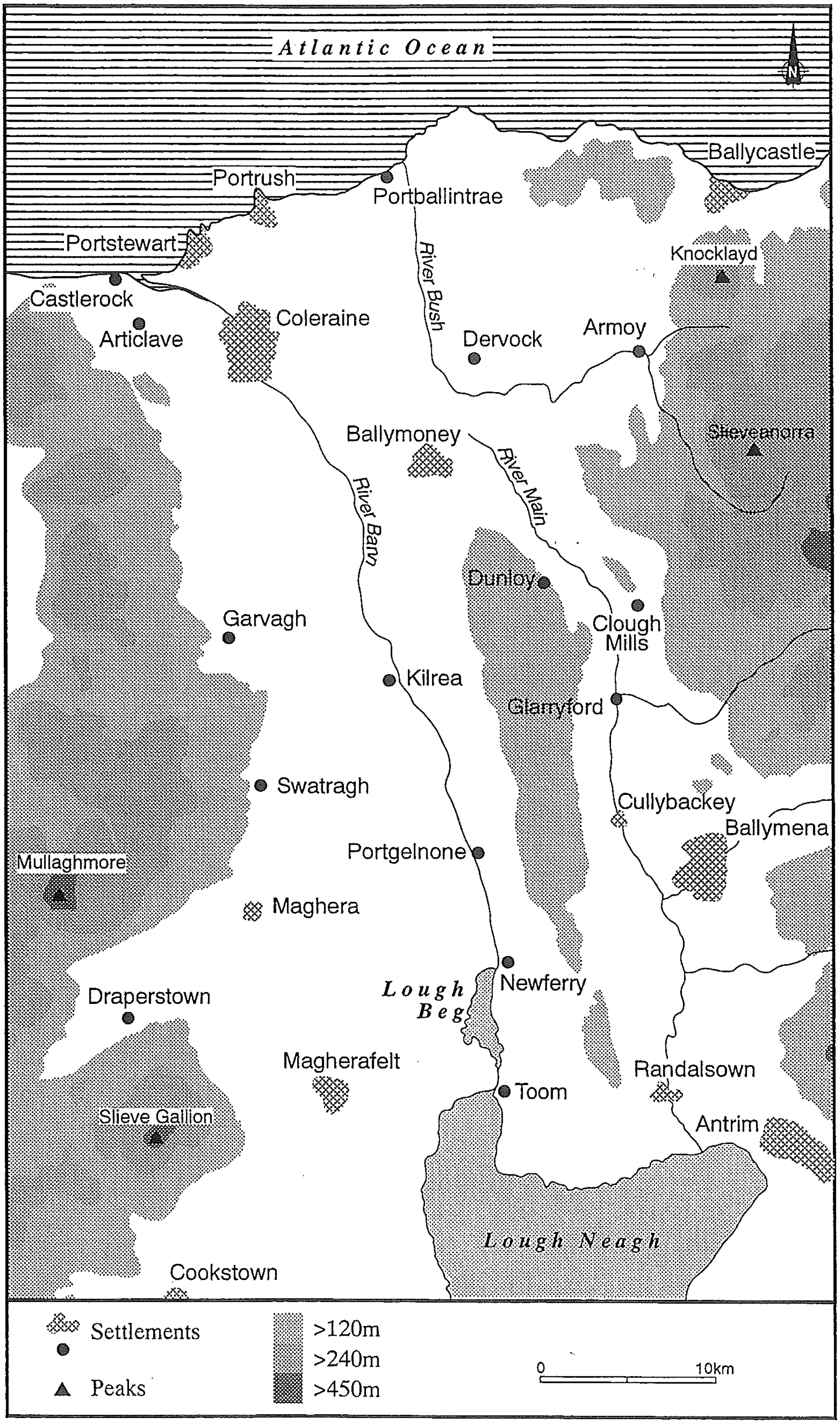


Fig. 1. Topography and drainage of the Lower Bann region.

The geology of the Lower Bann valley

John Roberts

The River Bann cuts a broad valley through the western portion of the Antrim Plateau (Fig. 2). The Antrim Plateau is a part of an extensive lava build-up of which some 1550 square miles are remnant. The lava field is part of the much more extensive Brito-Arctic or Thulean Province. This lava outpouring is a flood basalt event which occurred in the Palaeocene some 57 Ma, when over the time interval of just one million years some one million km³ of lava were erupted. In Northern Ireland the remnant thickness of the lava pile is about 850m, but from a consideration of the distribution of zeolite zones it can be suggested that some 500m of the lava pile has been eroded (Charlesworth 1963b). The reason for this outpouring is considered to be related to an episode of crustal tension associated with the opening of the proto-Atlantic.

The Lower Bann Valley is floored by Lower and Upper Basalts. Actual rock exposures are sparce, but borehole records show a succession of flows ranging in thickness from 4-6m with reddenned flow tops and a highly vesicular nature. Petrologically, the basalts are alkaline or olivine basalts with a high percentage of augite, although the Upper Basalts display more variability with four varieties recognised. However, in terms of the origin of the basalts, the occurrence of alkaline basalt does not represent petrogenesis from a regime of simple extension.

The influence of the basalts upon topography in the Bann Valley is minimal, indeed, the landscape is dominated by glacial landforms. The similarities in the structure of Upper and Lower Basalts is manifest in that even the juxtapositioning of the two horizons one against the other by the Tow Valley Fault produces little topographic evidence: the fault line has to be located using geophysical methods. A comparison of the orientation of the drainage network and known tectonic fracture trends in the basalts suggests a correlation between the two elements. Remarkably, the published maps do not show a major fault close to the line of the present day River Bann, although the generally north-north-west alignment of the valley accords well with mapped faults between Portrush and Ballycastle, and the alignment of the late dolerite dyke swarms. In addition, in some of its reaches, the Bann valley has been overdeepened with a subsequent infilling, the conditions for which would have been provided by fault zones with dislocated beds. The age of the faulting cannot be determined precisely, but activation of very much older faults cuts the Lough Neagh Clays in the southwest corner of Lough Neagh, i.e. movements of the post Middle Oligocene age.

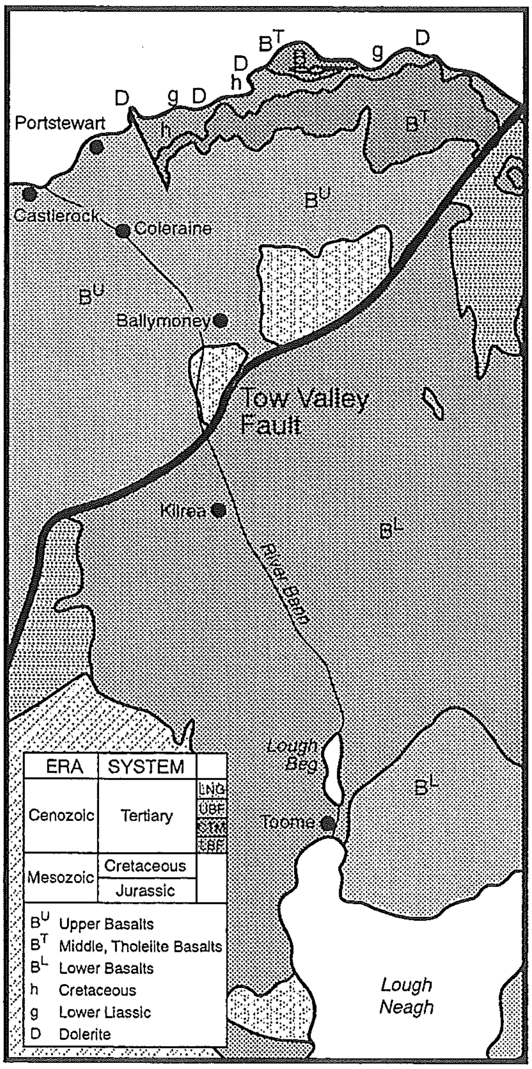


Fig. 2. Bedrock geology in the Lower Bann region.

Quaternary history of the Lower Bann valley

Jasper Knight

Introduction

In common with other marginal areas of the last British ice sheet, the Lower Bann region operated as a component of the wider North Atlantic glacio-climatic system during the Late Midlandian (Devensian) glaciation (c. 22-14 ^{14}C kyr BP) (Fig. 3). As such, it was affected by regional-scale controls on ice activity including changes in relative sea-level (RSL), climate, and shifts in the location and dominance of major ice centres (McCabe *et al.* 1998). The Lower Bann region contains evidence for advance and retreat of ice with both terrestrial Scottish and Irish sources. The timing, extent, and dynamics of these ice events are generally unknown due to poor lithostratigraphic and dating control (McCabe 1999). Additional unresolved problems include the dynamics and interaction of Scottish and Irish ice during overall deglaciation (c. 17-13 ^{14}C kyr BP), and their relationship to RSL changes. Reconstructed ice dynamics in the Lower Bann region using field geomorphic and sedimentary evidence may provide insight into the wider controls on ice sheet activity in the northeastern Atlantic during the last deglaciation.

Previous work

Investigation of the glacial history of the Lower Bann region was carried out initially by Dwerryhouse (1923) and Charlesworth (1939). Later local studies have added some detail to the regional picture, particularly regarding sedimentology, but Charlesworth's work has remained valid in many locations and areas of study. Both Dwerryhouse and Charlesworth were concerned mainly with the distribution and morphology of glacigenic landforms, including drumlins, striations, meltwater channels, terraces, and moraines. Other aspects, including the distribution of glacial sand and gravel, and erratics, were also described. Later workers took more specific approaches, concentrating on the relationship between ice oscillations and changes in RSL (i.e. Stephens 1963; Stephens *et al.* 1975; Stephens and McCabe 1977), and glacial diamict (till) fabrics and structures (i.e. Hill and Prior 1968). Some aspects of the glacial history of the Lower Bann region were discussed recently by McCabe *et al.* (1998).

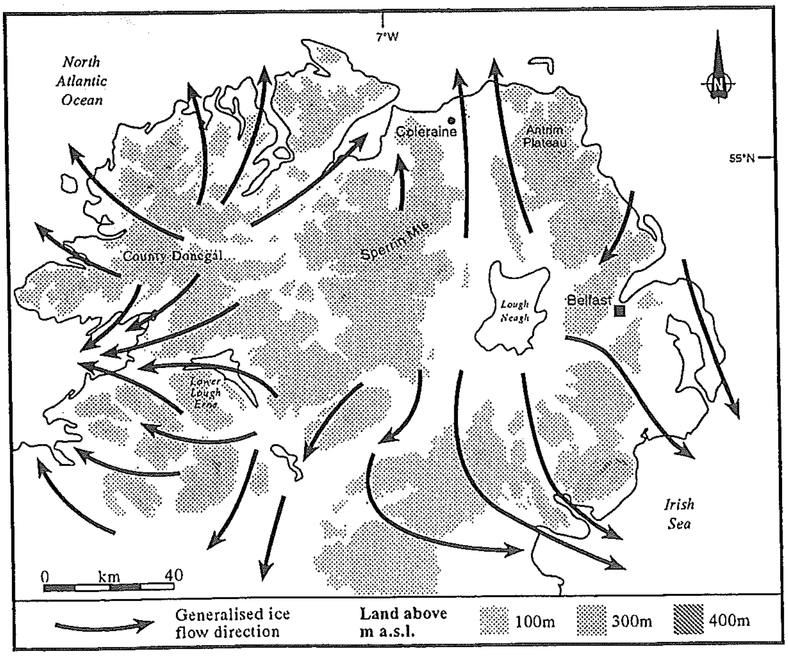


Fig. 3. Regional late Midlandian ice flow vectors in the north of Ireland.

Evidence for ice flow direction

Late Midlandian ice flow direction in the Lower Bann region was reconstructed mainly using the alignment of subglacial forms (drumlins, rock ridges and striations), and erratic carriage direction. Subglacial bedforms are present throughout the region and are generally aligned parallel to the Lower Bann valley axis (Fig. 4). Drumlins are present in lowland areas (< 200m OD) of the central Lower Bann and around the northern margins of Lough Neagh. The drumlins consistently show a southeast-northwest orientation, and are mainly bedrock-cored with a variable (2-10m thick) diamict carapace. Generally, depth of the sediment cover decreases in thickness northwards. The diamict is generally sandy, poorly-sorted, vaguely stratified, and dominated by subangular local basalt pebbles and cobbles. Remaining clasts (< 5% in some areas) are sourced mainly from the Tyrone Igneous Complex and the Tardree rhyolite. Overall, facies characteristics suggest limited clast transport distance of local material, and generally unidirectional ice flow from the Lough Neagh ice centre.

At and above the drift limit, rock drumlins and striations are mainly present. These are almost all consistent in direction with lowland drumlins which therefore suggests some contemporaneity of formation. Flow indicators on the flanks of the Antrim plateau and eastern Sperrins show the greatest directional variability.

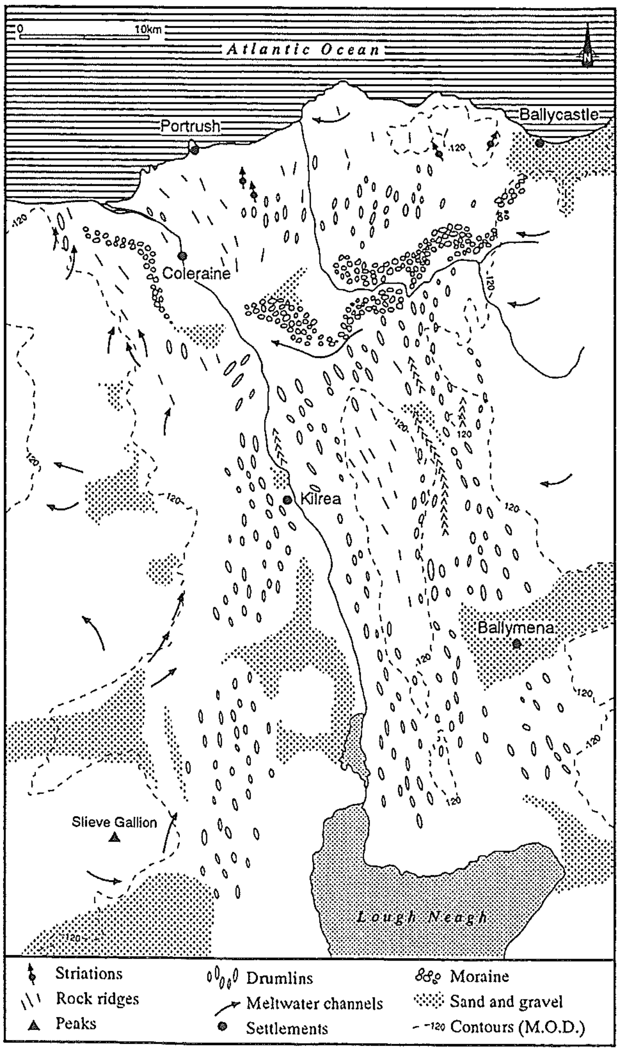


Fig. 4. Distribution of glacial landforms in the Lower Bann region (after Charlesworth 1939; Synge 1969; Stephens *et al.* 1975; McCabe 1987; McCabe *et al.* 1998).

Charlesworth (1939) considered that drumlins and other bedforms terminate south of the Armoy moraine, but this is not the case, and rock ridges and striations with the same alignment as those to the south are found consistently north of this limit (McCabe *et al.* 1998).

Glaciofluvial and ice-marginal landforms only indirectly record ice flow direction during overall deglaciation. Glaciofluvial sand and gravel is found mainly on the eastern margins of the Sperrins, the Lower Bann margins, and within the Armoy moraine between Armoy and Ballymoney (Fig. 4). The glaciofluvial sediment (< 15m thick but very variable) mantles subglacial flow indicators in most instances, and reflects ice retreat stages of both Irish and Scottish ice. Both ice masses formed glacial lakes which were impounded between the ice margin and adjacent uplands. West of the Lower Bann, the eastern Sperrin Mountain valleys were closed off by Lough Neagh ice, and on the northern and eastern flanks of the Antrim plateau by incursion of Scottish ice during the Antrim Coast Readvance which formed the Armoy Moraine (Charlesworth 1939, 1963). Elevations of deltas and associated meltwater channels generally decline with distance from upland flanks reflecting Irish ice shrinkage inwards and southwards towards the central Bann valley and the Lough Neagh Basin (Charlesworth 1939). Glaciofluvial sediments in lowland areas mainly comprise subglacial eskers, as at Vow and Glarryford (see Knight, this guide), and outwash fans and spreads associated with both these and the Armoy moraine. Eskers and outwash spreads postdate drumlinisation in the Lower Bann region and record integrated south to north subglacial drainage during deglaciation. Glaciofluvial terraces are also found discontinuously along the Lower Bann valley and record Irish ice meltwater outflow following Scottish ice retreat.

Erratic dispersal patterns

Two key erratic lithologies and source areas have been used in the Lower Bann region. (1) Granites, tonalites, lavas and tuffs from the Tyrone Igneous Complex in the southern Sperrins have been used as an indicator of north-going Irish ice from the Omagh Basin and Lough Neagh Basin ice centres (Charlesworth 1939). (2) Ailsa Craig microgranite erratics from the Solway Firth were considered diagnostic of incursive Scottish ice from the north and northeast. Reworking of some erratics from their original sites of deposition most likely occurred (Charlesworth 1924), but the generally mutually-exclusive erratic distributions was argued to reflect contact between Scottish and Irish ice throughout the last glacial period (Dwerryhouse 1923). However, the distribution of Tardree rhyolite suggests more complex Scottish-Irish ice activity (Stephens *et al.* 1975).

Reconstructed events during the last glacial-deglacial cycle in the Lower Bann region

Little sediment exposure in the Lower Bann region has meant reliance on the sequence stratigraphy of adjacent areas in the Antrim Plateau and Dungiven/ Foyle Basin (i.e. Colhoun 1971; McCabe 1999). It is assumed that the sequence of events during deglaciation was much the same for the Lower Bann region (i.e. McCabe 1999). The interaction of ice from Scottish and Irish centres, which is for the most part unknown, underlies the glacial history of the Lower Bann region. Three main events are most important geomorphically: (1) an Irish ice advance associated with north of Ireland-wide drumlinisation, (2) a Scottish readvance associated with formation of the Armoy moraine, and (3) final deglaciation of Irish ice Other (unknown) glacial events may have occurred but these have no identifiable geomorphic signature.

(1) Active north- and northwest-flowing ice from Lough Neagh was dominant in shaping most subglacial bedforms in the Lower Bann region. Drumlinisation in western and eastern Ireland involves fast ice flow from both inland ice centres (i.e. Omagh Basin) and tidewater margins (i.e. Donegal Bay), and is dated to around 16.6 ^{14}C kyr BI (McCabe *et al.* 1986; McCabe 1996). Activity of Lough Neagh ice was probably similar to that of adjacent centres, and the continuity of drumlins in th Lower Bann region suggests a short, fast ice oscillation, consistent with drumlinisation elsewhere

There is no evidence for an offshore ice-marginal position at this time, but ice flow may have been convergent with Scottish ice in the Malin Sea, the maximal extent of which is marked by moraine ridges on the Atlantic shelf break (Stoker and Holmes 1991).

(2) South and southwestward readvance of Scottish ice to the Armoy moraine limit was most likely a glacial surge event which took place around 14 ^{14}C kyr BP (McCabe *et al.* 1998, see Knight, this guide). The upthrust proglacial sediments comprising the moraine were reworked directly from the glacial forefield deposited ahead of the ice margin (Shaw and Carter 1980). The absence of deglacial sands and gravels associated with the readvance supports the ice surge model in which the ice sheet collapses and rapidly decays *in situ*. This is also consistent with evidence for rapid marine transgression following Scottish ice vacation while the north of Ireland coast was still isostatically depressed (Stephens *et al.* 1975; see Knight and McCabe, this guide).

(3) It is likely that Irish ice occupied much of the Lower Bann region outside the area of the Armoy readvance limit. There is no firm evidence to suggest that Irish ice readvanced either over or into the Armoy moraine, though meltwater in the emergent Lower Bann valley may have cut out and reworked some Armoy-related components. Parallel to the orientation of the Lower Bann valley are the esker systems at Vow and Glarryford (Fig. 4). Together, these systems record meltwater transfer and sediment deposition along well-developed south to north subglacial channels. General absence of ice-retreat moraines, as in other areas of the north of Ireland, may indicate insufficient sediment volume or partial ice collapse leading to stagnation zone retreat (i.e. Mulholland 1982). Morainic sand and gravel overlying drumlins is also present east of Lough Neagh (i.e. at Doagh), which may record a later ice retreat stage of Lough Neagh ice.

Remaining problems

There are three main issues which hinder a greater understanding of glacial events in the Lower Bann region, and more widely across the north of Ireland. (1) Radiometric dating is needed to establish a temporal framework for glacial events. Use of AMS ^{14}C and cosmogenic ^{36}Cl dating techniques can be used as elsewhere in Ireland (Bowen *et al.* 1996; McCabe 1996; McCabe and Clark 1998). (2) Onshore and offshore ice extent is unknown in many areas. This may be resolved by detailed fieldwork onshore, and use of geophysical methods offshore (Cooper and Quinn, this guide). (3) The sequence and characteristics of Scottish-Irish ice interaction may be better resolved by data from points 1 and 2 (above), and detailed sedimentological work at key sites. As yet, glacial reconstructions across the north of Ireland coast (Colhoun 1971; McCabe 1987) therefore remain little more than working hypotheses.

Holocene coastal evolution

Peter Wilson

Coastal evolution during the Holocene is linked with changes in relative sea level (RSL). A Holocene sea-level curve for the north coast of Northern Ireland was constructed by Carter (1982), but it was acknowledged as being constrained by few reliably dated index points and therefore represented a first approximation to the course of sea-level movements. Although additional coastal sedimentary sequences have been logged and dated since 1982 their contexts are such that they do not allow for substantial revision of Carter's curve. The papers by Carter (1982) and Wilson and McKenna (1996) provide the background detail for most of the events and sites outlined below. Locations of sites from which information pertinent to coastal evolution has been obtained are indicated on Fig. 5 and simplified stratigraphies and ^{14}C dates for those sites are presented in Fig. 6.

Following a high stand of RSL towards the end of the last (Midlandian) glaciation (cf. Stephens and Synge 1965; McCabe and Eyles 1988; Carter 1993; McCabe *et al.* 1994) RSL fell in response to rapid isostatic rebound; Carter (1982) suggested a RSL minimum of -30m OD may have been attained. Whatever the depth of minimum RSL the Irish shoreline was some distance seaward of the present coast during the latter part of the Lateglacial. During the early Holocene RSL rose rapidly as a result of both eustatic controls and a declining level of isostatic recovery, although rates of RSL rise are not known with certainty. Tidal flooding terminated peat growth at the Barmouth, Farranlester and Somerset, and substantial accumulation of mud occurred. A ^{14}C date of 8960 ± 110 years BP from peat at a depth of -6m OD at the Barmouth indicates the Bann was not estuarine at that time. While muds were accumulating in the Bann estuary peat was developing in the Mill Strand – Dhu Varren area of Portrush. Radiocarbon dates of 6120 ± 70 years BP from the top of the muds at Sandelford and 5920 ± 80 years BP from the top of the peat at Dhu Varren may be regarded as close estimates for the timing of the peak of the Holocene marine transgression.

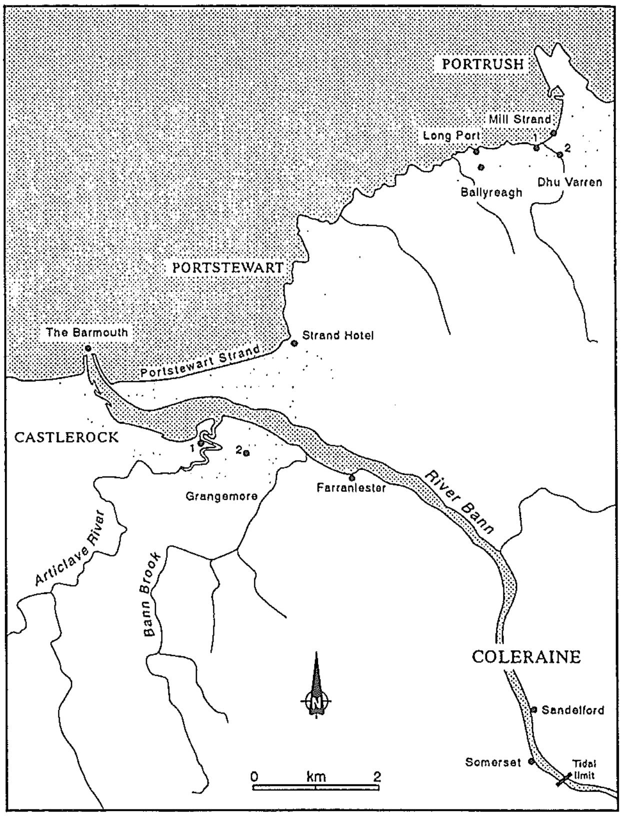


Fig. 5. The estuary of the River Bann and adjacent coast. Stippled areas are aeolian sands; sites mentioned in text are indicated.

Evidence from Grangemore indicates that within a few hundred years of reaching its maximum, RSL had fallen below 0m OD. An organic layer within dune sands at *c.* 0m OD attests to this. Hamilton and Carter (1983) obtained a ^{14}C date of 5315 ± 135 years BP from this material. More detail of this site and its significance is given in the section dealing with Grangemore sand dunes.

A consequence of Holocene RSL rise was the movement of clastic debris from the continental shelf towards the shore, leading to the development of shoreline barriers. Such a barrier of basalt and flint clasts underlies the dunes of Portstewart Strand and has provided an anchor point for subsequent establishment of aeolian dunes. Ventifacts have been reported from amongst the basalt clasts (Wilson 1991).

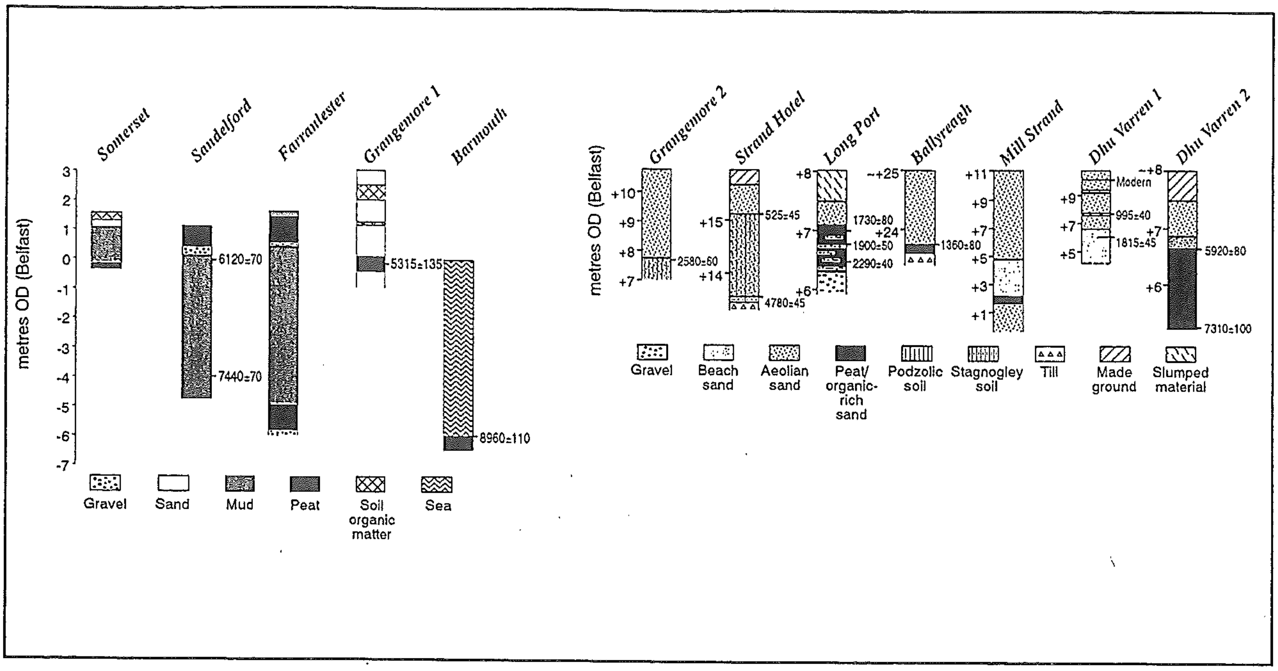


Fig. 6. Simplified stratigraphies and radiocarbon dates for sites indicated on Fig. 5.

The earliest dunes to have formed are those identified by Hamilton and Carter (1983) below the dated organic bed at Grangemore. Dunes of similar age also exist at Portstewart Strand but are no longer exposed. Stratigraphical and archaeological evidence indicates several phases of dune building, although it is not always clear whether these represent inputs of new sand from the inter-tidal zone or the reworking of previously established dunes.

At about 4800 years BP sand started to accumulate on the higher ground to the east of Portstewart Strand (Wilson 1992a). A long period of stability and pedogenesis ensued before further sand accumulation occurred after about 500 years BP. Aeolian sand extends along the cliff-top between Portstewart and Portrush but is not all of similar age. At Ballyreagh peat beneath the sand has been dated to 1360 ± 80 years BP, indicating sand deposition there while stable ground conditions occurred at the Portstewart site.

Interesting sequences are found at Long Port and Dhu Varren 1. At the former site supra-tidal terrace stratigraphy demonstrates evidence at +6 to +7m OD for alternating marine deposition and peat formation commencing before 2290 ± 40 years BP and terminating after 1730 ± 80 years BP. The sand/gravel units within the peat have been interpreted as products of storm-wave sedimentation. If that is correct the period defined by the ^{14}C dates appears to have experienced several such events. At Dhu Varren 1 a sand exposure at *c.* +4 to +11m OD contains several organic-rich horizons that indicate stable ground conditions during sand accumulation (Wilson and Braley 1996). In the lower part of the exposure the sand is coarser than that normally associated with north coast dunes and a ^{14}C date of 1815 ± 45 years BP from charcoal within a lens of charcoal and burnt bone indicates the lower part of the sand exposure was accumulating at a similar time to the sands and gravels found within peat at Long Port. The sand in the lower part of the Dhu Varren stratigraphy is therefore regarded as wavelain. Radiocarbon dates from organic horizons higher in the stratigraphy have returned ages of 995 ± 40 years BP and modern. The elevation of the sands enclosing these horizons and their grain size characteristics suggest they are aeolian. Thus, the timing of aeolian phases differs from those determined at Ballyreagh and Portstewart. The multi-phase but non-synchronous history of aeolian sand deposition between Portstewart and Portrush is probably a reflection of local sources and their susceptibility over time to aeolian erosion.

Palaeoenvironmental studies in the Lower Bann valley

Valerie Hall

West of the Bann there are some of the best lowland raised bogs in Ireland. These boglands contributed much both to those people who live near them and to others who may never have seen a bog. The turf, which warmed families and cooked the food for humans, pigs and chickens on the small farms which subdivide the rolling landscape of that part of Ireland, was cut vertically by spade from the edges of the large bogs bordering the western banks of the Lower Bann. The task of cutting turf for the family fire has inspired writers, famous and unnamed, to include memories of the distinctive smells and sounds of the bog in summer and winter and poems describing boglands near the home of Seamus Heaney, Nobel Prize winner, are now read and studied in places far from this land.

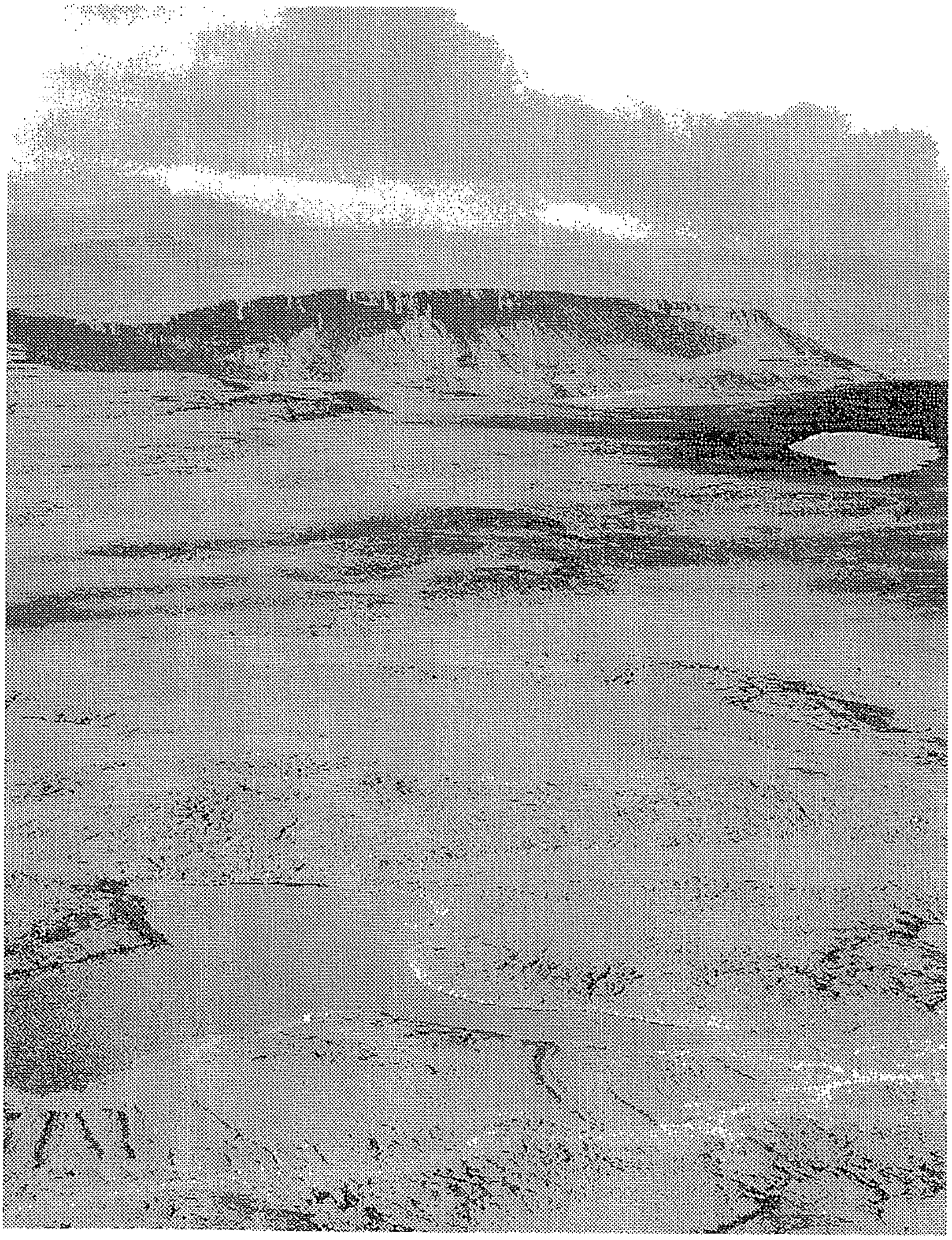
Places like Sluggan Bog, just north of Lough Neagh, Fallahogy Bog, south of Kilrea in Co. Londonderry and the Ballyscullion Bogs, on either side of Lough Beg, have contributed further to Irish cultural life as they have been the sites of investigation for scientists seeking to know more of the changing landscape of the north of Ireland during prehistoric and historic times. In the 1940s and 1950s, pollen analytical investigations of similar bogland in Denmark give insight into landscape change before and after the introduction of farming. It was similar investigations at Fallahogy Bog by Dr Alan G. Smith of the Department of Botany at Queen's University, Belfast during the late 1950s which lead to a lively correspondence with the great Danish palynlogist Johannes Iversen. Iversen's work in Denmark had shown that with the arrival of the first farmers about 6000 years ago there had been a reduction in tree pollen which he linked to local deforestation as the land was brought under agriculture for the first time, a developmental phase known as land-taking or 'landnam' in Danish. In a letter to Smith dated 4th January 1957 referring to new work undertaken by Smith on bogland at Fallahogy, Iversen ponders 'I wonder if your clearing phase is of exactly the same type as our "landnam". So far the latter type of farming culture is only traced in a rather limited geographical region, whether this is due to lack of investigation or to the fact that this culture was not introduced everywhere. Different types of agriculture seem to have been practiced simultaneously in Western Europe, e.g. the quite different Neolithic agriculture, without pastureland, in Switzerland registered pollen-statistically by Dr Troels-Smith. It is surprising that our type of clearing so far only is traced in a rather limited geographical region.'

That 'landnam' has been detected in the pollen records of sites throughout the British Isles owes much to the early work of scientists of the calibre of Professor, then Dr, Smith. Investigations by Dr Smith and others at Sluggan Bog in south Antrim contributed further to our understanding of landscape change during prehistoric times and extended the record back to Late-Glacial times and forward to the recent historic past.

The vertical peat banks characteristic of the edges of many Lower Bann valley bogs in the early to mid decades of this century have been of benefit to palaeoenvironmentalists even though the damaged peat faces have put the hydrological stability of the bogs into jeopardy. Deep bog cuttings reveal huge timbers embedded many metres deep in the bog. The pines and oaks which colonised the dry surfaces of these, presently wet, places have been the source of material for research on ancient timescales and climate change. Tree ring studies on large samples of both fossil oaks and pines have been possible because of the wealth of these timbers in fen and bogland surrounding Lough Neagh and the Lower Bann valley. The recent introduction of mechanised milling of peat for the horticultural trade at Ballymacombs More, north of Newferry on the western bank of the river, has revealed a staggering quantity of bog pine. At Sluggan so plentiful is this ancient sub-fossilised timber that it is cut for kindling and sold with the turf which is cut for fuel along the same peat bank.

Recent studies begun at Fallahogy Bog in 1990 have contributed to palaeoenvironmental studies in Iceland as well as Ireland. Volcanic ash from Icelandic volcanic eruptions throughout Post-glacial times has been incorporated into the peats and these studies have been the basis of tephrochronological studies throughout Ireland and England.

The bogs of the Lower Bann valley are extensive and easily accessible, making them of very great value to those investigating the past environments of Ireland and the wider North Atlantic seaboard. Further investigations are ongoing and will continue to keep these fine sites at the forefront of international past environmental investigations.



Anrim Plateau and Bog lands.

The archaeology of the Lower Bann

Ken Neill

The natural features of the river and its surroundings have heavily influenced man's impact on the Lower Bann, from the arrival of the first Mesolithic people to the present day. From earliest times the river acted as a corridor leading to Lough Neagh and beyond, and provided a ready source of food for early man. Areas of high ground overlooking the river, such as at Mount Sandel, were exploited for semi-permanent settlement. Low-lying areas within the flood plain, such as Newferry, seem to have been used for seasonal fishing over a long period. The extensive dune systems either side of the Bann mouth were exploited from the Neolithic onwards, and natural bars on the river like those at Toome and Camus provided ready crossing-places and became strategically important from prehistoric times onwards. Although settlements developed at both crossings, most prehistoric archaeological sites have been found on the higher better-drained ground overlooking the river.

Vast numbers of archaeological objects have been recovered from the river, with concentrations at the same natural bars, and many of them, such as Bronze Age weapons and Iron Age artifacts, provide some of the most important evidence for their period from Ireland as a whole. It is impossible to be sure how and why so many metal objects were deposited in the river. Some may have been lost during combat and others may have been eroded out of the riverbank or associated with some form of burial rite, but it seems plausible that many of these, often high status, objects reflect a ritual offering.

During the proto-historic period, the river seems to have formed an important political frontier, and Coleraine emerges as the most important settlement on the river, initially associated with a monastic settlement and later as a regional centre with its own river crossing and port. Other smaller settlements, such as Toome and Movanagher, also developed on the river around important crossings while others, such as Macosquin lie on smaller tributaries.

Mesolithic (7000-4000BC)

The earliest evidence for man in Ireland comes from perhaps the best known site in the Lower Bann valley, set above the east bank of the river at Mount Sandel (Fig. 7). Excavations here in the mid-1970s[1] uncovered remains of the earliest settlement yet found in Ireland and the earliest Mesolithic houses from anywhere in the British Isles[2]. The outlines of at least four successive huts around 6.0m in diameter, each with its own hearth, were preserved in a slight hollow along with adjacent areas of flint waste and pits, apparently used for storage. The flint assemblage was dominated by the microlith, the small blade or flake diagnostic of the early Mesolithic. The acid soil also allowed the preservation of burnt bones of pig, fish, birds, and a dog, water lily and apple/pear seeds, and hazelnut shells. Overall, the relatively substantial huts and the range of plant and animal remains suggest semi-permanent occupation by a small group over several seasons. With its range of material, Mount Sandel immediately became the key site for the Early Mesolithic in Ireland. Radiocarbon dates suggested

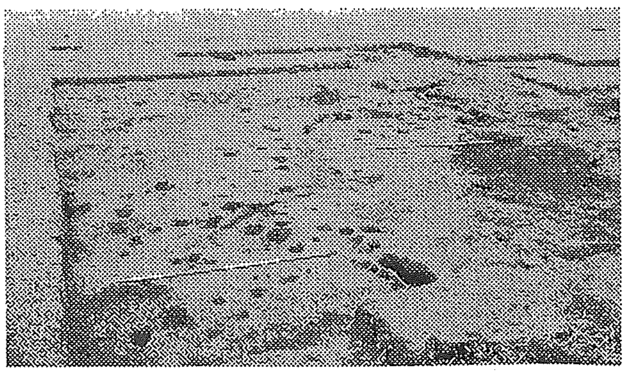


Fig. 7. (a) Mount Sandel Mesolithic site during excavation.

occupation sometime between 7000BC and 6500BC and pushed the earliest evidence for man in Ireland back by several centuries[3]. Analysis of the flint, however, indicates a markedly insular assemblage, suggesting that man had been in Ireland long enough to develop a distinctive technology by the time Mount Sandel was settled[4]. Thus, although this is the oldest settlement to be found in Ireland, it does not date from the initial colonisation and earlier sites remain to be found – some of them perhaps subsequently inundated by a rise in sea level.

Further, though less extensive, Early Mesolithic material has been recovered from several similar locations in the immediate area. Microliths and part of the outline of a possible hut were excavated in the face of a bluff overlooking the river at Mount Sandel Lower[5], and pits, a post hole, burnt flint and fish and animal bones were recovered at Castleroe 2km to the south[6]. Slightly further afield, evidence for Early Mesolithic activity, in the form of flint scatters, has been found at Movanagher, Portna, Glenone, and Culbane[7]. This distribution fits the general pattern throughout Ireland, where evidence tends to be found along the coast or in low-lying ground close to rivers or lakes[8]. While this may reflect a dependence on water-borne food resources and coastal or river routeways, the use of flint from eastern Antrim and chert from the Irish midlands suggests[9] widespread contacts and movement throughout Ireland.

Later Mesolithic sites area also concentrated on the Lower Bann, indeed so many of the large butt-trimmed flint flakes which replace the microlith as the diagnostic tool have been found along the river that they are generally known as 'Bann flakes'. Thousands of Late Mesolithic flint blades and several hundred axes have been recovered from the Culbane area of the Lower Bann[10] and periodic excavations at Newferry, immediately north of Lough Beg, uncovered a succession of Late Mesolithic material and associated hearths and charcoal spreads spanning the period from around 5500BC to 3500BC[11]. These sites, however, are located in the flood plain of the river and may represent seasonal fishing 'camps', periodically occupied when the river level was sufficiently low, rather than more long-term settlements[12]. This concentration of Late Mesolithic sites within the flood plain has been contrasted with the apparently more permanent Early Mesolithic sites such as Mount Sandel, located on slightly higher better-drained ground overlooking the river[13], although any such conclusion must be treated with caution, given the small number of sites involved. Indeed, almost all evidence from throughout the Mesolithic consists of flint tools and associated waste, although an excavation in 1950 at Toome Bay uncovered several pieces of worked hazel and pine from a Late Mesolithic context, allowing an all too rare insight into the wider technology of the period[14].

Neolithic (4000-2000BC)

Material which provides the closest evidence for 'continuity' from the Mesolithic comes from Newferry, where the succession of Late Mesolithic material was succeeded by an uppermost layer containing distinctive Neolithic flints and pottery[15]. However, given the intermittent nature of settlement at this seasonally flooded and thus stratigraphically complex site, the succession may be more apparent than real. A small amount of Neolithic material was also found at both Mount Sandel sites[16], but no associated structural evidence was uncovered and it seems likely that the adjacent sites were occupied intermittently throughout prehistory because of their favourable location. Several probable Neolithic hearths and associated flints were found during quarrying of a gravel hillock at Somerset on the opposite side of the river in 1955[17], possibly indicating the continuing importance of the area overlooking the natural weir at Ballyness throughout prehistory. In general though, the introduction of agriculture must have involved an increased environmental impact and a study of pollen from sites such as Fallahogy bog near Kilrea indicates a distinct fall in tree pollen and a rise in grass pollen, interpreted as a phase of forest clearance, around 3800BC[18]. More specific evidence for clearance comes from nearby Culbane, where six stone axes and a sandstone polisher were found around the turn of the century[19]. The distribution of porcellanite axes has its greatest concentration in Antrim and eastern Londonderry and it has been suggested that the number of axes in eastern Londonderry may reflect fairly dense agricultural settlement in the Neolithic[20]. Further evidence for Neolithic settlement, consisting of occupation layers containing numerous flint tools and pottery sherds, can be found in the extensive dune systems at Portstewart and Grangemore on either side of the Bann estuary[21].

In contrast to the Neolithic settlement evidence from the Lower Bann, most of the surviving megalithic tombs from the period are found on the higher ground overlooking the valley with notable concentrations on the Long Mountain to the east and on the slopes overlooking Swatragh and Kilrea to the west. The former includes the well-preserved court and passage tombs at Craigs and the latter Tamnyrankin and Knockoneill court tombs. Portal tombs are also markedly absent from the river valley but tend to be found on slightly lower ground, with a massive capstone preserved at Crevolea, north-west of Aghadowey and a second well-preserved example at Tirnony, north-west of Maghera. The fourth type of megalith, the wedge tomb, is generally dated to the later Neolithic or the succeeding Bronze Age and is spread over a wider altitudinal range than portal or court tombs. As with the court tombs, most examples, including Kilhoyle on the slopes of Donald's Hill and Slaghtneill south-west of Swatragh, are located on higher ground well above the Lower Bann. The wedge tomb at Beardiville, known locally as Gigmagog's Grave, is however located at a much lower altitude (70m) between the Bann and the Roe, overlooking the north coast. The river valley itself does, however, contain the remains of several less easily classified stone tombs, including three aligned stones at Crossreagh West on the edge of the Portstewart dunes and the megalithic cist within an earthen mound known as the 'Daff Stones' at Moneydig. Other tombs, such as the 'Giant's Bed' shown on early OS maps at nearby Carranroe have been destroyed and it is possible that the relative scarcity of megaliths in the river valley is at least partially a reflection of differential rates of destruction. The valley also contains a number of isolated standing stones, some of which may be the last remnant of a stone tomb, while others may mark burials or routeways. Such isolated stones are difficult to date, several excavated examples have been tentatively identified to the Bronze Age[22], but others may be Neolithic.

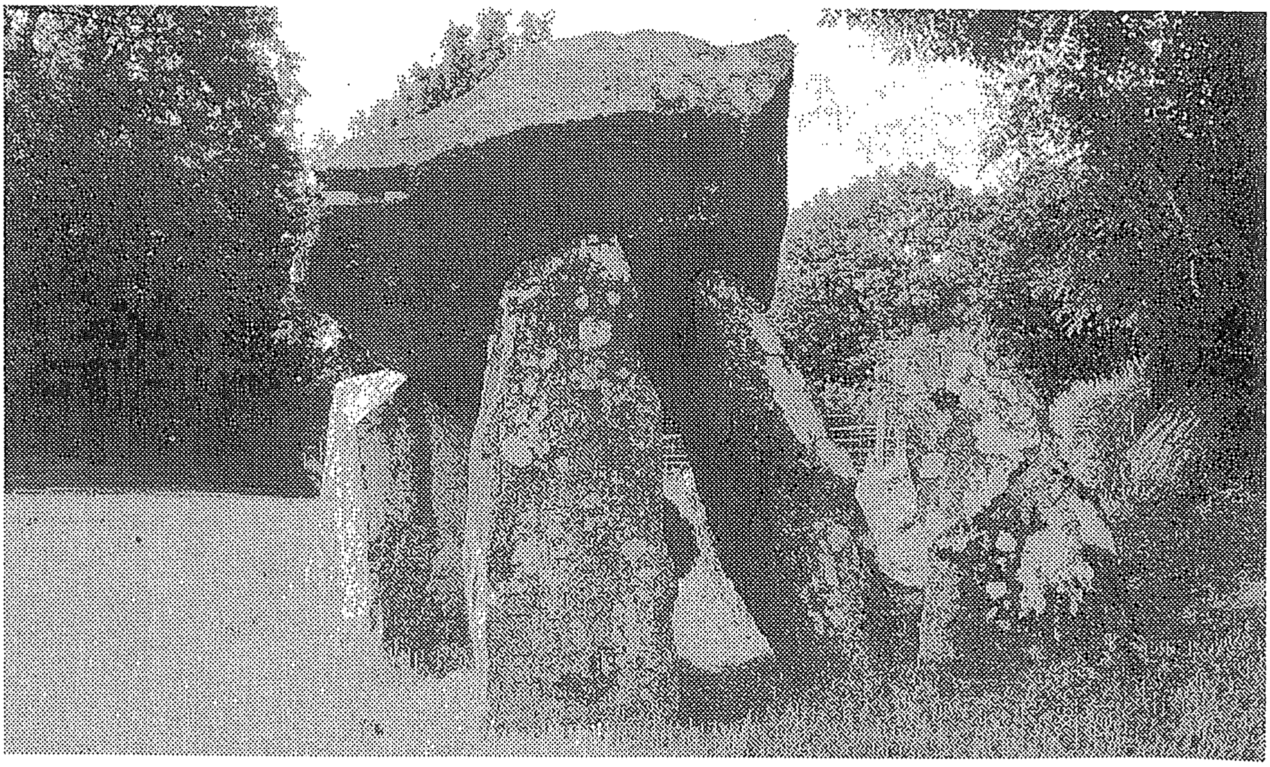


Fig. 7. (b) Tirnony Portal tomb.

Bronze Age (2000-500BC)

Although most excavated wedge tombs contain Bronze Age artifacts, the period saw a move away from large elaborate tombs towards simpler single graves, often accompanied by distinctive pottery vessels. Several forms of grave can be identified, including simple pits, stone-lined cists and more elaborate stone cairns and earthen barrows. Burial practice also varied and although the majority of excavated graves contain cremated remains, others contain inhumations and many cemeteries or even individual graves contain a mixture of the two.

Isolated burials are recorded from a wide variety of locations, although the general lack of above ground features means that most are discovered by chance and only investigated if the discovery is reported. Several such burials have been found in the river valley, including an isolated example at Portna and a more complex site at Urbalreagh, south-east of Portrush, where three burials and two urns were found within an associated ring-ditch[23]. Excavation of a hillock at Crossgare in 1944[24] after a cremation had been exposed during gravel extraction revealed a roofless cist containing an upright bowl, charcoal and cremated bone 2m, to the west. A third burial containing an inverted urn, placed on a flat stone and covering the cremated remains of an adult male was found a further 3m to the north. Bronze Age burials are also found within stone cairns or earthen barrows and several possible barrows are located on the eastern side of the Lower Bann, although none have been excavated. A well-preserved round cairn 17m in diameter and up to 2m high was excavated at Cornacleary, south-west of Garvagh in 1939. A large undisturbed cist containing the flexed skeleton of a tall adult male with an accompanying pottery vessel was uncovered near the centre of the cairn, with a smaller rectangular cist and two circular examples towards the periphery.

It is these burial and ritual monuments which form the bulk of evidence from the Bronze Age. Although Bronze Age burials in general are relatively common in Ireland, specific Beaker burials, common in Continental Europe and southern Britain, are not. Elsewhere, many Beaker graves contain distinctive archer's kits, consisting of a barbed and tanged flint arrowhead and a stone wrist guard or bracer. Although there is a marked concentration of both types of artifact extending into the Lower Bann valley[25], they are rarely found in a burial context. One important exception, consisting of an urn containing cremated bone and a bracer was discovered at Drumsteeple in 1830 and recorded in the 1835 Ordnance Survey Memoir for Aghadowey parish[26].

Bronze Age settlements and associated material are much more elusive and no structures have been found in the valley. Scattered shards of Bronze Age pottery were found at Mount Sandel and more conclusive evidence for settlement comes from the dune systems either side of the Bann mouth, where hearths, pottery, flints, animal and possibly even human bones have been periodically exposed at several locations over the last century[27]. Faced with this scarcity of dateable material, archaeologists have tended to subdivide the Bronze Age on the basis of the range of metal artifacts from the period. As in earlier times, the Lower Bann emerges as a major focal point for material, much of it recovered during drainage operations. The increased presence of weapons in this material has been interpreted as reflecting the emergence of a new warrior class, increasingly preoccupied with display and status if not outright warfare. In particular, the relative abundance of bronze swords recovered from the Lower Bann in comparison to their scarcity elsewhere has led to the suggestion that they may have been deliberately deposited in the river for ritual purposes[28]. Evidence for the production of a wide range of bronze weapons and tools locally comes from Killymeddy, near Ballymoney, where a series of two-piece moulds for spearheads, dirks and sickles were found in 1910[29]. High status personal ornaments have also been recovered from the general area, including 421 amber beads from a necklace from a bog at Kurin, south-east of Garvagh[30]. The Bann itself also provides important evidence for the transition into the succeeding Iron Age in the form of a number of distinctive Halstatt C swords. Throughout most of the rest of Western Europe these are made of Iron and their appearance marks the beginning of the Iron Age, but the Irish examples are of bronze, presumably reflecting the adoption of a new weapon style but using long-established bronze-working skills.

Iron Age (500BC-AD500)

If anything, the Iron Age is even more elusive than the Bronze Age and no structures or burials, positively dated to the period, are known from the Bann valley. Some scholars have suggested that the great earthwork overlooking the Bann at Mount Sandel can be equated with the pre-Christian tribal centre of *Dún Dá Beann*, but this interpretation has been questioned and the mound may have been built as late as the Middle Ages[31]. Some 4km to the west and set on a rock outcrop overlooking the Bann valley, the scant remains of the great stone fortification known as the Giant's Sconce can be more confidently identified as *Dún Ceithirn*, mentioned in the Annals of Ulster in AD629 but possibly dating from the earlier Iron Age. The hillfort at Dunmull, south-east of Portrush and overlooking the Bann estuary occupies a similar location and may date from the same period. Some less extensive Iron Age remains have been found in the valley itself, including charcoal and two glass beads recovered from an enigmatic pit at Mount Sandel[32], and some of the pottery and a glass bead from the Bann dune systems[33]. Most of the evidence, however, again focuses on metal objects, apparently deliberately deposited in the Bann, perhaps reflecting a continued tradition of votive offering and with particular concentrations at fords or natural bars. For example, a number of iron axes similarly shaped to earlier bronze examples, have been recovered from the Toome Bar[34]. Other notable Iron Age finds, mostly in bronze rather than iron, include sword scabbard fragments decorated in the distinctive Early Iron age La Tène style, a horse-bit, and the exquisite cast bronze disc dredged from the river at Loughan Island, south of Coleraine in 1939[35]. An unusual stone decorated in the same La Tène style was discovered built into the gable of Derrykeighan church[36], near Dervock, indicating Iron Age settlement in the general area. Evidence for subsequent 'contacts' with the wider world includes the large hoard containing over 5.67kgs of silver ingots and plate and 1,506 Roman *siliquae,* over half of them clipped, which was found in the townland of Ballinrees, 6km south-east of Coleraine in 1854[37]. Judging from the coin evidence the hoard appears to have been deposited around AD420-425.

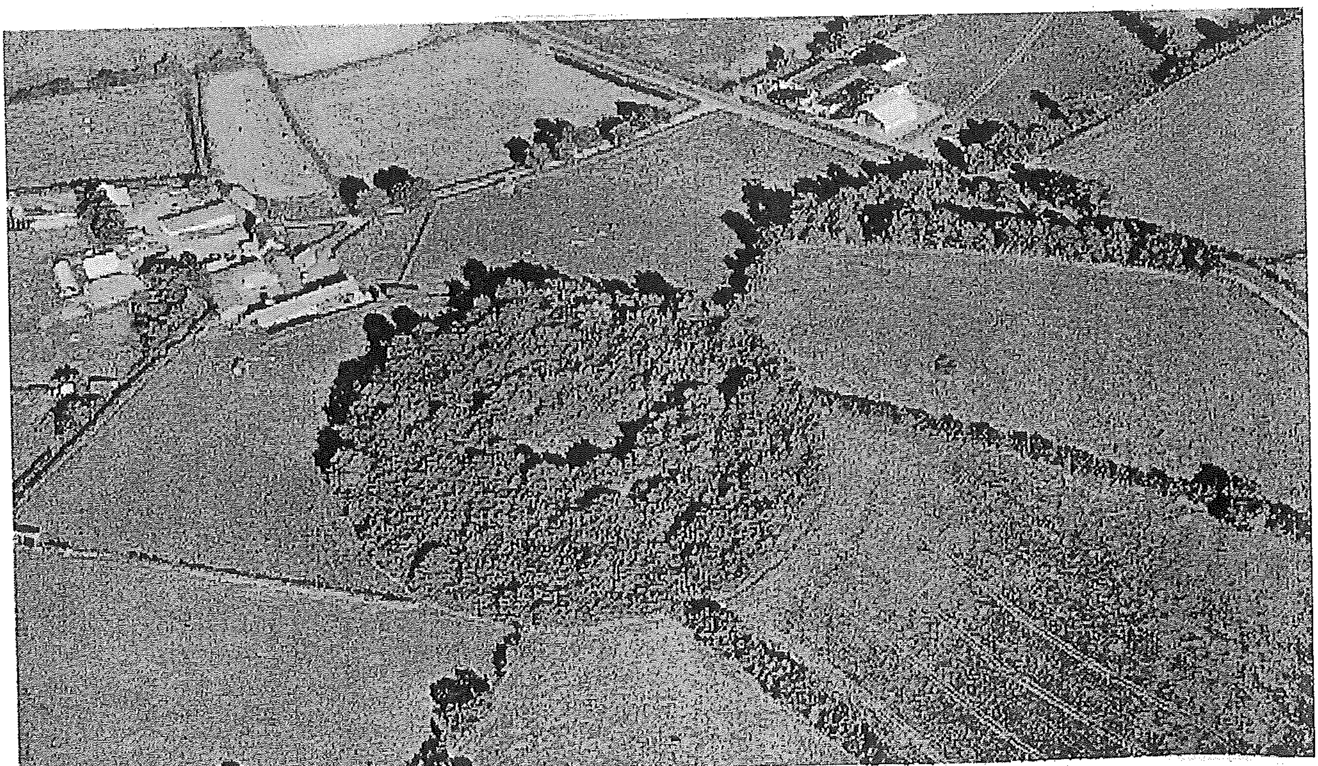


Fig. 7. (c) Dunglady Multivallate Rath.

Early Christian\Later Iron Age (AD500-1200)

The most common Irish monument from this period (or any other) is the rath or ringfort, an enclosed rural settlement, usually consisting of a roughly level circular interior surrounded by a bank and ditch. They are particularly common on land between around 60m and 150m and are much less common in lower and less well-drained river valleys. Nevertheless there are several fine examples within the Bann valley, mostly situated on slightly better-drained prominences or on the sloping ground overlooking the river. These include the multivallate raths of Lisnacannon, south of Ballymoney, and Dunglady, near Upperlands as well as the univallate site at Finkiltagh, north-east of Portglenonne, with several house-platforms visible in the interior. Some raths were built up to form flat-topped mounds, and several such earthworks can be seen to the east of the Bann, although some of them could equally well be either prehistoric barrows or even mottes from the Medieval period. One substantial mound, at Big Glebe, east of Articlave, was excavated in 1976[38], revealing that most of the earthwork had been constructed in a single operation, with two phases of Early Christian occupation on the summit. One of the most impressive chance finds from the area dating to this period is the gold penanular brooch found in 1855 by a labourer digging potatoes close to the east bank of the river overlooking the Camus ford and now known as the Loughan Brooch[39].

Souterrains, underground tunnels and associated chambers also date from the Early Christian period and are often found within raths, although many others occur without any visible associated above-ground remains. They were built as a refuge against attack but may also have been used to store food. While low-lying flood plains are impracticable for such underground, stone-built, structures, a number are known from the land overlooking the river, with a notable concentration in a zone either side of Coleraine. These include the site at 'Cave Hill' adjacent to the University of Ulster at Coleraine and the fine three-chambered example at Dunalis[40].

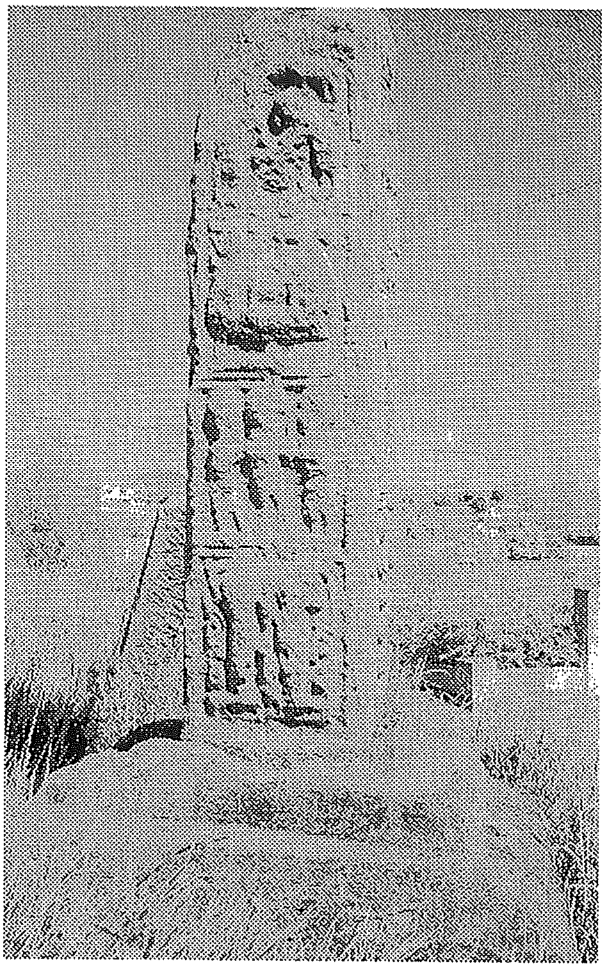


Fig. 7. (d) Camus High Cross, west face.

There are also a number of early ecclesiastical sites close to the river, several of which continued as a focus for settlement up to the present day[41]. For example, a monastery was traditionally founded at Coleraine by St Patrick and visited by St Columba, as well as being burnt in AD731 and raided by the Vikings in AD932. Both the monastery and the surrounding settlement were plundered on several occasions in the 12th century and the church is thought to have been destroyed when a castle was built on the site in the early 1200s. A second important monastic settlement was located a short distance upstream on the west bank of the Bann at Camus, overlooking an important crossing point over the river. Traditionally associated with St Comgall, Camus apparently maintained links with Bangor in Co. Down until at least the 10th century and a parish church was here until worship was moved to Macosquin in the 17th century. Although there are no visible remains of the monastery itself, the damaged remains of the shaft of a high cross, re-erected near the graveyard gate, are still visible. The red sandstone fabric is heavily weathered, but several scenes can still be recognised including a baptism, Adam and Eve, the Ark and the Sacrifice of Isaac. The graveyard also contains a bullaun – a hollowed boulder often found on early sites, possibly originally used with a pestle to grind food or other material. A second bullaun, known locally as 'St Columkille's Stone' is located at Desertoghill Old Church, lending some weight to the tradition that this was an early site founded by Columba and a third example can be seen close to the ruined church on Church Island in Lough Beg. Other possible early sites, but without any known early material, include Aghadowey, Ahoghill and Duneane. Unprovenanced ecclesiastical material from the river, probably associated with one of the early sites includes the fragment of a Bell Shrine and a Crozier, found during dredging near Toome Bridge[42]. The river valley has also provided one of the few pieces of potential evidence for the documented presence of Vikings in the region (including the raid on Coleraine in 932), in the form of a sword handle, found in a field on the west bank of the river close to Loughan Island[43].

Medieval (1200-1600)

The Lower Bann valley contains several prominent mounds, which may represent the earthen strongholds or mottes built by the Anglo-Normans after John de Courcy established a raiding base near Coleraine in 1197[44]. However, while there is no doubt about an Anglo-Norman presence in the area, several of the mounds are open to alternative interpretations. For example the prominent earthwork at Mill Loughan could be a barrow and the scale of the mound at Ballycairn suggests that it may have functioned more as a lookout than a motte proper. Documentary references show that several strongholds were built in the area, including de Courcy's original base, possibly represented by the massive earthwork at Mount Sandel. The *Annals of Ulster* also record the construction of a castle at Coleraine in 1214, using materials from pre-existing buildings and thus probably built of stone. The castle probably stood on the east bank of the Bann with a second, known as Drumtarsy to the west[45]. Other stone strongholds close to Coleraine in the later Middle Ages include sites at Castleroe and Fish Loughan[46]. These, together with castles at Ballyreagh, between Portstewart and Portrush, and Cross, just east of Agivey Bridge, represent the powerbases of prominent local dynasties such as the McQuillans and O'Cahans, but apart from a few stones at Ballyreagh, there are no visible remains.

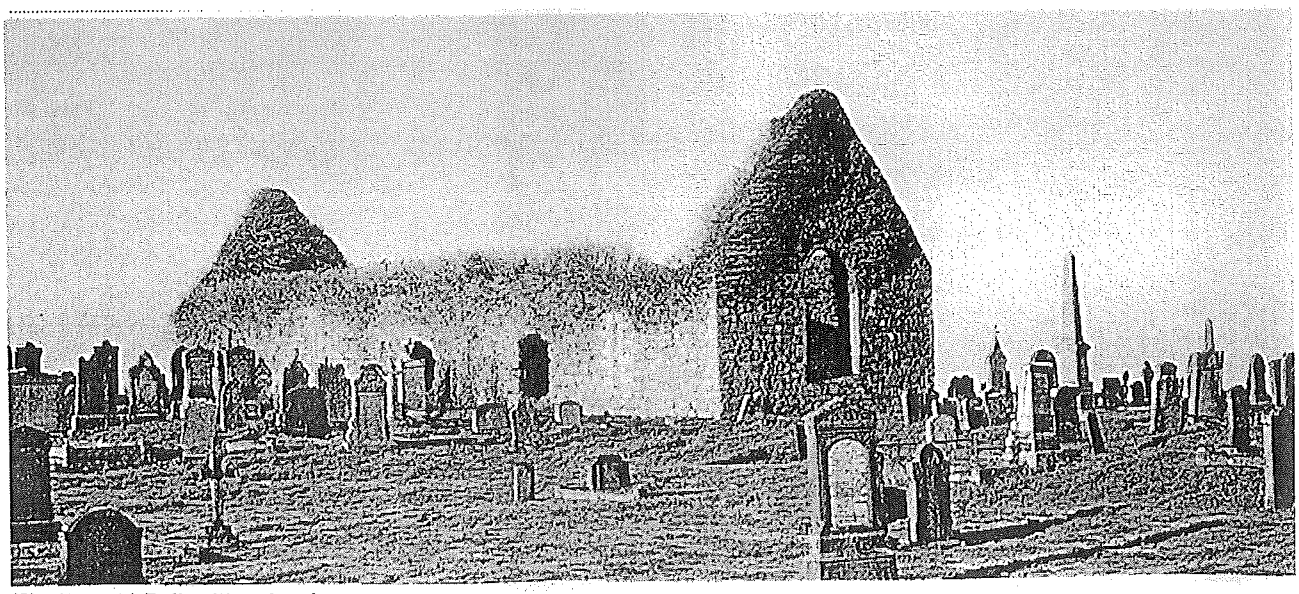


Fig. 7. (e) Ballywillan church,

Important ecclesiastical foundations in the area from the medieval period include the Cistercian Monastery of *Clarus Fons* at Macosquin[47] and the Dominican Friary in Coleraine. Although neither have left any visible remains, the ruins of several medieval parish churches are still visible, including Church Island, Lough Beg and Agherton, south of Portstewart. The most impressive church remains, however, are to be found at Ballywillin outside Portrush, where several narrow pointed 13th-century windows are preserved within the fabric of a substantial parish church.

Plantation

Coleraine was further developed as the major town on the Lower Bann by the London Companies during the plantation of the early 17th century, with a planned lay-out of timber-framed houses, an inner fortification or citadel and an outer enclosing bank and ditch.

Located on the river close to the Bann estuary, the town was well-placed to play a major role in the wider plantation and development of the Bann valley and beyond. Several other sites in the Lower Bann were developed by the London Companies to provide administrative and defensive centres. These included Macosquin (Merchant Taylors), Aghadowey (Ironmongers), Movanagher (Mercers) and Bellaghy (Vintners) where the remains of the plantation bawn and house have recently been conserved. Most of these plantation centres were developed at pre-existing settlement foci, such as the Cistercian site at Macosquin, and earlier structures were also often used for more short-term purposes – for example Church Island on Lough Beg was temporarily occupied in the 1640s and the church ruins used to store ammunition[48].

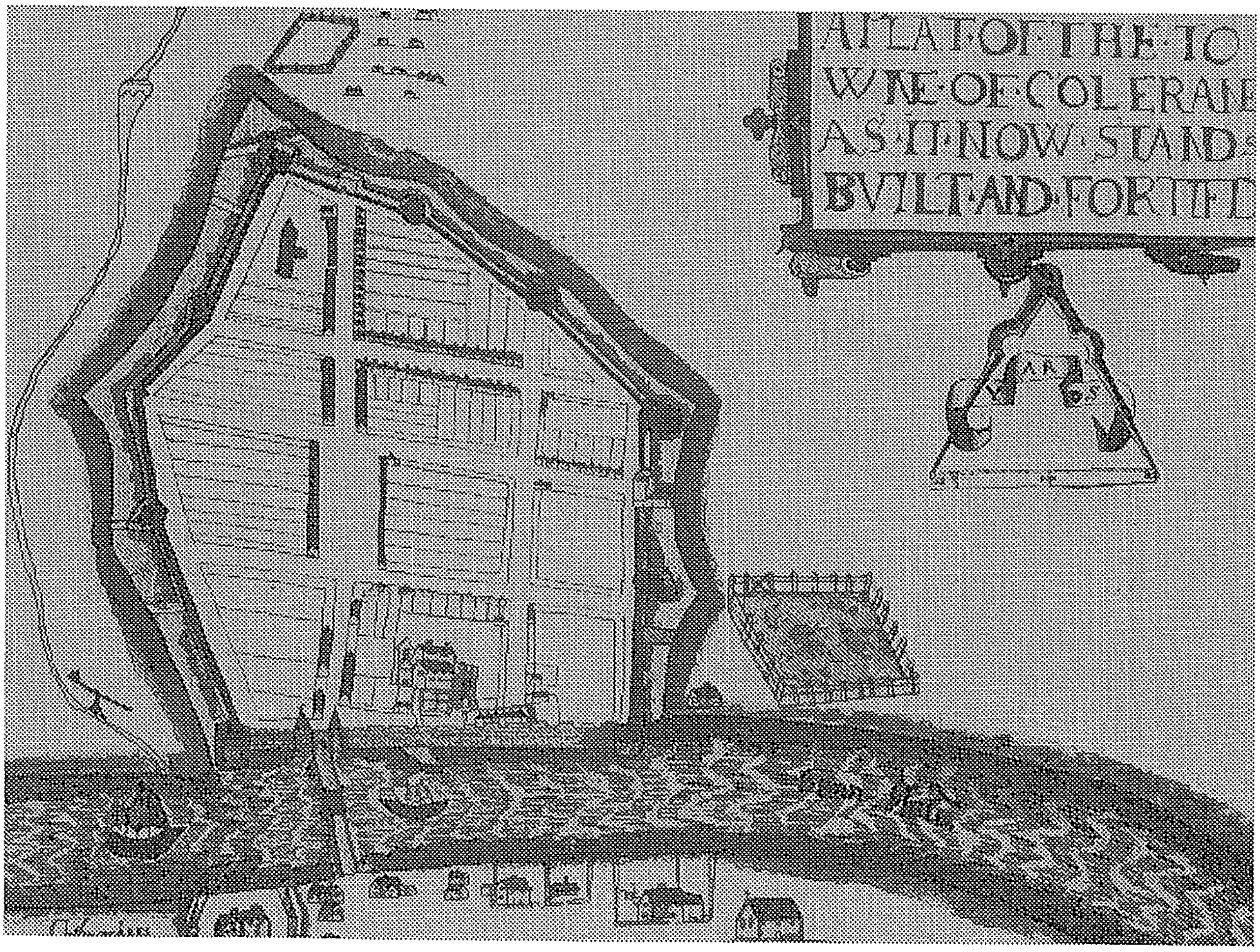


Fig. 7. (f) Coleraine in 1622 (PRONI).

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Glarryford

Jasper Knight

Morphology

The Glarryford esker system is located along the valley of the upper River Main between Ballymoney and Ballymena (Fig. 8). The valley is a subglacial Nye channel cut into the Lower Basalt and bounded by Long Mountain to the west and the Antrim Plateau to the east. Glacial landforms in the area developed during generally south to north ice flow from the Lough Neagh dispersal centre. Small drumlins aligned SSE-NNW are present in lowland areas, and streamlined rock ridges with the same orientation are present above the drift limit (c. 150m OD on Long Mountain). At Glarryford the drumlin landscape has been partly overlain, partly cut out, by an esker and related subaqueous fan deposits (< 12km long, 1km wide) which trends northwards, up the regional gradient. The esker system is discontinuous with fragments up to 3km long, is flanked by flat-lying sand and gravel spreads, and meanders from west to east across the valley. The esker crestline (< 10m high) is sharp and undulating, contrasting with the low-angle sand and gravel fans and Holocene lowland raised bogs alongside which onlap both components. The area therefore has both scenic and economic (sand and gravel aggregate) importance (Knight *et al.* 1999).

Sedimentology

Esker sediments are exposed at Bell's pit (grid reference 3046, 4176) and Boyd's Bridge pit (grid reference 3043, 4179), both west of Clogh Mills. These sediments comprise interbedded and

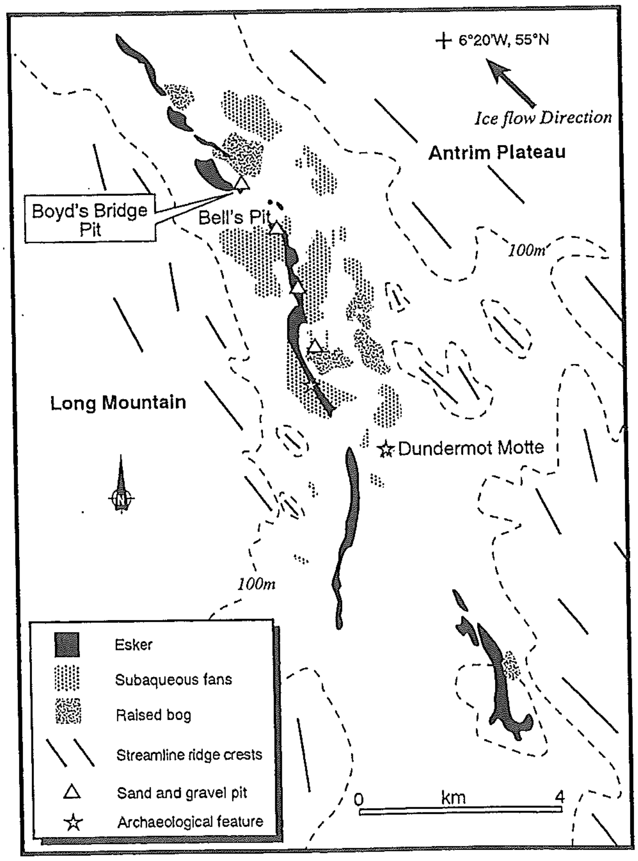

Fig. 8. Glacial geomorphology of the Glarryford area.

discontinuous coarse sand, granule, pebble and cobble gravel beds. Beds are generally massive to chaotic and separated mainly by erosional contacts. Clasts within the beds are dominated by basalt with a minor chalk and flint component (< 3%). The nearest significant possible southerly source area for the chalk/flint clasts is to the west of Lough Neagh, and may suggest previous transport into the Lough Neagh Basin (Dardis 1982). At Bell's pit, adjacent to the main esker ridge, chaotic, stacked and imbricated boulder gravels are folded and squashed by ice retraction of the subglacial tunnel. Fold axes strike 040°-220°. A section transverse to the esker is present on the north side of the pit. Here, gravel beds are laterally continuous, interbedded with sand and granule lenses and stringers, and show a characteristic dip away from the esker core. Clasts in the central part of the esker core are welded together by a calcite cement. This is likely to have derived from dissolution of small inclusions of calcite present within the basalt (and seen in clasts at this site). The calcite occupies vesicles within the basalt. At Boyd's Bridge, laterally continuous and flat-lying gravel beds are present, interbedded with sand and granule interbeds and drapes. These sediments can be viewed as the lateral equivalent of the esker core sediments.

Interpretation

The Glarryford esker forms part of the subglacial drainage system flowing from south to north from the Lough Neagh ice centre. Sediment size, lack of sorting and its flow up-gradient suggests a steep hydraulic gradient, steep ice surface, and pressurised subglacial meltwater source area, probably in the Lough Neagh Basin itself. Overall morphology and disposition of components of the esker/flanking fan system suggests strong, turbulent flow within enclosed subglacial channels with fans deposited in flanking slack water environments (Gorrell and Shaw 1991; Brennand and Sharpe 1993). Facies variability indicates deposition by a series of distinct meltwater pulses. These may have been seasonally driven, which is supported by the presence of contorted flanking sediment which were deformed during winter contraction of the ice tunnel. At Boyd's Bridge, sediment continuity and bedding characteristics, and absence of channels, suggest deposition by high-energy subglacial sheetflows adjacent to the main esker conduit.

Acknowledgements

Steve McCarron (UUC) drew the diagram.

Ballyboyland

Jasper Knight

Ballyboyland quarry, 5km west of Ballymoney, shows basalt bedrock overlain by glacial diamict (Fig. 9). The basalt upper surface is smoothed and rounded by glacial abrasion. Striations are present on this surface and record northward ice flow from the Lough Neagh ice centre. Diamict (< 6m thick) is generally massive, poorly-sorted, bimodal, and arranged in flat-lying, tabular and interbedded units (< 1.5m thick). The bedrock surface varies from flat and sharply planated to angular and poorly defined. Depressions in the bedrock surface (< 4m deep) are infilled with angular local bedrock-derived pebbles and boulders which form vague layers within and across the top of the depressions. These clasts have been clearly detached from adjacent bedrock highs and transported northwards. Block detachment may have been encouraged by vertical bedrock fractures. Some of the deepest depressions have steep, smooth U-shaped sides and are infilled with more massive diamict. Diamict beds (< 1m thick) overlying the depression infills are generally massive, matrix-supported, pinch out laterally, and contain discontinuous lines of flat, single clasts.

The overall sediment sequence records deposition by subglacial debris flows and lodgement processes in response to the presence of obstacles at the ice-bed interface (bedrock highs). Depressions in the bedrock surface may have formed by subglacial plucking of jointed bedrock blocks by freeze-on and dilation processes. This mechanism is supported by the size, angularity, and position of plucked blocks adjacent to rockhead. Some depressions with smooth, steeply-inclined bedrock sides may have been formed by subglacial meltwater erosion prior to infilling. Depressions of similar size and shape developed in diamict have been attributed by Dardis and Hanvey (1994) to leeside 'supercavitation' by meltwater during drumlinisation. Infilling by angular local bedrock blocks may have occurred as a result of matrix fluidisation over bedrock highs (under high hydraulic pressure), followed by matrix and clast 'freezing' within the depressions as hydraulic pressure decreases (Pusch *et al.* 1990; Kumpulainen 1994). This model can also explain how sediment was mobilised and deposited by debris flows. Successive debris flows offlap northwards, consistent with other flow indicators.

Acknowledgements

Steve McCarron (UUC) drew the diagram.

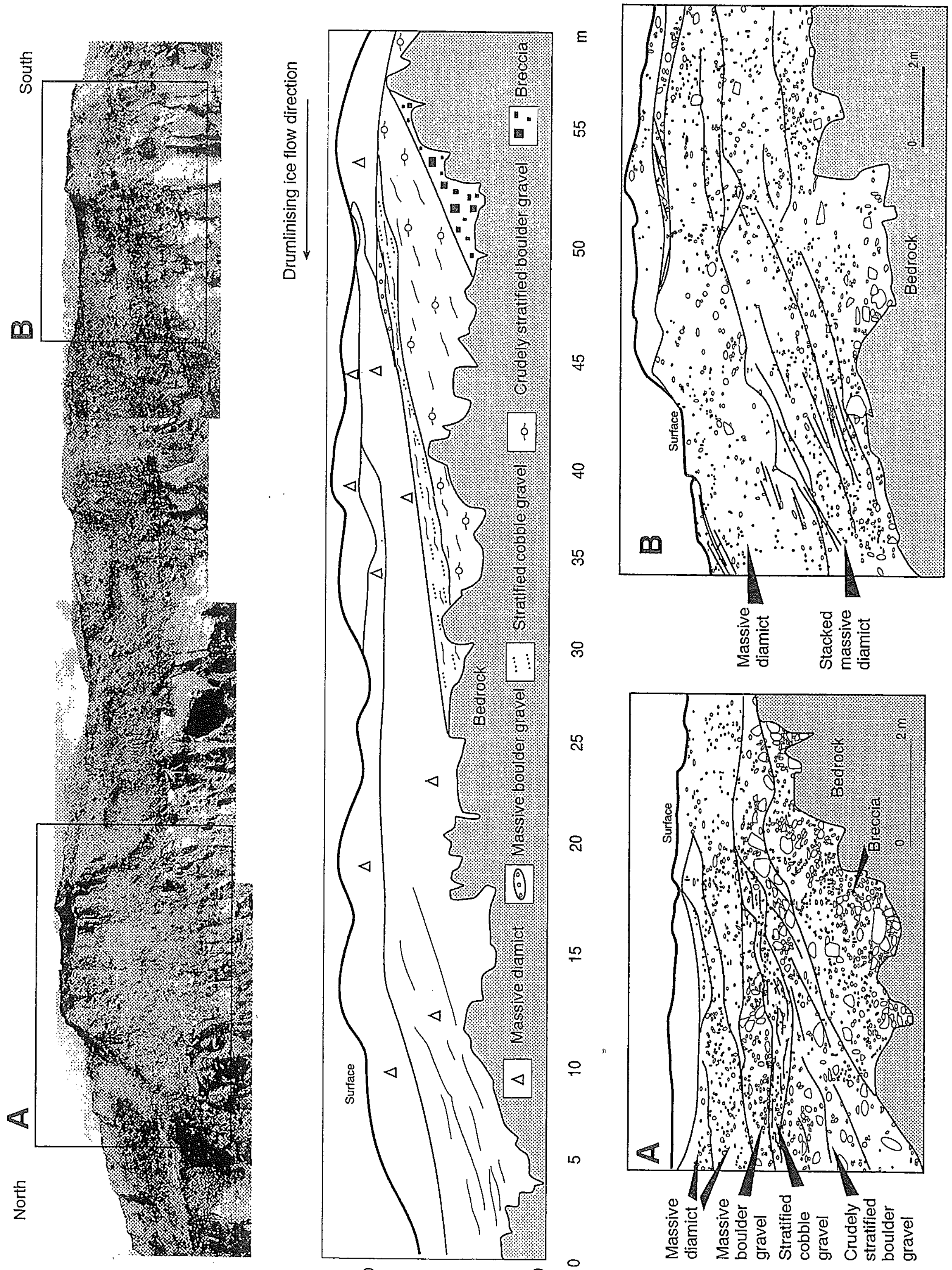

Fig. 9. Sediment sequences at Ballyboyland.

Chironomidae in Lough Neagh

Clare Carter

One of the characteristic features of the shore of Lough Neagh in the summer is the presence of swarms of flies - on a calm day often dense enough to be mistaken for columns of smoke rising from the trees. These are Chironomidae (Diptera), or non-biting midges. The adult stage is short-lived and the majority of the life cycle is spent as a larva in freshwater (there are some species with terrestrial or marine larvae). The larvae are benthic and are among the most ubiquitous animals in freshwater in all parts of the world. For this reason, they have been widely used as indicators of lake type, a classification first proposed by Thienemann (1922) and summarised in Brinkhurst (1974). Thus, in Europe, a lake with a profundal chironomid fauna of *Heterotrissocladius subpilosus* Brundin would be classed as ultraoligotrophic, whilst one with *Chironomus plumosus* (L.) is eutrophic. This use of chironomids as indicators can be extended to the reconstruction of past lake environoments because the chitinised head capsules, on which most chironomid identification depends, remain in lake sediment, like pollen and diatoms, and are generally well represented.

Lough Neagh

Lough Neagh is the largest lake in the British Isles, with an area of 383 km^2, and mean depth 8.9m. Its depth is relatively uniform except for one area in the north-west which reaches 33m (The Trench) (Fig. 10). It is a eutrophic lake with high phytoplankton production but does not regularly stratify in the summer because of its shallowness and exposure to wind. The most abundant profundal chironomid is *Chironomus anthracinus,* an indicator of moderately eutrophic conditions which can survive in Lough Neagh because the lack of stratification means that oxygen does not become depleted for long periods in the profundal zone.

As part of a joint project between the University of Ulster and Queen's University, Belfast, long sediment cores were taken, with a Kullenberg corer, from several areas of Lough Neagh. One is the Trench, 33m depth, and a second, south-east of the Trench, where the water depth is 17.5m. Five 8m-long cores were obtained from the Trench and 3, 8m long ones, from 17.5m. In both cases, the top 1m of the cores are missing. The Trench cores are dark organic mud, water content varies from 70% at 800cm, to 60% at c. 400cm and up to 75-80% at the top of the cores. Organic content is c.15% at the bottom, 10-11% at 400cm and 16% at the top. There is greater variation in the 17.5m cores, the bottom 2m is more minerogenic than the rest of the cores, and the 1m above that shows faint laminations. The water content is 45% at the base of the cores, rising to 60-65% at 500cm and a peak of 82% near the surface. Organic content is c. 6% from 800-600cm, rising in steps to 20% at 150cm. Within both sites, cores can be correlated by Whole Core Magnetic Susceptibility. Dating and other evidence (AMS, ^{210}Pb, ^{137}Cs, Pb and Zn concentrations, pollen stratigraphy) indicate that the Trench cores represent post-plantation lake history, while the 17.5m cores cover post-glacial time.

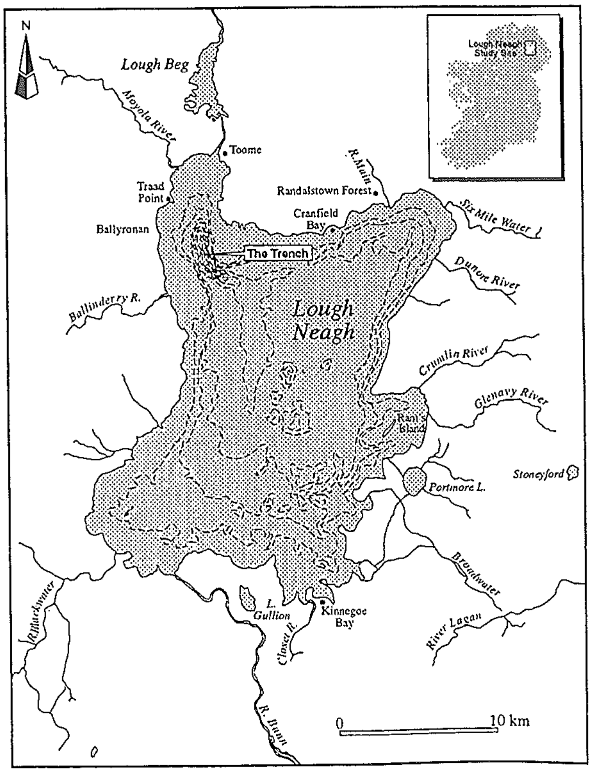

Fig. 10. Location of study site, Lough Neagh.

Post-glacial chironomid fauna

Looking first at the post-glacial history of the chironomid fauna of the lough (core LN95-7; Fig. 11), the first point is the absence of chironomid remains in the lower part of the core. This is unexpected as both diatom and zooplankton remains are found at these depths. It is possible that the fauna was very sparse at that time, available food being limited, and any head capsules are therefore widely dispersed in the sediment. The first genus found (550 cm) is *Protanypus,* a cold-adapted species which is found fairly consistently, though always in low numbers, from 550cm to 150cm (4500 BP). Thereafter, a fauna largely similar to the present-day one develops, although the proportions of different genera vary. The initial chironomid community (540-400cm, c. 11,000-10,400 BP) can be characterised by *Microtendipes* and other genera today largely living in water shallower than 17m, and Orthocladiinae, a sub-family known for its intolerance of low oxygen conditions and now found only in the littoral of Lough Neagh. This is therefore probably a period when oxygen was not a limiting factor in the profundal of Lough Neagh, but food resources for chironomids were also not abundant. This period is followed by one in which

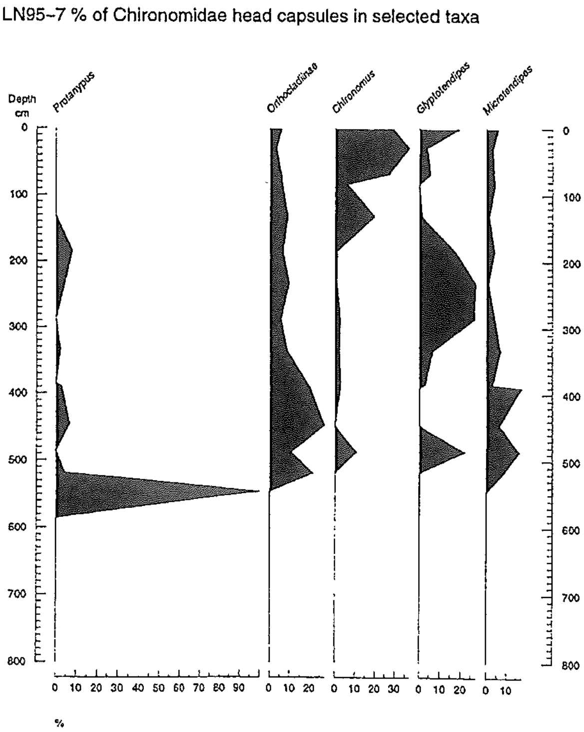

Fig. 11. LN95-7 % of Chironomidae head capsules in selected taxa.

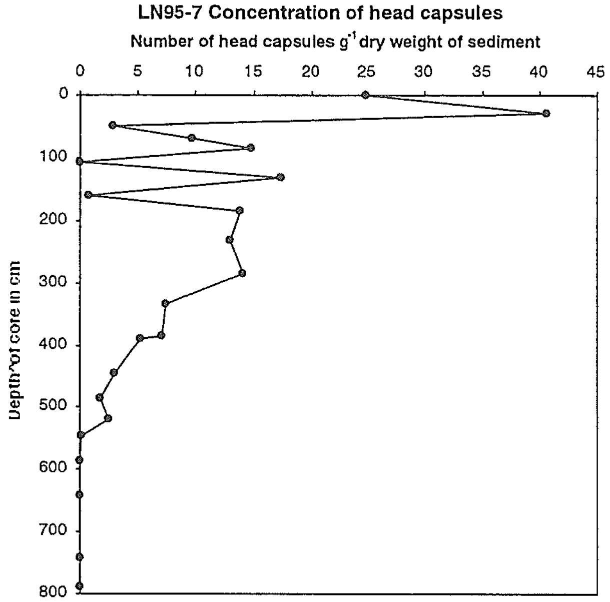

Fig. 12. LN95-7 Concentration of head capsules.

Glyptotendipes is the dominant genus (400-180cm, 10,400-5800 BP). This is the period of diatomite formation. *Glyptotendipes* is found in the lough now but cannot tolerate severe oxygen depletion. Above 180cm, *Chironomus* becomes the dominant genus, as it is in the profundal of Lough Neagh today. The concentration of head capsules in the sediment (Fig. 12) is low initially, but steadily increases during the *Microtendipes* period, and this increase continues until 300cm (c. 9100 BP). Concentration then remains the same from 300 to 180cm, the end of the *Glyptotendipes* period. Thereafter, the variability in number is greater than before but there is a steeper upward trend. As *Chironomus,* the dominant genus at this time, is larger than other genera, this represents a proportionally greater increase in the chironomid biomass. The post-glacial history of the chironomid fauna would therefore indicate an initially cold, well-oxygenated lake in which food resources were not very abundant. This is followed by a period in which food began to increase but oxygen was still plentiful. There is no direct evidence apart from a greater proportion of genera which are now found in shallower water, but it is possible that the lough level was lower during this time. Later, food became more abundant and eventually oxygen started to become a limiting factor, leading to the dominance of *Chironomus.*

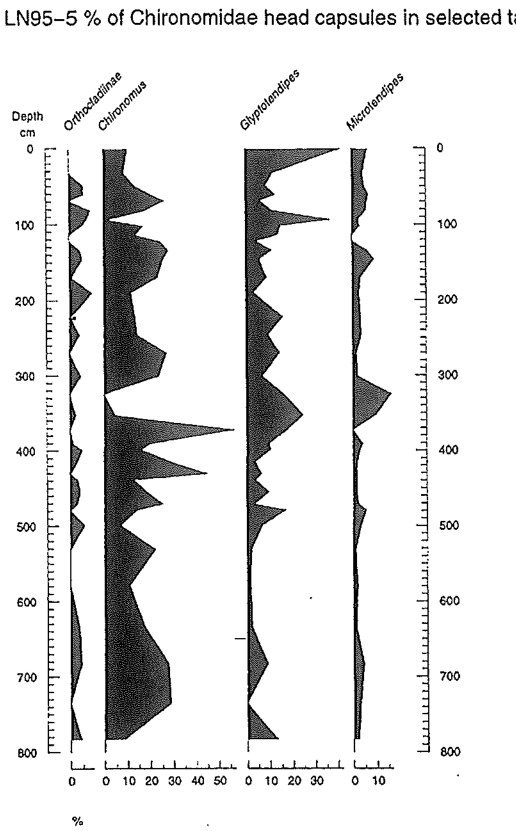

Fig. 13. LN95-5 % of Chironomidae head capsules in selected taxa.

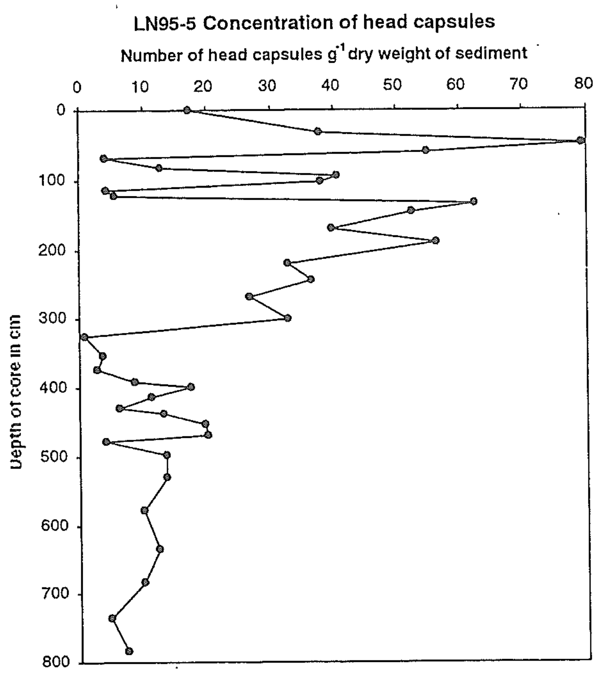

Fig. 14. LN95-5 Concentration of head capsules.

Recent lake chironomid fauna

The more recent history of Lough Neagh is demonstrated in core LN95-5, from the Trench (Fig. 13). The Trench cores have a very high sedimentation rate, almost 6cm y^{-1} over the top 250cm (^{210}Pb dating, McGee, unpublished). Comparison of this core with LN95-7 (there is no overlap) shows that the Orthocladiinae are less abundant, but the only genus found in LN95-7 which is absent in LN95-5 is *Protanypus.* There are a number of genera in LN95-5 not found elsewhere. There has not been a significant change in the composition of the chironomid fauna over the length of the core, it is still composed mainly of *Chironomus* and *Glyptotendipes,* but there has been a change in the concentration of head capsules in the sediment (Fig. 14). There is a slight rise in concentration up to 500cm, followed by a period of fluctuation and decline (500-320cm). This may be due to forest clearance and increased minerogenic input (this dilutes the food resource). After 320cm, there is a rapid increase in concentration, coincident with the introduction of piped sewage and the onset of cultural eutrophication in Lough Neagh. More recently there have been two short periods with low numbers, around 120cm and 70-80cm, for unknown reasons. Thus, the anthropogenic influence on Lough Neagh has been manifest in the chironomid fauna through an increase in numbers of what was already a community indicative of some degree of eutrophication.

Acknowledgements

Many people involved in the UU/QUB project have contributed to the work reported here, particularly T. Baxter, D. Jewson, S. Leroy, R. Løvlie, E. McGee, J. Pilcher, and C. Robinson.

Lough Neagh and Bann valley diatomite deposits

David H. Jewson, Tania Baxter, Rick W. Battarbee and Nigel G. Cameron

Introduction

Diatomite deposits at Toomebridge, on the shores of Lough Neagh, and along the Bann Valley (Fig. 15) are known locally as 'Bann Clay'. Seamus Heaney, who lived in the area during his childhood, has a poem called by that name (see Heaney 1969). The poem refers both to the commercial extraction as well as the origins:

> It underruns the valley,
> The first slow residue
> Of a river finding its way
> Above it, the webbed marsh is new,

In fact, the diatomites and their associated deposits are over 7,500 years old and contain an important record of the history of early man in Ireland (e.g. Whelan 1930; Movius 1936; Jessen 1949; Mitchell 1955; Woodman 1977, 1978; Woodman and Mitchel 1991). There is evidence of continuous occupation at Newferry on the River Bann for over 5,000 years (Woodman 1977; Woodman and Mitchel 1991), which is the longest known for the Mesolithic in Ireland. The main reason why man was attracted to these sites was the fishing. Migratory species, such as eels and salmon, could be caught in narrow channels during low water levels in summer. It is likely that they used some form of traps, so human activity was closely linked to changes in the environment of the river and lake. At Toome, there were patches of reedswamp and sand-banks at this time. Early man made his summer camp on the banks (Mitchell 1955; Woodman 1977; Woodman and Mitchel 1991). With increasing water levels and winter flooding, these banks gradually became overlain with diatomaceous muds. Today, the extent of the flood plain at Toome can be seen in the flat meadows extending west as far as the Elk Bar, over 1 kilometre from the river. On the east side of Toomebridge, the ground rises more quickly and the diatomites only extended about 100 to 150m. These deposits are now almost completely removed except at the river edge, where the diatomite can be clearly seen as a white layer. There are other deposits down

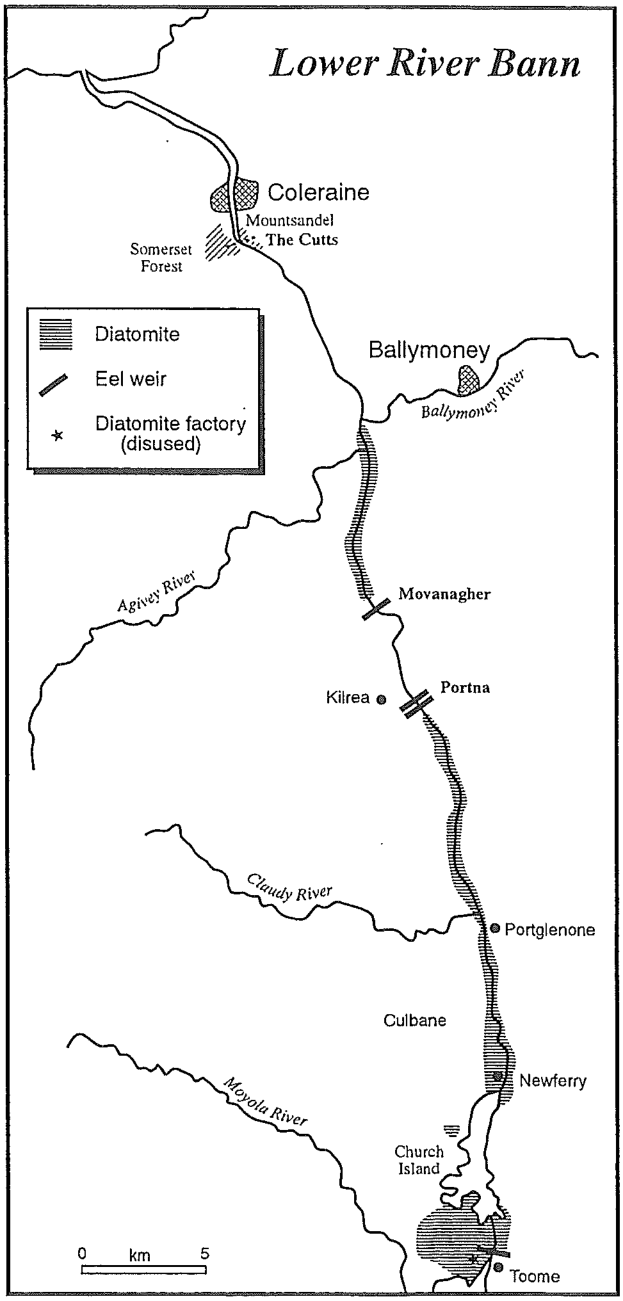

Fig. 15. The Lower Bann valley showing the areas of diatomite (after Woodman and Mitchel 1991).

the River Bann, notably at Newferry. There were then two more small lake basins to the north. Descriptions and stratigraphical analyses of selected sites along the river are described in more detail below.

The present day water levels of Lough Neagh, Lough Beg and the Lower Bann are the result of three periods of engineering that aimed to improve the navigation, lower the level and control the annual variation. The first scheme was started in 1846. Before that, it was possible to ford the river at Toome. Further lowerings were carried out in the 1940s and 1950s. The present statutory lake requirement is to maintain the level between 12.46m and 12.61m above OD Belfast. This is a reduction of about 1.5m below the summer level before the McMahon engineering scheme in the last century was started. However, the maximum winter levels have shown a bigger decline, from extremes of 16.4m OD before 1846 down to 12.61m by the late 1950s, so a drop of about 3.8m. However, for short periods in wet winters the lake level does rise to over 13.2 m OD, and this is important for maintaining unusual coastal sand habitats.

Together, the various deposits of diatomites, reedswamps and raised bogs that lie along the Lower Bann Valley, contain a unique spatial record of what was happening around the shores of the lake and the river. It is highly unusual for such sites to remain undisturbed, so they provide excellent potential for reconstructing past conditions, especially for comparison with offshore lake sediments formed at the same time.

Palaeoecological investigation of lakes at the University of Ulster was stimulated by Prof. Oldfield in the late 1960s and led to the important work by Battarbee (1978) on Lough Neagh, which was the first example of the use of sedimentary diatom records to quantify rates of change due to pollution. More recently, a joint programme was initiated between the Freshwater Laboratory at the University of Ulster and the Palaeoecology Unit at Queen's University, Belfast, to investigate changes in environmental conditions in the Lough Neagh basin during the Holocene.

Background to diatomites

Diatomite deposits are aquatic in origin and mainly consist of the remains of microscopic planktonic plants called diatoms (see Fig. 16a) that have a cell wall made of silica. They are sometimes described as plants living in a glass box. In the diatomite, all the organic matter of the dead cells has been oxidised, so the deposits appear white. The diatomite deposits were extracted commercially for over a century, finally ceasing production 5 years ago. Diatomites are used in many processes depending on their quality (i.e. amount of contamination from impurities). The purer they are, the higher the commercial value. They are used as abrasives (e.g. car polish, toothpaste, cosmetics, etc.), inert filters (e.g. cider, beer, sugar production), catalysts, in making bricks, etc. Large deposits are found all around the world but most diatomites (e.g. in California, Spain, Kenya, etc.) are millions of years old and of marine origin. Some freshwater deposits do occur in England, Wales and Scotland but all are small and mainly from dried lake muds. Most were dug out in the Second World War, in the need to supply the armaments industry with a 'stabilising' absorbent for explosives (nitroglycerine) in artillery shells.

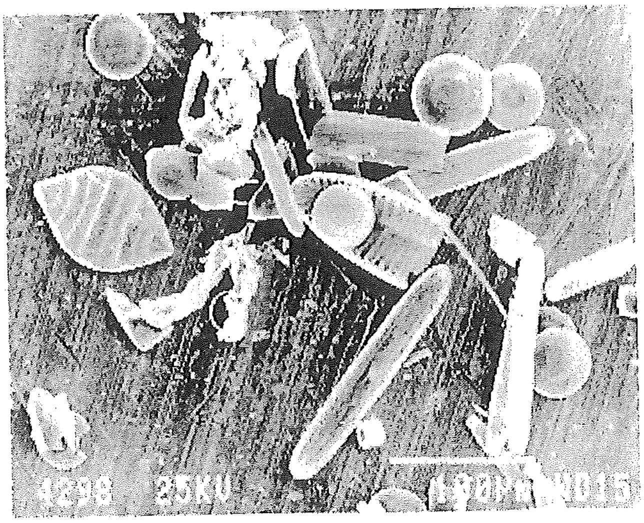

Fig. 16. (a) Diatoms from the Toome diatomite deposits. The samples have been filtered, dried and photographed on a scanning electron microscope. The asymmetric shapes are species that live on the bottom, e.g. *Pinnularia* and *Cymatopleura*. The symmetric, disc-shaped forms are planktonic species, e.g. *Stephanodiscus*.

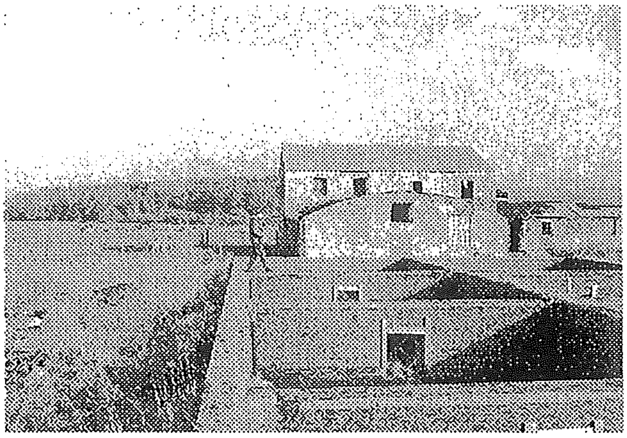

Fig. 16. (b) The disused diatomite factory at Newferry. The conifer forest behind the buildings is planted on material dredged from the river, which includes diatomites.

In fact, the majority of the diatomite dug out at Toome was used for the same purpose. Extraction rates peaked during World War II and then demand gradually declined (Fig. 17). This was partly because different types of ordnance were used but also because it was becoming less profitable to extract. At that time, the diatomite was still dug by hand and over 80 people were employed, so it was a labour intensive process. Added to this, the Lough Neagh diatomite was not the best grade available. This meant that there were considerable periods when digging stopped, waiting for an improvement in the market. In a report in 1983, Smith pointed out that the mining company, Kenyon, had 600-700 tonnes of diatomite stacked and dried but was unable to sell it, due to cheaper and superior imports from the USA and Europe. At that time, he believed that the situation was unlikely to change without either better working methods or a new use for the material. Both occurred and production did start again. A mechanical digger was used and only 3 or 4 people were employed. The diatomite was dried, powdered and bagged at Toome and then sent across to England, mainly for use in the production of insulation bricks for ovens. The factory has recently ceased working again and now the site has been turned into a series of small industrial units. In 1983, Smith believed that a maximum of 20,000 tonnes was left at Toome, out of an original deposit of 337,500 tonnes, i.e. less than 5% remained. In the last decade, this has probably been further reduced by about 1,000 tonnes per year and much of what is left has been disturbed. The first factory was on the site of the present RUC Police Station at the east end of the bridge over the River Bann. The buildings and drying sheds of the factory that replaced it can still be seen several hundred metres to the west of the bridge at the new industrial site. Another factory also functioned at Newferry to the north of Lough Beg. This took diatomite from deposits alongside the river, as well as surrounding fields. Some of the buildings and drying pans still remain. Production from this factory was also used for cosmetics, such as face cream, with the diatomite acting as mild skin abrasive.

Unfortunately, for many years the importance of the deposits was overlooked in the development plans for the Lough Neagh and River Bann area. One example is the archaeological site of Prof. Mitchell (1955) at Toome. This was partly destroyed by the engineering works associated with the lowering of the lough in the 1950s but mainly by commercial extractors of sand and diatomite, who were unaware that the site was of any archaeological or geological value. Until the 1970s, Mitchell's site at Toome was believed to be the earliest known site of man in Ireland. From Prof. Woodman's work (1978), we now know that the occupation at Mountsandel in Coleraine was earlier (back to 9,000 years ago) and occupation probably spread from there along the River Bann. One of the most important sites was in the Culbane area but, unfortunately, this was probably destroyed when the diatomite was removed. A similar fate befell the sites of Prof. Whelan (1930), Prof. Movius (1936) and Prof. Jessen (1949).

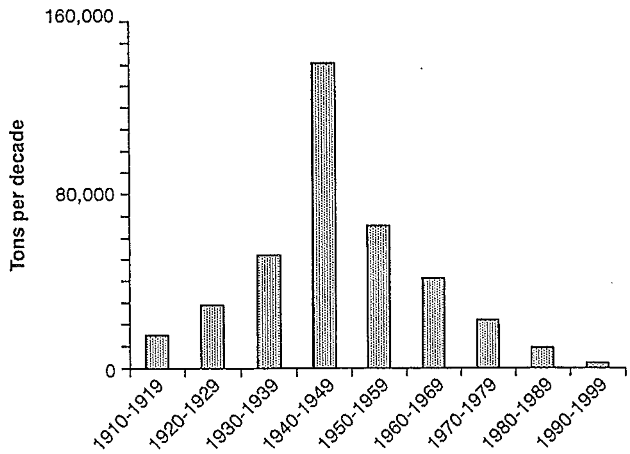

Fig. 17. Tons of diatomite extracted per decade from the Bann valley deposits (compiled from Smith 1983 and Kenyons, personal communication).

In 1990, the Conservation Branch of DOENI supported a 6 month study by the University of Ulster and University College London (UCL) to try and identify what was left of the deposits and to recommend a possible conservation strategy (Jewson *et al.* 1991). One of the major problems in assessing what should be conserved was the lack of information on the variation in composition of the deposits. There had been some short descriptions of diatoms in archaeological works, the earliest being by Chaffers (in Jackson 1909), followed by Petersen (in Jessen 1949) and finally by Battarbee (in Woodman 1977). The two earlier records are of limited use, due to taxonomic improvements, but from Battarbee's report there was sufficient evidence to suggest that there were major environmental changes with time, especially a shift from shallow to deep water species in the more recent deposits.

The Lough Neagh diatomites are known all around the world to diatomists but, unfortunately, few of them know the exact location of their specimens. They have just been given material from the factory, so they usually have no detailed information on the depth or place of origin, except Toome or Ballyscullion East. In this report, the details are given of some of the results of the 1990 survey along the Bann Valley.

Results

The cored material and monoliths are stored in a constant temperature room (4°C) at the Freshwater Laboratory of the University of Ulster, Traad Point, Ballyronan. Diatom slides are archived at the Environmental Change Research Centre at UCL.

A. Toome

One of the deepest sequences studied in 1990 was at Toome. The location of the site, to the west of the road bridge, is shown in Fig. 15. It was a prime site for looking at spatial variation, having remained undisturbed throughout the recent commercial and domestic development of the area. Unfortunately, it was destroyed in 1997 by the building of a fish processing plant. However, a small field at the back of the factory has been retained and has been declared an ASSI.

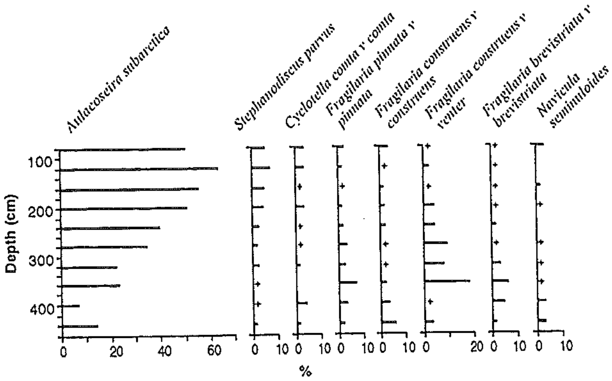

Fig. 18. Depth distribution of the percentage frequencies of the most common diatom species in core TB4 from the west bank of the River Bann at Toome, Northern Ireland.

A total of over 30 genera and 140 species were identified from this site, the most common are plotted in Fig. 18. The basal levels (400cm and 440cm) had relatively low percentages of planktonic species, such as *Aulacoseira subarctica*, whilst non-planktonic taxa, such as *Fragilaria* and *Navicula* were relatively common. The non-planktonic taxa *Fragilaria construens v. venter*, *Fragilaria brevistriata* and *Acnanthes minutissima* reached maxima at 320-360cm. A clear increase in the dominance of *Aulacoseira subarctica* occurred from 360cm and this species increased to over 60% at 120cm. It still dominates in the lake today. A similar percentage increase, but of smaller magnitude, occurred in another planktonic species, *Stephanodiscus parvus*. Diatoms were absent above 83.5cm.

The increase in the planktonic component of the diatoms and in particular *Aulacoseira subarctica*, supports the idea of rising water levels with extensive winter flooding (see Battarbee in Woodman 1977). This species is still very abundant in the lake today (Jewson 1992).

The chronology of this sequence has been approximated by comparison of pollen frequencies with other pollen sequences from this area. Only 8 levels were analysed but the basal levels (400-455cm) had high coryloid and relatively high *Pinus* percentages and so were probably of Boreal age (Jessen 1949). Though there was an enigmatic *Alnus* maximum at 455cm, the Boreal-Atlantic transition (defined by the *Alnus* rise to sustained high percentages) occurred between 325-400cm (*Alnus* reaches 25-30% of the total pollen).

The depth of deposit that could be exploited commercially was from 83.5cm to 172.5cm. The section below this increasingly contained organic matter, being below the local water table (172.5-252cm), which made it less attractive and harder to extract. However, from an ecological point it becomes more interesting. It has the highest *A. subarctica* percentages.

At this site, the white (i.e. low in organic matter) commercially dug diatomite formed relatively late in the Atlantic period, i.e. well after the first rise of *Alnus* and, perhaps, even after the elm decline (between 240-160cm). The uppermost layers where pollen was analysed, show traces of agricultural activity: general tree decline, including post elm decline, increased grass, weeds (*Plantago lanceolata*), single cereal grain; so certainly post 5000 BP.

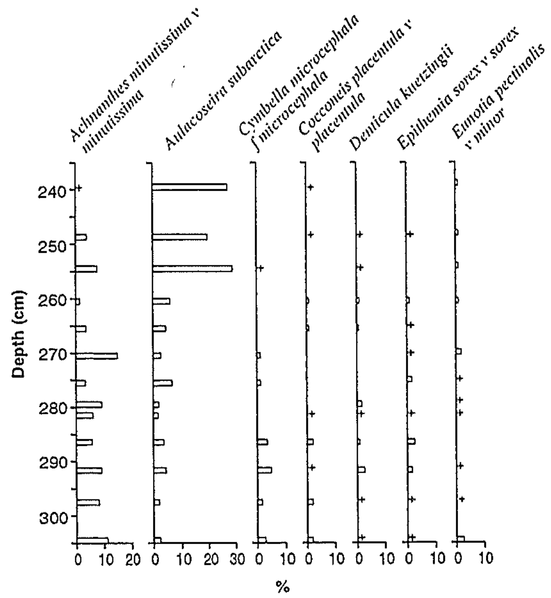

Fig. 19. Depth distribution of the percentage frequencies of the most common diatom species in core NF13 from Ballymacombs More Bog to the west of the River Bann at Newferry, Northern Ireland.

B. Newferry

The diatomite deposits at Newferry extend on both sides of the river. This is an important area that is internationally famous from the work of Whelan (1930), Movius (1936), Jessen (1949), Woodman (1977, 1978), Smith and Collins (1971) and Smith (1981, 1984).

1) *Ballymacombs More Bog* (see Fig. 15). This is one of the classic sites of the Danish scientist, Prof. Jessen, who was commissioned to look at Irish peat bogs in the 1930s by the Royal Irish Academy's Committee for Quaternary Research (whose chairman was Dr. Praeger, the distinguished Irish naturalist). The aim was to see whether Irish peat bogs were suitable for using the pollen techniques that he had developed in Denmark. One of his assistants was Frank Mitchell who went on to become Professor at Trinity and has contributed so much to our understanding of post-glacial events in Ireland (see Mitchell 1976, 1986). Ballymacombs More Bog is mainly being extracted by the Bullrush Peat Company (which is ironically a Danish company), although there are several other smaller local concerns. Most of the bog has been removed but the interface with the diatomite is still intact.

The main building and a few settlement tanks of an old diatomite factory still exist to the north of the Car Park at the old ferry crossing (Fig. 16b). All the diatomite in the surrounding area (up to the bog) has been dug out although right beside the building there still exists some diatomite with charcoal layers. This is some way from the previously documented habitation sites on the opposite side of the river, which suggests that occasionally the extent of occupation may well have been extensive. The present owners of the land and part of the bog (Mawhinney) have been trying unsuccessfully to get a grant to refurbish the roof of the main building, so it can be used for agricultural purposes (the equipment inside has been stolen or heavily vandalised). The Mawhinney family has prevented a complete loss of the building by doing limited repairs but have been unable to get a grant to conserve it further. It would be nice to see the shell of the building kept, even if it is for a different purpose.

Samples were taken with a Russian corer from the bog at Ballymacombs More, Newferry (Fig. 19). About 1m of peat had been removed from the surface of the bog. Samples were taken from 220 to 304cm below the present surface of the bog. Diatomite of reasonable quality was between 279.5 and 237.5cm. Below 304cm was sand.

A diagram showing only the most common taxa has been plotted (see Fig. 19). The basal levels, like core TB/04 at Toome, had the highest percentages of bottom living species, principally *Fragillaria* spp. and *Acnanthes minutissima*. Between 260cm and 255cm, the planktonic diatom species *A. subarctica* increased in dominance, and between 255 and 240cm remained at frequencies of approximately 20-30%. Although some of the non-planktonic taxa declined, e.g. *Fragilaria lapponica*, a significant percentage of benthic species did still occur. The results appear to fit with rising water levels but there are local differences between the other sites, which will require more detailed analysis before we can be certain what was happening.

Pollen analysis was done on 8 levels from this core. Again there were high *Corylus/Myrica* and *Pinus* (and oak) frequencies in the base of the sequence, which would suggest that the mud formed during the Boreal period. The *Alnus* rise occurred at between 260-270cm, i.e. at the Boreal-Atlantic transition. *A. subarctica* increased just after this, between 255-260cm. *Alnus* percentages were suppressed by *Filicales* (undifferentiated fern spores) in the uppermost levels but by this time there was no diatomite forming. The chronology is in agreement with other Newferry work. The diatomite formation ended before the elm-decline or suggestion of cereal cultivation.

2) O'Neill's Field, east bank of River Bann at Newferry. A 305cm sequence was sampled from the field lying on the Antrim side of the River Bann and to the north of the Newferry Road. This was one of the last, large undisturbed sites in the area. It is just to the north of Woodman's site where there was 5,000 years of continuous occupation (Woodman 1977, 1978).

Diatom identification and species frequency was looked at in 5 levels (Fig. 20). The basal level prepared for diatom analysis (260-261cm) was dominated by non-planktonic species, such as *Acnanthes lanceolata* var. *elliptica*, *Acnanthes calcar*, *Fragilaria pinnata* and *Navicula jaernefeltii*. The remarkably high frequencies of these species suggests

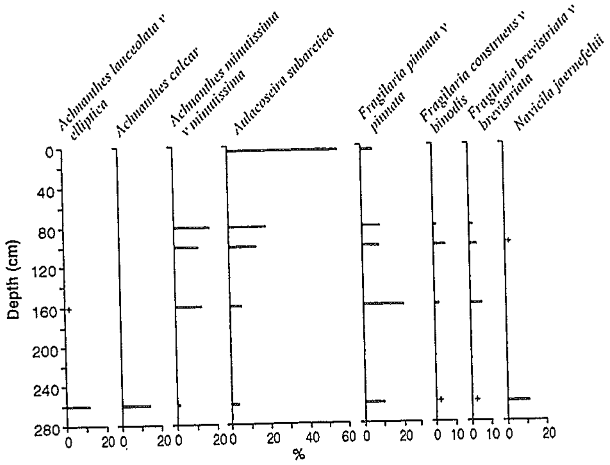

Fig. 20. Depth distribution of the percentage frequencies of the most common diatom species in core NF1 from O'Neill's field on the east bank of the River Bann at Newferry, Northern Ireland.

that at this time sediment was accumulating in a small, shallow and isolated water body with distinct water chemistry. In the three succeeding levels the frequency of *Acnanthes minutissima* rises (> 10-20%) and the planktonic species *Aulacoseira subarctica* becomes co-dominant. The unusual bottom living species of the basal level are absent. At 5-6cm *A. subarctica* reaches a frequency of almost 60% and non-planktonic species are at low percentages.

Pollen samples were prepared from 4 depths. However, exceptionally low pollen concentration and poor preservation prevented analysis of the basal level (260-261cm). Elsewhere in this sequence either pollen concentration was poor or other components of the sediment were difficult to remove and made counting difficult. However, *Alnus* reached a high frequency by 160-161cm, before the rise of *A. subarctica*. *Pinus* is notably absent. The basal pollen sample is, therefore, likely to be of (early) Atlantic age. A similar high *Alnus* percentage was found at 100cm. At 5-6cm *Alnus* had decreased and Graminae constituted over 40% of total pollen along with a significant presence of Liguliforae type pollen.

There are several possible explanations of the pollen in the surface samples but it does appear that these surface layers are truncated, probably due to erosion. There were few signs of occupation in these deposits.

Portglenone to Portna

There are a number of deposits all along the river banks of varying quality and thickness. It is likely that these were formed in a separate basin north of Portglenone reaching as far as Portna, after that there is a rapid change in level down to the next basin at Agivey. Most of the deposits have been dug out for bricks or removed by a boat, which took the diatomite back down the Bann to Newferry (the sunken remains of this could still be seen in 1999). Stratigraphical analysis showed the period of *A. subarctica* increase and even the basal sediments had relatively high *Alnus* pollen. This suggests that they were formed towards the end of the main 'diatomite' period. However, they could just be on the edges of the deposits. They highlight the problem of trying to find good sites on this stretch of the river. The quality of deposits is very variable (reflecting original hydrological conditions) combined with many of the best areas having been dug-out. The conifer forest plantations also have some deposits but these are mainly the dredging spoil from the various drainage schemes (see Woodman 1978).

Agivey Bridge area

These are very limited deposits compared to the others and too high in organic matter for most commercial uses but they have been used in the past for local brick making. The interest in this area has been the possibility of tracing a marine transgression. Jessen (1949) sampled here, as this was the first suitable site he could find above Somerset Forest at Coleraine (see Fig. 15). One of the sites sampled in 1990 was close to Jessen's, just north of the river bridge on the east bank (AGB/2). Another, AGB/3, further to the north on the west bank had the longest sequence of any, going back to the dominance of hazel. Analysis of the diatom communities did not show any marine or brackish influence, although there were more bottom-living species. This would fit with it being a smaller, shallower basin than the others, with a relatively larger proportion of shore habitats compared to planktonic.

Concluding remarks

The Bann Valley diatomites have been the subject of a long history of distinguished study (e.g. Jackson 1909; Whelan 1930; Movius 1936; Jessen 1949; Mitchell 1955; Smith 1983, 1984; Smith and Collins 1971; Woodman 1977, 1978; Woodman and Mitchel 1991). Although many of the important sites have been lost, the future for a limited number of the remaining sites now looks better. This is partly due to the cessation of diatomite extraction but mainly due to the efforts of the Conservation Branch of the Department of Environment, which is in the process of designating a number of sites as ASSIs. However, instead of a single threat, the sites are now under pressure from a wide variety of sources that include developments for housing, recreation, drainage, new bridges, etc. So, it is important that there is a wider awareness of the importance of these deposits and the need to conserve them *in situ*.

Acknowledgements

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Armoy moraine

Jasper Knight

Introduction

The composite ridge system of the Armoy moraine is a well-known morphological feature (Dwerryhouse 1923; Charlesworth 1939; Stephens *et al.* 1975; Shaw and Carter 1980; McCabe 1987; McCabe *et al.* 1998) but its origins and internal composition are poorly understood. It is generally agreed, however, that it represents the southernmost limit of Scottish ice during a late-stage readvance (Stephens *et al.* 1975, Fig. 21). Stephens *et al.* (1975) suggest an age of 13,500 yr BP for the readvance, based on correlation with dated sites in western Scotland. McCabe *et al.* (1998) correlate the readvance with the Killard Point stadial ice limit (dated to 13,800 ^{14}C yr BP) in eastern Ireland.

Morphology

The Armoy moraine extends discontinuously west to east from just north of Articlave to the western flank of Knocklayd (< 50km long). The moraine comprises a number of ridge components which are aligned generally east-west, parallel to overall ridge margins (Stephens *et al.* 1975; Gibson 1993). The ridge system as a whole varies in width, morphology and elevation. Generally, the widest ridges (containing the most sediment) are located in lowland areas (i.e. around Armoy and Stranocum; < 35m high, 4km wide), whereas ridges in upland areas are smaller, more defined, and associated with outsized boulders (i.e. at Articlave). Other ridges (i.e. Seacon, Dervock) are separated from the main ridge system by areas of more extensive kettling or outwash spreads with deep postglacial infills (i.e. Garry Bog). The southern margin of the Armoy moraine is oversteepened by meltwater channels.

Sedimentology

The internal composition of the Armoy moraine has been described from only one site, by Shaw and Carter (1980), during building of the Ballymoney bypass. In this exposure (Fig. 22), stacked and interbedded sand, gravel, silt, and laminated clay beds are thrust along major WNW-dipping fault planes. The imbricate sediment sequence indicates north to south bulldozing into shallow-water proglacial sediments. The modest amount of glaciotectonic shortening supports this limit as the maximum readvance ice extent.

A temporary exposure was present in 1995 at Castleroe, just north of the main ridge. The exposure (< 30m long, 6m high) contains a basal sand and gravel unit overlain by possibly two diamict units. The sand and gravel unit comprises flat-lying to slightly northward-dipping normally graded gravel beds containing Tyrone Igneous Complex erratics. Trough cross-bedding, cut and fill structures, and small normal faults are present in the sand and gravel unit. The overlying red diamict is flat-lying and separated from the lower unit by a variably erosional to graded contact. The diamict is

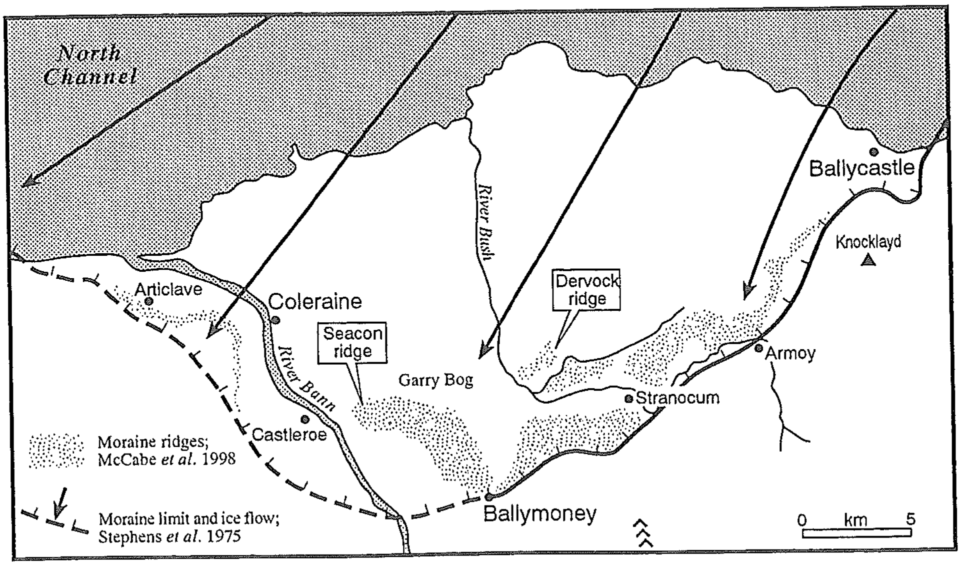


Fig. 21. Location and morphology of the Armoy moraine (after Stephens *et al.* 1975; Gibson 1993; McCabe *et al.* 1998).

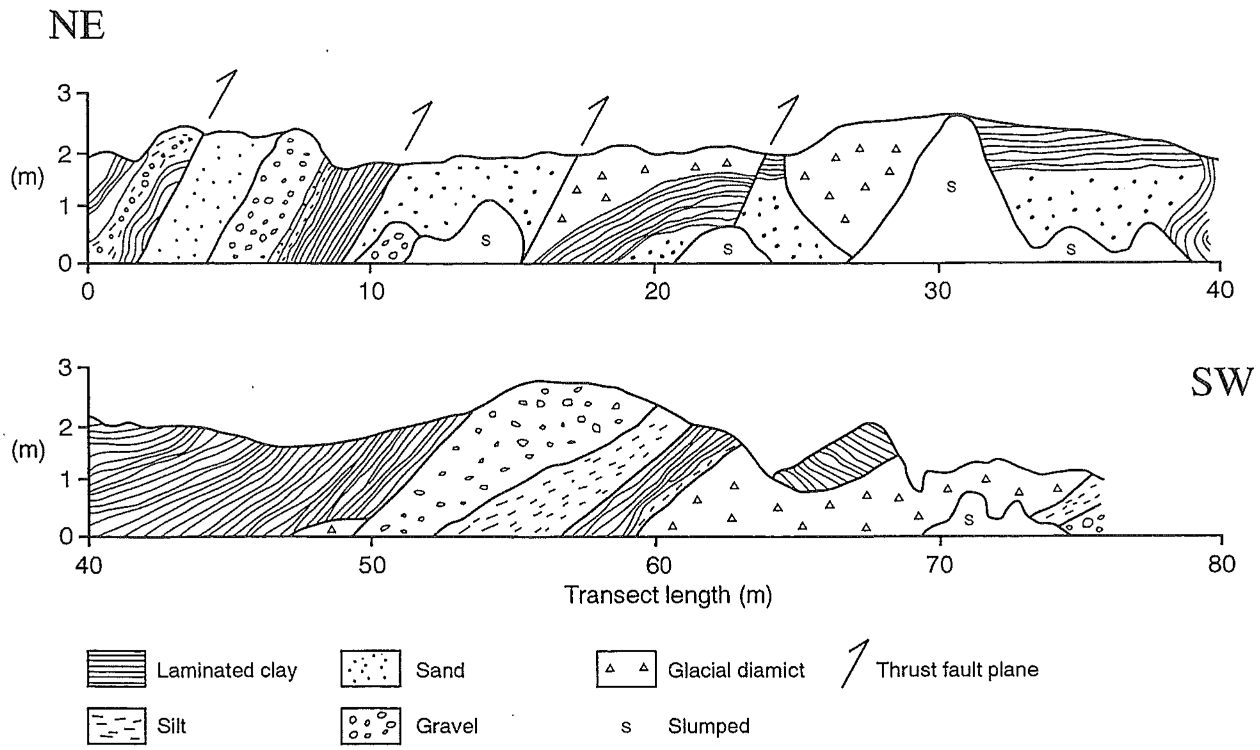


Fig. 22. Internal composition of a transverse section of the Armoy moraine (redrawn from Shaw and Carter 1980). Note the vertical exaggeration of scale.

massive, clast-poor, and unstratified. Sand and gravel lenses are present in the basal part of the unit. The upper black diamict unit has a graded to serrated lower contact and contains flat-lying, strongly-cemented calcareous concretions. The black diamict colour may be due to the presence of organics. The concretions indicate vigorous groundwater circulation cells and steep hydraulic gradients generated ahead of the ice margin. The overall sediment sequence is interpreted as a kettlehole deposit developed on braided outwash sediments deposited by Irish ice located in the central Bann valley south of the Armoy moraine limit. The outwash was buried by waterlain muds and silts which infilled the kettlehole. Deposition of this sequence probably immediately postdates Scottish ice retreat from the Armoy limit, and re-establishment of Irish ice drainage through the Lower Bann. Stephens *et al.* (1975) suggest that Irish and Scottish ice may have been in contact during the readvance.

Nature of Scottish ice readvance and retreat

Overall, the variable external morphology of different moraine components suggests a complex morphosedimentary response to Scottish ice readvance. Armoy moraine structures and sediments are consistent with modern moraine analogues in Iceland and Svalbard (i.e. Boulton *et al.* 1999). Overall moraine signature is dependent on topography, sediment type and availability, ice/substrate thermal regime, and ice-front tectonics. These factors appear to have been important in north Antrim where sediment within the Armoy moraine was derived mainly by reworking of proglacial sediment during ice readvance (Shaw and Carter 1980). The location of Scottish ice immediately prior to readvance is unknown, but the sediment thickness (> 60 m; Shaw and Carter 1980) and arcuate nature of the Armoy moraine, and the absence of deglacial sediment north of the moraine, suggest it was a surge-type glacier. The truncated nature of sediments within the moraine (Fig. 22) may suggest that it was overridden, although there is no equivocal evidence for this.

Karst and coastal features of the Late Devensian and Holocene in Larrybane Bay, Co. Antrim

Michael J. Simms

At Larrybane Bay, on the north Antrim coast, vertical cliffs of late Cretaceous Ulster White Limestone rise to a height of some 30m above the beach. Towards the centre of this gently crescentic bay a distinct raised beach platform is visible at about 6m OD (grid ref. 34/055448). A spectacular tufa-draped sea cave is associated with this platform and forms the main feature of interest at this site, though several other sea caves at a similar level towards the western end of the bay are also worthy of some attention. Together the platform, sea caves and associated features record evidence of events and processes on this stretch of coast from the late Devensian through the Holocene.

The tufa-draped cave has been widely known for more than a century and was referred to by Martel (1897) as 'Larrybane Stalactite Cave'. The 'cave' itself is formed by a local overhang, up to 10m high and extending almost 10m into the cliff, and has a fairly angular form defined by joints and bedding planes. Large tufa columns and stalagmite bosses together form a grill which blocks access to the inner part of the cave almost entirely except for two narrow openings. The roof of the 'outer' overhang has many tufa stalactites, the largest of them about a metre in length, while more tufa stalactites hang from the roof of the 'inner cave'; several show a definite slant towards the entrance. A small drip-fed gour pool towards the base of the central tufa column contains numerous cave pearls up to a centimetre in diameter. They are cream to off-white in colour, with a bluish tinge.

Tufa deposition is not confined to the area of the cave and associated overhang but extends for more than 50m to the east. Several fairly large active tufa cascades extend to the base of the cliff from seepage points more than halfway up. A few large tufa stalactites are associated with these cascades. Elsewhere in the bay tufa deposition occurs on only a very minor scale.

The areas of active tufa deposition near the entrance to the cave and elsewhere along the cliff are covered with a soft crust dominated by the bryophyte *Barbula tophacea*, sterile leprous lichens such as *Lepraria*, and occasional liverworts. Where tufa deposition has ceased, this biotic layer has fallen away to reveal the mostly hard and compact tufa beneath; this is sufficiently compact to support the saxicolous lichen *Opegrapha saxicola* agg.

Three other caves are present towards the western end of Larrybane Bay. That furthest to the west is the largest and has two entrances. It was referred to as the 'Fern Cave' by Martel (1897). It too has a generally angular shape but contains only limited development of tufa stalactites and cascades. The next cave to the east contains a flowstone cascade and curtains at the inner end; these clearly are inactive, being encrusted with mosses, liverworts and leprose lichen crusts. The limestone on the upper part of the walls in this cave is pierced by numerous blind, light-orientated photokarren tubes. The third cave, still further east towards the 'Stalactite Cave', has a bell-shaped section. Photokarst is well-developed in the upper part of this passage also.

Interpretation

The location of Larrybane Stalactite Cave, immediately above the 6m bench, is strong evidence that it is an abandoned sea cave associated with the late Devensian '25 Foot Raised Beach'. There is no evidence for enlargement of Larrybane Stalactite Cave by dissolution, hence it cannot be regarded as a true cave in karst terms. This is true also of the other abandoned sea caves described above. The angular form of the cave and associated overhang differs from the more rounded shape typical of other sea caves in the Ulster White Limestone and suggests that ice-plucking, associated with the seasonal break-up and drifting of sea ice, or collapse along major joints and bedding planes, were significant processes in its original development; the presence of groundwater seepage, indicated by the abundant tufa deposits which coat the cliff today, may have been a contributory factor attaching the winter sea ice to this part of the cliff. The great height of Larrybane Fern Cave, to the west, suggests that here collapse has been a major contributory factor. The other two sea caves at the western end of the bay have a more typical rounded section formed by mechanical corrasion.

Larrybane Stalactite Cave represents the finest example of tufa deposition anywhere on the outcrop of the Ulster White Limestone and one of the most spectacular anywhere in Ireland. Water seeping through the Ulster White Limestone along joints and bedding planes becomes saturated with calcium carbonate. Carbonate-saturated water emerging from fractures on the cliff face loses carbon dioxide by degassing, causing precipitation of calcium carbonate. Degassing is enhanced where the water film is thinnest, on sharp edges or projecting plant material. Consequently, the abundance of bryophytes promotes tufa deposition while, in turn, the carbonate-rich water supply encourages the growth of *Barbula tophacea*, a species characteristic of tufa springs. Further evidence for significant biogenic influence on deposition is seen in the slanting orientation of stalagmites and stalactites in the more dimly lit parts of the cave; it arises through enhanced growth of bryophytes, and their subsequent encrustation by tufa, on the side facing towards the light. The bluish tinge of the cave pearls, mentioned above, suggests that cyanophytes (blue-green algae) are involved in their formation.

This site is exceptional in its relatively large volume of tufa and its continuing activity. It suggests that the tufa deposits, if sensitively sampled, could yield an important record of Holocene environmental change in this area. Several recent publications have suggested that tufa deposition is sensitive to climatic and environmental change and that there has been a late Holocene 'tufa decline', with few tufa sites still active (Goudie *et al.* 1994; Griffiths and Pedley 1995). However, more recent work has indicated that much of this apparent decline reflects significant under-recording of active sites, most of which are much smaller than the well-documented fossil sites (Baker and Simms 1998). This would appear to be the case in Ireland where, despite a huge outcrop area of limestone, there are remarkably few documented tufa sites, though recent field observations suggest that small to medium-sized sites or no less common than in England and Wales.

Carbonate deposition is not the only biokarst process which this coastal limestone has experienced through the Holocene. Endolithic algae also are involved in small-scale dissolution of the limestone. This has led to the development of photokarren; centimetre-scale light-orientated limestone pinnacles (Bull and Laverty 1982; Simms 1990). In the old sea caves to the west of the Stalactite Cave these show an unusual morphology, forming a series of light-orientated tubes a centimetre or more in diameter and several centimetres deep. They are unknown from other limestones and may be peculiar to the Ulster White Limestone, a consequence of its high albedo reflecting light and so allowing algae to excavate deeper cavities. Photokarren are fairly delicate structures which form slowly in dimly lit places; as such they provide a potential measure of supralittoral biokarst dissolution rates through the Holocene. Erosion is too severe in active sea caves for such structures to form and hence their presence in the upper part of the sea caves at the western end of Larrybane Bay indicates that these caves formed, initially, in association with higher relative sea level during formation of the '25 Foot' raised beach and that the present isolation of all but the lowest parts of these caves from even high Spring tides has allowed the photokarren to develop.

Portballintrae

Jasper Knight and Marshall McCabe

McCabe *et al.* (1994) examined sediments at Portballintrae. This is a horseshoe-shaped embayment cut into the Lower Basalt Formation which acted as a local sediment depocentre, and protected the sediments against Holocene coastal erosion. The sediments and other glacial elements was argued by McCabe *et al.* (1994) to reflect offshore Irish ice advance and decay under high and changing RSL conditions.

Bedrock is exposed on beach level in the centre of the embayment. The bedrock is cut into small-scale (dm height) roches moutonnées and glacially-faceted surfaces with some south-to-north oriented subglacially-sculpted bedrock forms (s-forms; Kor *et al.* 1991) and striations. Sediments are exposed on the western side of the embayment. The sediment/bedrock contact is not seen clearly. Sediments (< 10m thick) form three main facies which are laterally continuous across the exposure. The lowermost facies (2m thick) is a massive to vaguely-bedded diamict containing dispersed local basalt clasts supported by a dominant sandy-silt matrix (Fig. 23). Contorted sand to slay stringers and lenses are also present within the diamict. The central facies comprises rhythmically-bedded sand and silt which drapes the underlying diamict. Individual sand and silt laminations (few mm to cm-scale thickness) are laterally continuous, undeformed, and show consistent characteristics across the exposure. McCabe *et al.* (1994) identified four sub-facies (sand and silt streaked mud, mud-streaked sand, rippled sand, laminated mud drape) on the basis of internal bounding contacts and facies variability. Streaks and ripples form along a continuum and have a consistent north to south directional component. Laminated mud drapes are present over ripple crests and are associated with hummocky cross-stratified sand lenses. The uppermost facies of the exposure comprises interbedded and discontinuous sand and gravel lenses organised in vaguely stratified layers and cut and fill channels.

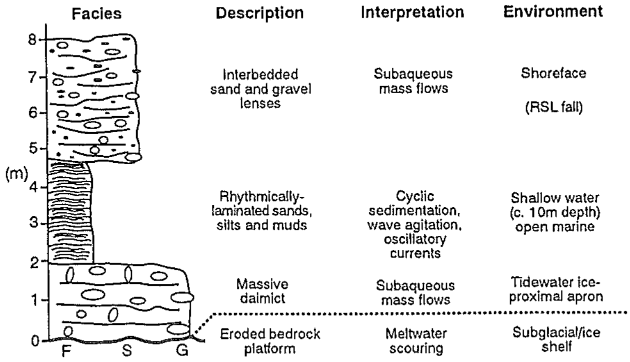


Fig. 23. Sedimentology at Portballintrae (after McCabe *et al.* 1994).

Overall, the facies sequence records changes in open water depth and energy levels associated with changes in the position of the ice margin on the continental shelf, and the possible role of isostatic rebound. A subglacial environment with available free water is indicated by the presence of the striated bedrock platform showing s-forms. The overlying massive diamict reflects reworking and resedimentation events on an ice-proximal tidewater apron dominated by mass flow and debris flow processes, similar to present-day Alaskan tidewater glaciers. The overlying rhythmically-bedded sand, silt and mud laminations reflect deposition in an open-water marine setting. On the basis of ripple dimensions and spacing McCabe *et al.* (1994) estimate palaeo-water depth to be c. 10m. The repeated nature of the stratigraphy suggests sediments responded to storm events, oscillatory bottom currents (as evidenced by the hummocky cross-stratification) and sediment agitation below the wave-base. Absence of dropstones and other indicators suggests that the ice margin is likely to have retreated inland from a tidewater setting at the coast, possibly due to RSL rise. The uppermost interbedded and poorly-sorted sand and gravel facies reflects shallow water sedimentation in a higher-energy environment, possibly on a shoreface/ beachface affected by intermittent erosive events. McCabe *et al.* (1994) attribute the fall in RSL associated with this uppermost facies with glacioisostatic rebound of the coastal zone, and landward migration of the glacial forebulge.

Grangemore sand dunes

Peter Wilson and John McGourty

The sand dune system at Grangemore is located on the south side of the estuary of the River Bann and west of the Articlave River and covers an area of *c.* 0.4 km^2 (Fig. 24). Although separated from the dunes at Portstewart and Castlerock by these rivers Grangemore is part of the same single physiographic unit - i.e. beaches, dunes and estuary - that has evolved during the last 6000 ^{14}C years. In contrast to the Portstewart and Castlerock dunes, the Grangemore system has a relatively subdued appearance and more mature vegetation that may be due to its position within the estuary, which has effectively isolated it from modern beach sediment sources, and/or an extended usage for sheep and cattle grazing. Unlike the neighbouring dunes there is no calcium carbonate (shell fragments) within the Grangemore sands. This probably reflects a long history of stability and leaching associated with pedogenesis, rather than an initial absence of carbonate.

History of investigation

Scientific interest in the Grangemore dunes developed during the mid-to-late 19th century. Portlock (1843) found estuarine clays beneath the dunes and this was subsequently confirmed by Praeger (1893) who reported a bluish clay, containing foraminifera, interbedded with sands in the banks of the Articlave River. The clay was noted as being slightly above the high water mark. In the banks of a small stream about 1.3km west of the Articlave River, Praeger described a sequence of alternating sands and clays. The clays were regarded as estuarine because of their contained fossil fauna. The surface of the uppermost clay unit was 3ft (0.9m) above the high water mark and was buried by blown sands.

From about 1870 Grangemore became one of several north coast dune systems to be visited regularly by antiquarian collectors who found numerous examples of worked flint, hearth stones, bones, shells and pottery (Gray 1879; Knowles 1887, 1889, 1891, 1901; Hassé 1890). Finds continued to be reported during the present century (Hewson 1934; May and Batty 1948) and embrace cultures spanning the Neolithic to Medieval periods.

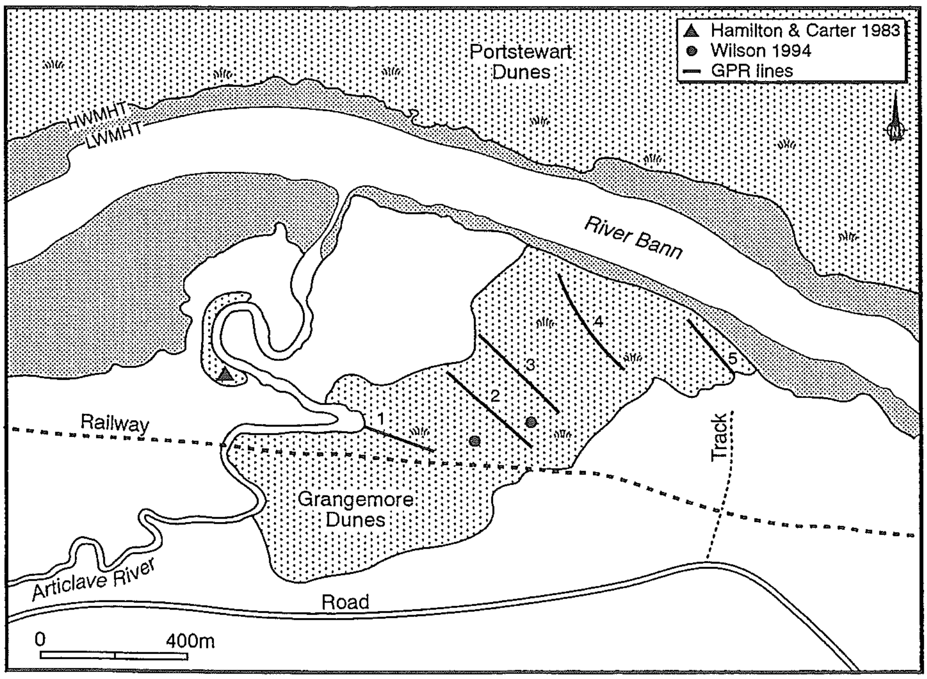


Fig. 24. The Grangemore dune system showing locations of exposures described by Hamilton and Carter (1983) and Wilson (1994), and traverse lines for ground penetrating radar investigation.

Stratigraphic investigations of two exposures along with ^{14}C dates have provided evidence pertinent to evolution of the dunes and current studies using ground penetrating radar are demonstrating an additional dimension to knowledge of the system.

Hamilton and Carter (1983) described a silt/organic-rich interdune deposit, up to 0.5m thick, exposed in a meander of the Articlave River (Fig. 24). The top of the silt/organic bed undulated between -0.1 and +0.1m OD. The dune sands both above and below this bed consisted of poorly-bedded quartz sands with low angle concave cross-beds. Ripple drift structures were not apparent. Within the overlying sands, two distinct soil horizons with immature podzolic development were noted. The silt/organic-rich bed contained pockets rich in leaves, fruits and mosses and a sample of these macro-fossils yielded a ^{14}C date of 5315 ± 135 years BP. Pollen was rather uncommon but the spectrum obtained indicated a generally forested environment whose characteristics were compatible with the age estimate obtained. The macrofossils suggested derivation from a single community and, along with their excellent state of preservation, indicated a local source, probably from vegetation growing in or on the margins of a dune slack.

Buried podzolic soils were described at two locations within the Grangemore dunes by Wilson (1994). These soils meet the morphological (i.e. horizon sequences and colours) and chemical criteria for classification as humoferric podzols. A ^{14}C date of 2580 ± 60 years BP was obtained on organic matter taken from the bAh horizon of one profile. The soils are developed in very well sorted fine sand.

Interpretation

Estuarine clays similar to the sub-dune clays recognised at Grangemore by Portlock (1843) and Praeger (1893) have since been identified at several other sites within the estuary of the River Bann (Jessen 1949; Battarbee *et al.* 1985). On the basis of their top surface elevations these clays are considered to relate to the Holocene marine transgression that culminated *c.* 6000 ^{14}C years BP. Although the clays have not been investigated in detail, Jessen (1949) recorded that they were underlain by early Holocene peat at two sites (Farranlester and Somerset) further up river, while Battarbee *et al.* (1985) obtained a ^{14}C date of 6120 ± 70 years BP from close to the top of the clay sequence at Sandelford. This date for the timing of the maximum relative height of the transgression agrees well with a date of 5920 ± 80 years BP from peat at Portrush that was buried by beach sand. The recorded elevations of the clays (0 - +1.3m OD) indicate that the Holocene transgression rose above present OD. The estuarine clays thus record sea-level rise and flooding of the Bann estuary during the early and mid-Holocene.

The interdune silt/organic-rich bed reported by Hamilton and Carter (1983) was interpreted to result from flooding of a dune slack by the ancient Articlave River. The aeolian sands below the dated horizon are the earliest Holocene dunes so far identified in Ireland. Furthermore they indicate that sea level must have fallen below 0 m OD. before *c.* 5300 ^{14}C years BP to facilitate dune formation at this site. Carter (1982) used this information in construction of a Holocene sea-level curve for the north coast of Northern Ireland. Together, the estuarine clays that underlie the dunes and the interdune silt/organic-rich bed constrain the maximum relative height of the Holocene transgression in the Bann estuary to the period 6000-5500 ^{14}C years BP and demonstrate it was a short-lived event.

The buried podzolic soils at Grangemore described by Wilson (1994) indicate a period of land-surface stability (vegetation colonisation and pedogenesis) during dune sand accumulation. This period, dated at around *c.* 2600 ^{14}C years BP, probably correlates with one of the phases of stability, marked by buried soils, in the sands exposed in the banks of the Articlave River (Hamilton and Carter 1983). The ^{14}C date is in broad agreement with the archaeological evidence from the sand dunes at Portstewart for a land-surface stability phase during the Bronze Age. Thus, the available evidence for dune development phases on both sides of the Bann estuary appears to indicate synchronous periods of stability.

The presence of buried podzolic soils at Grangemore is indicative of freely-drained conditions and favourable circumstances for the mobilisation and translocation of iron and organic matter at the time of their formation. This suggests that the soils progressed through a series of development stages similar to those outlined by Wilson (1992b) for soils in freely-drained sites on aeolian sand.

Ground Penetrating Radar

Ground penetrating radar (GPR) is a device that transmits electromagnetic (EM) short-pulse high-frequency (range 1-1500 MHz) energy into the ground. The reflections from subsurface features are due to dielectric properties within different materials (Davis and Annan 1989; Jol 1995). GPR has been used for non-destructive underground exploration for two decades. Applications in the frequency range 1-200 MHz have been used to image geological structures, for civil engineering site surveys (McCann *et al.* 1988), and for mining. Intermediate range frequencies (200-500 MHz) have been used to detect movement of hazardous waste in soils (Harari 1996), to aid archaeological surveying, and to image sedimentary structures (Collins and Doolittle 1987; Davis and Annan 1989). The 500-1500 MHz frequency range is used in the detection of faults in construction, for example, roads, railways and bridges (Beres and Haeni 1991; Gawthorpe *et al.* 1993; Casper and Kung 1996; Annan 1997).

Knowledge of the internal structure of the dunes along the north coast of Northern Ireland is limited. This is due to the physical problems in excavation of unconsolidated sediment, and the possible disturbance to the ecosystem (Brookfield 1977; Schenk *et al.* 1993). GPR radar profiles produce an image of sand dune internal structure and possibly highlight potential areas for ^{14}C and luminescence dating. GPR surveys were carried out in four dune systems,

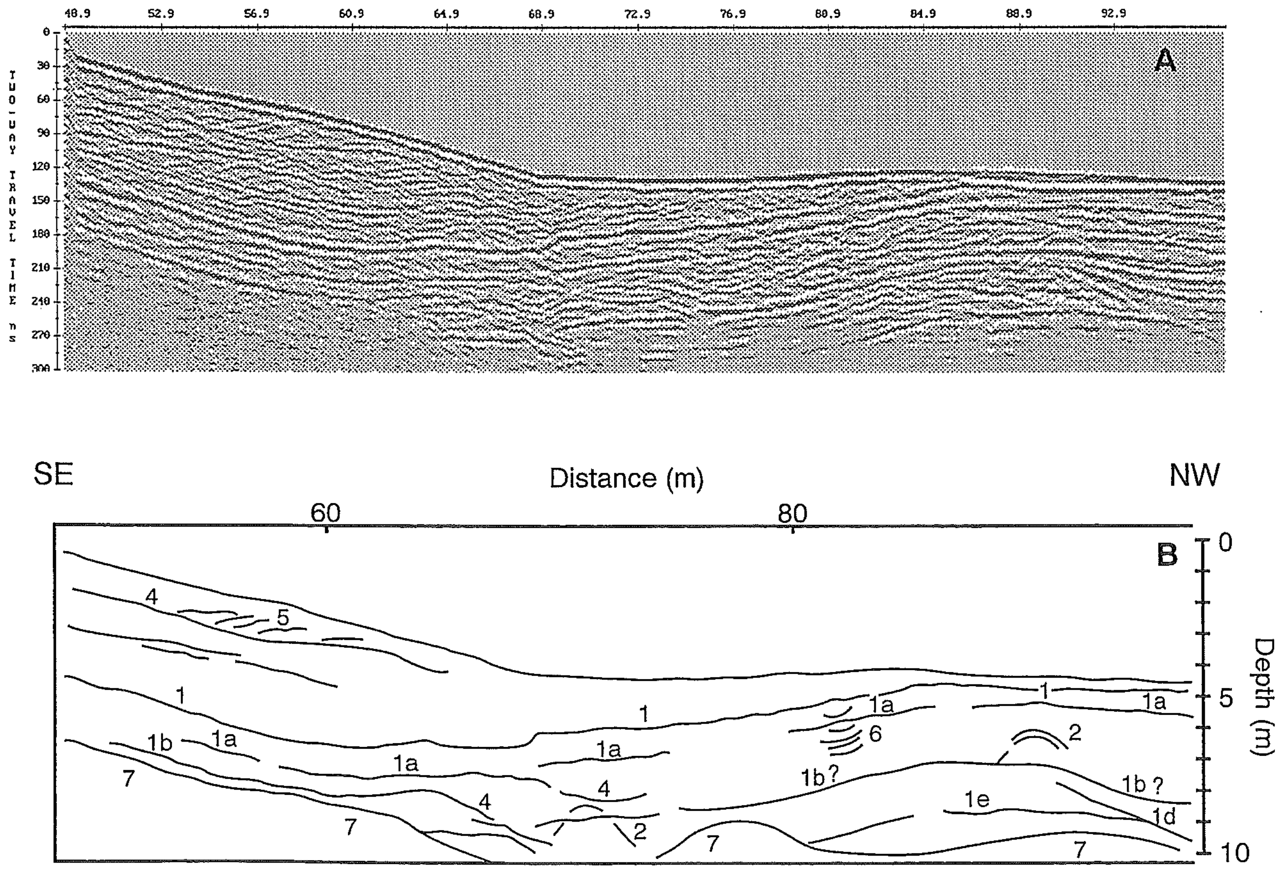


Fig. 25. (a) Topographically-corrected GPR image of transect 5a. (b) Interpretation of GPR image 5a. 1: a, b, c, d, e strong reflector (possibly due to moisture content or buried soil horizon); 2: hyperbola – subsurface target; 3: dune spurs; 4: erosional face; 5: depositional surface; 6: slumped material; 7: water table.

including Grangemore, along the north coast during May 1999.

At Grangemore five transects ranging between 200-300m in length were selected for GPR survey; ease of GPR operation and dune topography of the dune prior to profile survey were considered in transect selection. Transect topography was surveyed initially using a Differential Global Positioning System. The GPR system used was a Pulse EKKO‘ IV with 200 MHz antennae spaced at 0.5m, with a spatial sampling interval of 0.1m, using the perpendicular broadside reflection survey mode as described by Jol (1995) and Annan (1997). The near surface wave-velocity used in the determination of reflector depth was calculated using common-midpoint (CMP) sounding (see Jol 1995; Annan 1997). The value determined was 0.07m ns^{-1}, giving a reflector definition width of 0.1-0.15m; any value less than this will not produce an image (Jol 1995). Antenna frequency and velocity give a potential depth penetration of 18m (Smith and Jol 1995; Grant *et al.* 1998) but actual penetration was 7-9m; attenuation of signal occurred below these depths.

Each GPR transect was split into segments *c.* 50m in length, the purpose of which was to isolate any problems encountered during operation. The transect discussed below is located at the eastern end of the dune system and runs southeast to northwest towards the River Bann (line 5 on Fig. 24). The transect was 200m in length and was surveyed in four sections; two of these will be described briefly and interpretation is provisional.

Transect 5A (Figs. 25a, b) began at the corner of a farmhouse boundary wall. The start of the survey image (0.3m) shows no distinct reflectors near the surface until a distance of 12m from the start. From thereon a near-surface reflector (marked 1 on Fig. 25b) is present throughout the radar image and

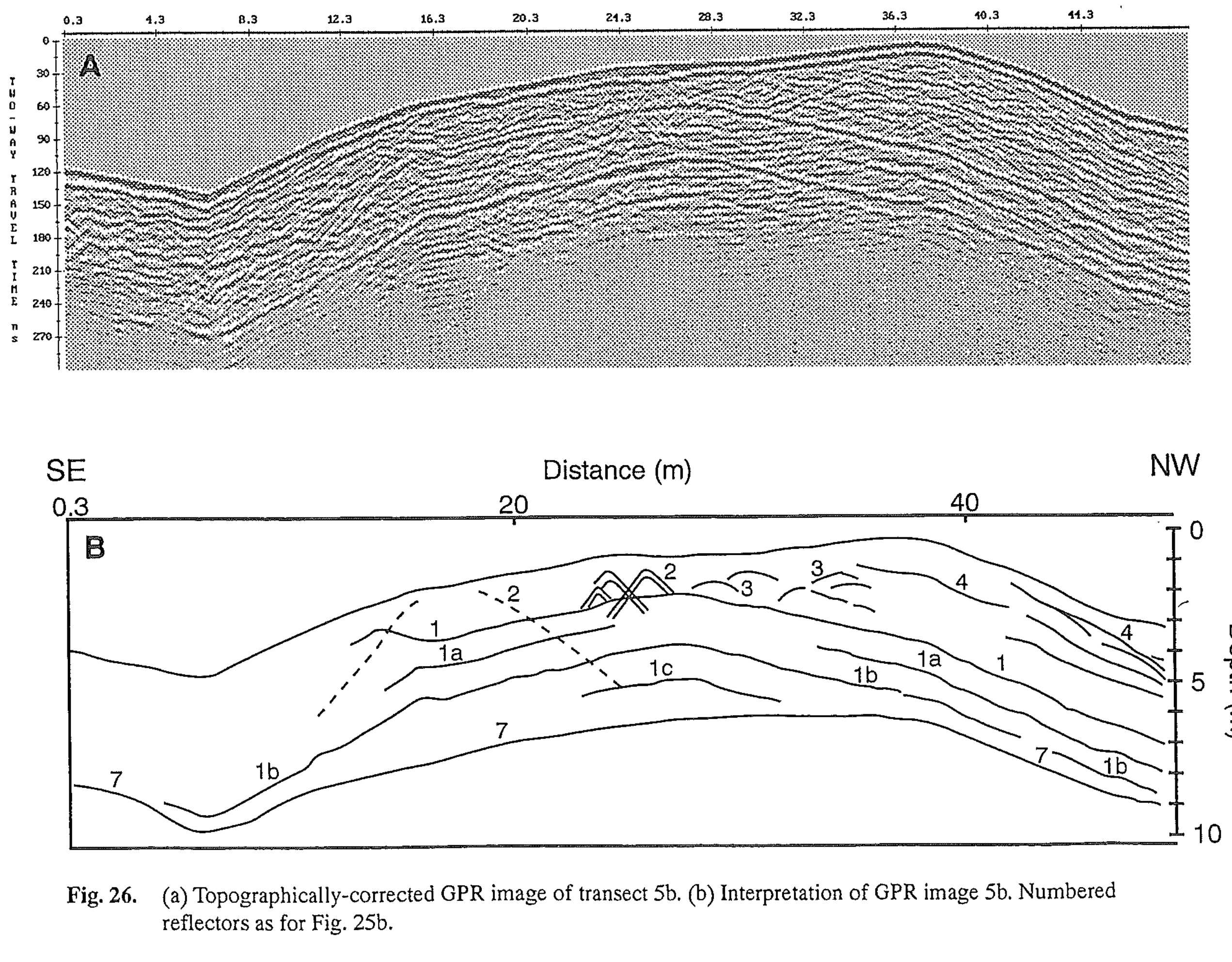


Fig. 26. (a) Topographically-corrected GPR image of transect 5b. (b) Interpretation of GPR image 5b. Numbered reflectors as for Fig. 25b.

through each of the other three segments. The beginning of this reflector is cut by an acutely dipping reflector; it is difficult to ascertain whether this is an hyperbola of a subsurface object as there is a faint trace of a corresponding tail, but if so, it is a large target (Beres and Haeni 1991). There is a strong reflection near the surface at 24m due to subsurface targets; the image shows the characteristic hyperbola (2). Other prominent reflectors occur below 1, but 1a, 1b, and 1c display characteristics similar to 1. The probable cause of these reflectors is moisture retention within the sands and they may indicate periods of stability during dune development and associated organic matter incorporation into the sands (Harari 1996). Near the surface at 32-36m there are a series of convex reflectors considered as dune spurs (3) (Bristow *et al.* 1996). On the dune slope at 40m there are a series of small erosional faces (4) and subsequent deposition (5) (Fig. 25b). The high attenuation of the radar signal below the reflectors is considered to be that of groundwater (7) (Harari 1996), as it follows a close approximation of the dune surface (Shaw 1988; Newson 1994). Others have ascertained groundwater as a rectilinear reflector irrespective of dune topography (Annan 1997; Van Overmeeren 1998).

In transect 5B (Figs. 26a, b) the erosional face seen in 5A (Fig. 25a) is continued along with reflectors 1, 1a and 1b. Reflectors 1 and 1b follow a similar form, that is they dip and rise then almost merge 1m below the surface at around 85m. Reflector 1a is cut by an erosional face (4) at 60-65m, the reflection from this face (4) is possibly a continuation of 1a, representing a discontinuous surface, that is, deposition, erosion and renewed deposition (Brookfield 1977). Between 80-97m there are prominent moisture laden radar reflectors: 1d and 1e. Also in the image there is a small area with a series of concave reflectors (6) associated with slumped material (Annan 1997). In the middle of the transect, above the water table (7), the radar image displays a complex series of reflectors that could be associated with an erosional face (4) of 1b, slumping (6) or the hyperbola (2) below.

The GPR survey of transect 5 at Grangemore has highlighted specific areas for further investigation in particular the presence of reflector 1 in all the segments. Further fieldwork and processing (boreholes, data interpretation) will enable a better understanding of the influence that moisture, organic matter, grain-size and mineralogy have on reflections in radar images. The purpose of using GPR was to map subsurface structure, locate buried soil horizons, determine the development and structure of the dunes, and assess potential areas of sampling for dating purposes.

High-resolution geophysical investigations of the inner continental shelf, North Coast of Ireland

Andrew Cooper and Rory Quinn

Introduction

The Natural Heritage Directorate in Northern Ireland is responsible for the conservation, maintenance and management of the marine reserves and areas of special scientific interest. To assist in this task, the Coastal Research Group (UUC) in conjunction with Environment and Heritage Service (Department of Environment for Northern Ireland) is conducting a marine geophysical survey of the inshore coastal waters of Northern Ireland. This research programme aims to map the coastal geomorphology and maritime archaeology of the inshore coastal waters utilising a suite of state-of-the-art marine geophysical equipment. The investigation of the inner continental shelf off the north coast (described here and the accompanying paper by Lawlor and Cooper) represents one component of this research programme.

Regional Overview

The coastline between Lough Foyle in the east and Ballycastle Bay to the west varies in character between beach-dune systems and near-vertical bedrock cliffs. At Magilligan Point, on the northeast corner of Lough Foyle, the coastline is characterised by Holocene blown sands which form large areas of the dune system (Fig. 27). Between Magilligan and Ballycastle, the coastal area is characterised by Tertiary basalt and underlying Cretaceous limestone with occasional thick dolerite intrusions such as the sill that forms Portrush and the Skerries. Further to the east, in the area between Portrush and Ballycastle Bay, the Lower Basalts are succeeded by tholeiitic lava flows, most spectacularly developed at the Giant's Causeway (Atkins 1997).

The bathymetry of the north coast exhibits a low gradient offshore slope between Lough Foyle and Portrush (Fig. 27). East of Portrush, the bathymetric gradient is steeper with a series of basalt and chalk outcrops and topographic variations in unconsolidated sediment. Offshore, the substrate comprises sand and gravel deposits of Holocene age. The north coast sand deposit extends eastward from the Magilligan Foreland on the northeast shore of Lough Foyle along the Antrim coast (Atkins 1997).

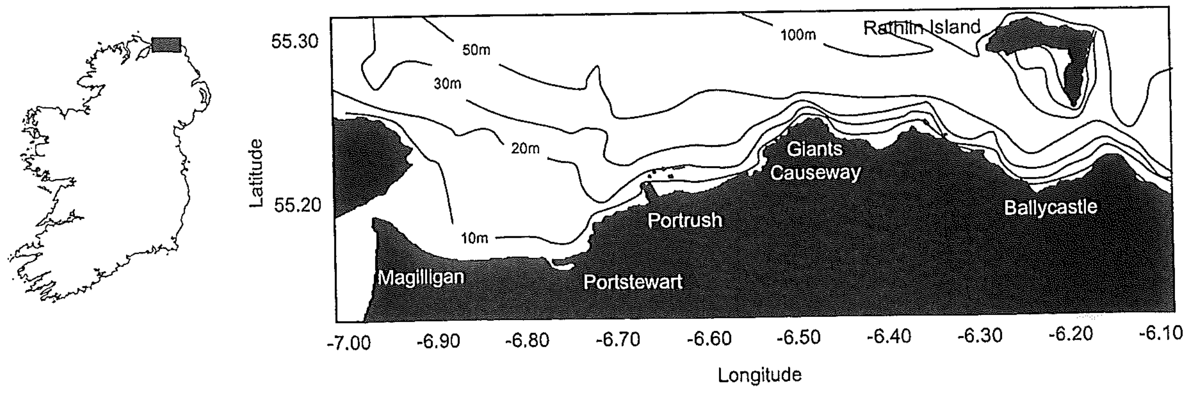


Fig. 27. Location and bathymetry of the north Antrim/Londonderry coast.

Methodology

The marine geophysical instruments most widely applied to coastal research are side-scan sonars and sub-bottom profilers (Fig. 28). Both sub-bottom profilers and side-scan sonars are acoustic devices which use high-frequency (1-500 kHz) sources to produce images of the seabed (side-scan sonar) and sub-surface (sub-bottom profiler). Side-scan sonar is considered a non-penetrative technique as the acoustic source images the seabed but does not image the sub-surface (Fig. 28). Conversely, sub-bottom profilers penetrate the seabed and image the sub-surface stratigraphy. Both systems comprise three main components:

- Top-side processing and display systems which are conventionally housed in the wheel-house of the survey vessel
- Sub-sea hydrodynamically stable towfish
- Data cable which links the topside electronics with the sub-sea towfish.

Side-scan sonar: Theory of operation (Fig. 28b)

The acoustic pulse from the side-scan sonar is transmitted from and received by a single streamlined towfish (Fig. 28a). The towfish has both port and starboard transceivers that generate pulses with large vertical beam angles (*c.* 150°) and narrow horizontal beam angles (*c.* 0.5°). The vertical beam is angled from the horizontal so that the majority of source energy is directed towards the seafloor. The reflected energy is received by the transducers and processed onboard in real-time. This configuration produces images of the seafloor by either digitally recording and/or transmitting directly to a thermal printer. The area of the seabed imaged by the side-scan system is primarily dependent upon water depth and operator preference. For optimum resolution, the towfish is flown at a height of approximately 10-20% of the scanning range above the seabed. Side-scan sonar data are in effect a tonal map of the seafloor. In general, coarse grained sediments (gravel and sand) and bedrock appear as dark areas on the sonagraph and finer grained sediment (muds and clays) appear as light patches.

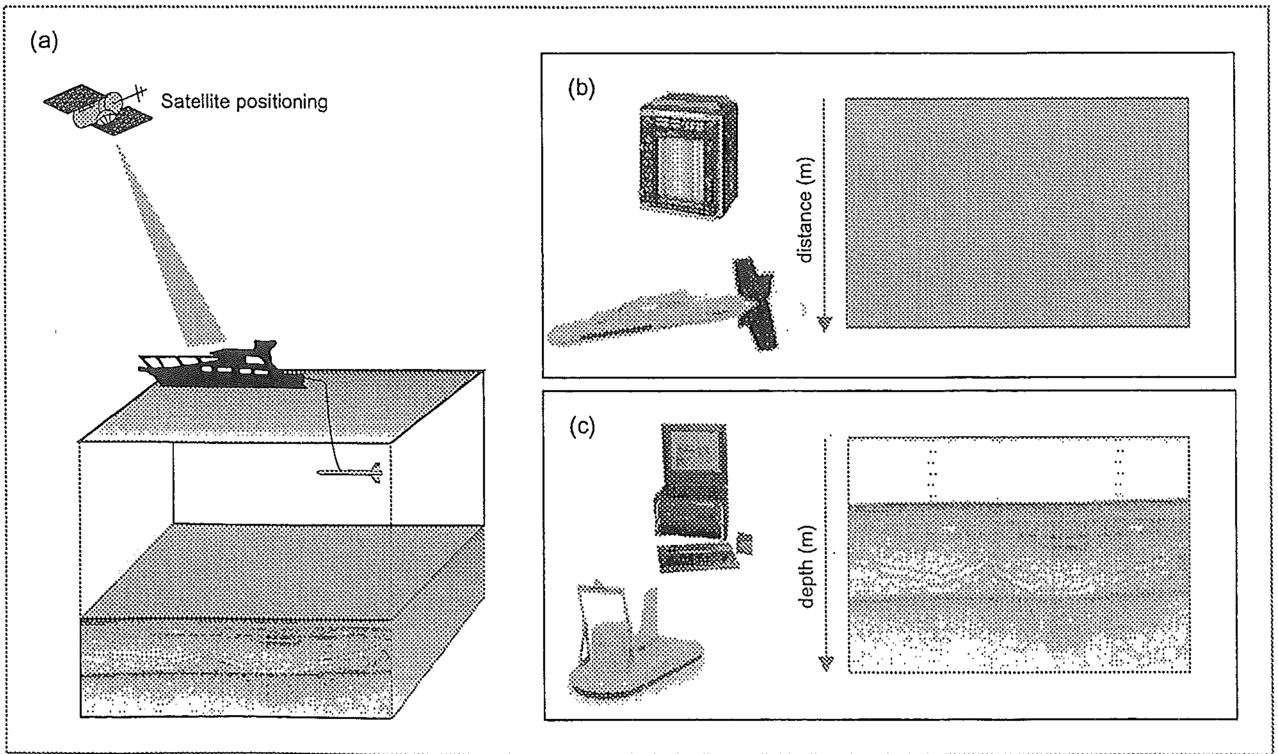


Fig. 28. Illustration of data collection instruments.

Sub-bottom profiler: Theory of operation (Fig. 28c)

Sub-bottom profilers utilise lower frequency acoustic sources than side-scan sonars, which penetrate the seabed and reflect off stratigraphic horizons within the sediment pile. Sub-bottom profilers operate on the principles of seismic reflection, which characterises materials by density (q) and velocity (V_p). The product qV_p is known as the acoustic impedance. If a contrast exists in the acoustic impedance across a boundary, then a reflection occurs and a boundary between sediment types is imaged. Sub-bottom profilers generate a data set that can be processed to give a cross-section in the direction of movement of the survey vessel. The most effective type of sub-bottom profiler for high-resolution surveying is the Chirp profiler, which utilises a swept-frequency source to limit the trade-off between penetration and resolution. Chirp systems, with typical bandwidths of 10-15 kHz offer a vertical resolution of the order 0.2m.

Between August 1995 and August 1999, an area in excess of 300 km^2 off the north coast of Ireland was surveyed in a reconnaissance investigation of the inner shelf stratigraphy (Fig. 29). The remainder of this paper outlines the preliminary results of the Chirp sub-bottom profiler investigation off the north coast (Cooper *et al.* 1998), whilst the accompanying paper (Lawlor and Cooper, this guide) details the results of the side-scan sonar survey.

Case Study: Seismo-stratigraphic investigation of the inner continental shelf, North Coast of Ireland

Introduction

Ireland was ice-covered during the last glaciation and is therefore ideally situated to test hypotheses regarding mechanisms and rates of Holocene sea-level rise and the associated shoreline response. The British Isles have tilted in response to isostatic adjustments, and a variety of models suggest the Holocene lowstand varied in elevation around the islands (Carter 1982, 1992; Lambeck 1991). Wingfield (1995), however, indicated that the evidence for Holocene lowstand levels in the work of Carter (1982, 1992) and Lambeck (1991) were based primarily on onshore sections and offshore evidence was limited.

Although sea level curves have been compiled for the northeast coast of Ireland (Carter 1982), reliable index points constraining these curves are sparse. The general pattern describes a late glacial transgression as ice retreated and land levels were isostatically depressed. Highstand levels reaching +100m are described by McCabe and Eyles (1988) during which an extensive deposit of glaciomarine clays was deposited (McCabe 1997). Subsequent rapid uplift led

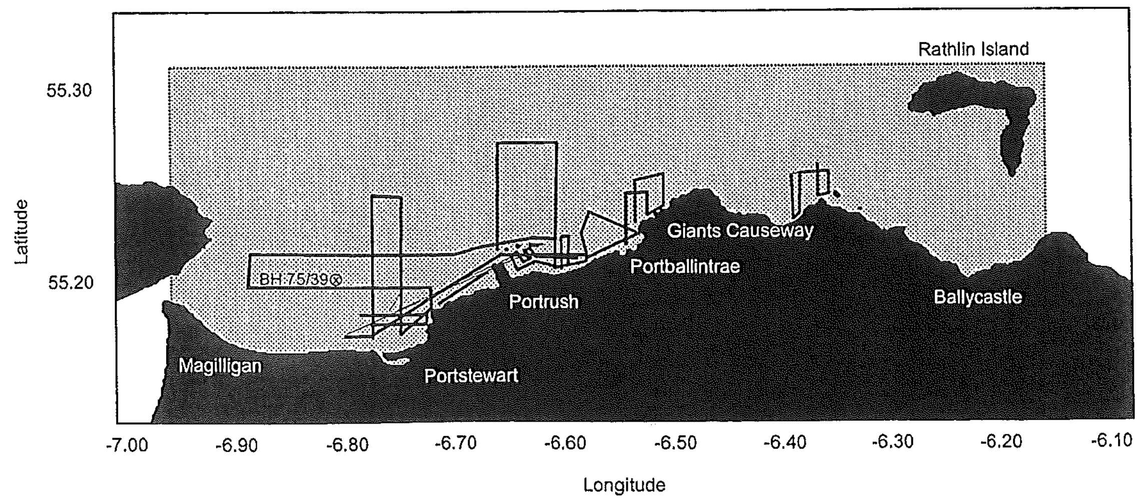


Fig. 29. Location of seismo-stratigraphic lines, north coast.

to marine regression into the early Holocene, constrained by evidence showing a fall below present at *c.* 12,000BP to an undetermined lowstand depth. Sea level subsequently rose as eustatic trends exceeded uplift and this led to a higher than present level between 6,500 and 5,500BP (Wilson and McKenna 1996) before falling by a few metres and rising to the present level. The depth of the lowstand at *c.* 12,000BP is unknown, but vital in the reconstruction of uplift rates, shoreline evolution and in the post-glacial immigration of flora and fauna to Ireland. In this paper, a preliminary account of the inner shelf stratigraphy is presented, which includes information related to the depth of the Holocene sea-level lowstand.

North coast survey methodology

The north coast Chirp survey utilised an EdgeTech Chirp 2-16kHz sub-bottom profiling system pulsing at 8 pulses per second, whilst the side-scan surveys utilised an EdgeTech Model 272-TD acquisition system operating at 100 and 500 kHz. GPS positioning data was logged digitally from a Trimble GeoExplorer II.

Results

Interpretation of the shore-normal Chirp profiles reveals a consistent stratigraphic sequence comprising three basic units (Fig. 30). The basement reflector is overlain with a locally observed unit (Unit 1) in which sub-parallel landward dipping reflectors are occasionally present. Unit 1 is succeeded by the more ubiquitous Unit 2, which is typically 2-6m thick and drapes the basement and Unit 1, where present. Unit 2 has a planar upper surface and locally contains internal horizontal reflectors. Unit 3 is developed adjacent to the modern coastline and extends seawards to depths not exceeding 30m. This unit varies in thickness between 0 and 8m and contains internal seaward dipping parallel reflectors and channel fills. Unit 3 tapers seaward and terminates at water depths between 28 and 30m. In the western section of the study area notches, occasionally mantled by contemporary shelf bedforms, are observed in the Chirp profiles at 30m depth.

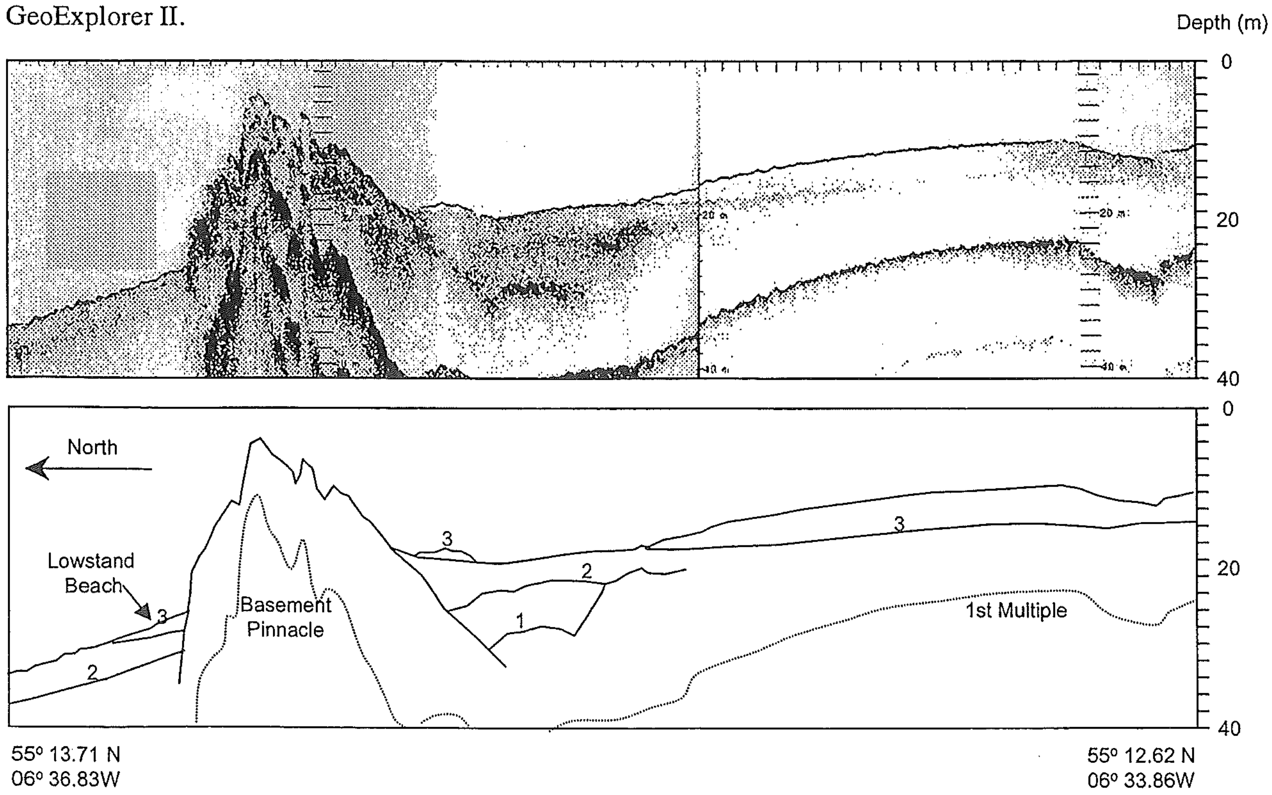


Fig. 30. Example seismic profile and stratigraphy interpretation.

Discussion

Although the results and interpretation presented in this manuscript are preliminary, the uniform stratigraphy in the study area and the consistent tapering of Unit 3 at 30m is noteworthy (Fig. 30). Data from two boreholes within the study area aid interpretation of the offshore seismic data: British Geological Survey borehole 75/39 (BH 75/39) records 13m of Holocene sand overlying 20m of late glacial clay (Bazley *et al.* 1997) and a borehole at Magilligan Point records the transition from marine to estuarine and back to marine at depths of -32m and -27m respectively (Carter 1982). Additionally, the onshore outcrop of late glacial shelf sediments at Portballintrae described by McCabe *et al.* (1994) indicates the glacial diamict at the site is draped by wave-worked shallow shelf sands and muds with subsequent planing of this surface during marine regression.

The basement reflector interpreted in the Chirp profiles is interpreted as bedrock. Evidence from side-scan data and onshore exposures indicates this bedrock is predominantly basalt with dolerite intrusions. Unit 1 is interpreted as the glacial diamict described by McCabe *et al.* (1994) at Portballintrae where the modern coastline is interpreted as a contemporary notch cut into an otherwise complete onshore-offshore sequence. Landward dipping reflectors within this Unit are interpreted as either primary bedding indicating southward movement of ice or as post-depositional tectonic deformation structures produced by ice push.

Unit 2 is interpreted as equivalent to the shallow glaciomarine deposits described from Portballintrae (McCabe *et al.* 1994) and linked to pelagic deposition modified by wave reworking in a shallow shelf environment during late glacial times. Unit 3 is interpreted as the subsequent regressive sequence deposited as sea level withdrew from a late-glacial highstand. During deglaciation it is likely the ice-free coastal hinterland was lightly vegetated and isostatic uplift resulted in rejuvenated rivers flowing across a sediment-rich land surface. Unit 3 is therefore envisaged as representing extensive fluvio-deltaic sediments discharged to the coast during a rapid fall in sea level to the proposed lowstand depth of -30m.

Internal reflectors within this unit suggest seaward sediment aggradation, while the occurrence of internal channel-shaped reflectors is indicative of fluvial channel fill of a lowstand wedge. Where a planar terrace fronts the Unit, it is interpreted as an intertidal platform. Precise dating of this lowstand is not yet possible, but evidence indicates it occurred between 12,000 and 7000BP (Carter 1982; Wilson and McKenna 1996). The consistent depth limit of this lowstand wedge at -30m represents the contemporary coastline (Fig. 31a), whilst the variable shore-normal extent of the shoreface covered by Unit 3 (between 1 and 7 km long - see Fig. 31a) may provide an indication of sediment sources during regression, with supply at a maximum in the west and minimum in the east.

The absence of evidence, while not yet conclusive, for a lowstand at a depth greater than -30m has obvious implications for the theory which suggests that the post-glacial immigration of humans and other mammals into Ireland was via a land bridge between Scotland and Ireland. Reconstruction of the coastline based upon a -30m lowstand clearly precludes a landbridge between Ireland and Scotland (Fig. 31a); it is not until the coastline is reconstructed based on an unrecognised -50m lowstand that a landbridge is possible (Fig. 31b). Instead, at a lowstand of -30m, a series of islands dominate the North Channel that separates the two countries. These islands may have provided sufficient stopping points to make island-hopping an alternative immigration mechanism for animals. It is most likely, however, that humans immigrated into Ireland by boat from Scotland. The presence of the earliest human remains in Ireland at Mountsandel on the River Bann is intriguing in this context.

Acknowledgements

This research is funded by Environment and Heritage Service, Department of Environment for Northern Ireland, and NATO.

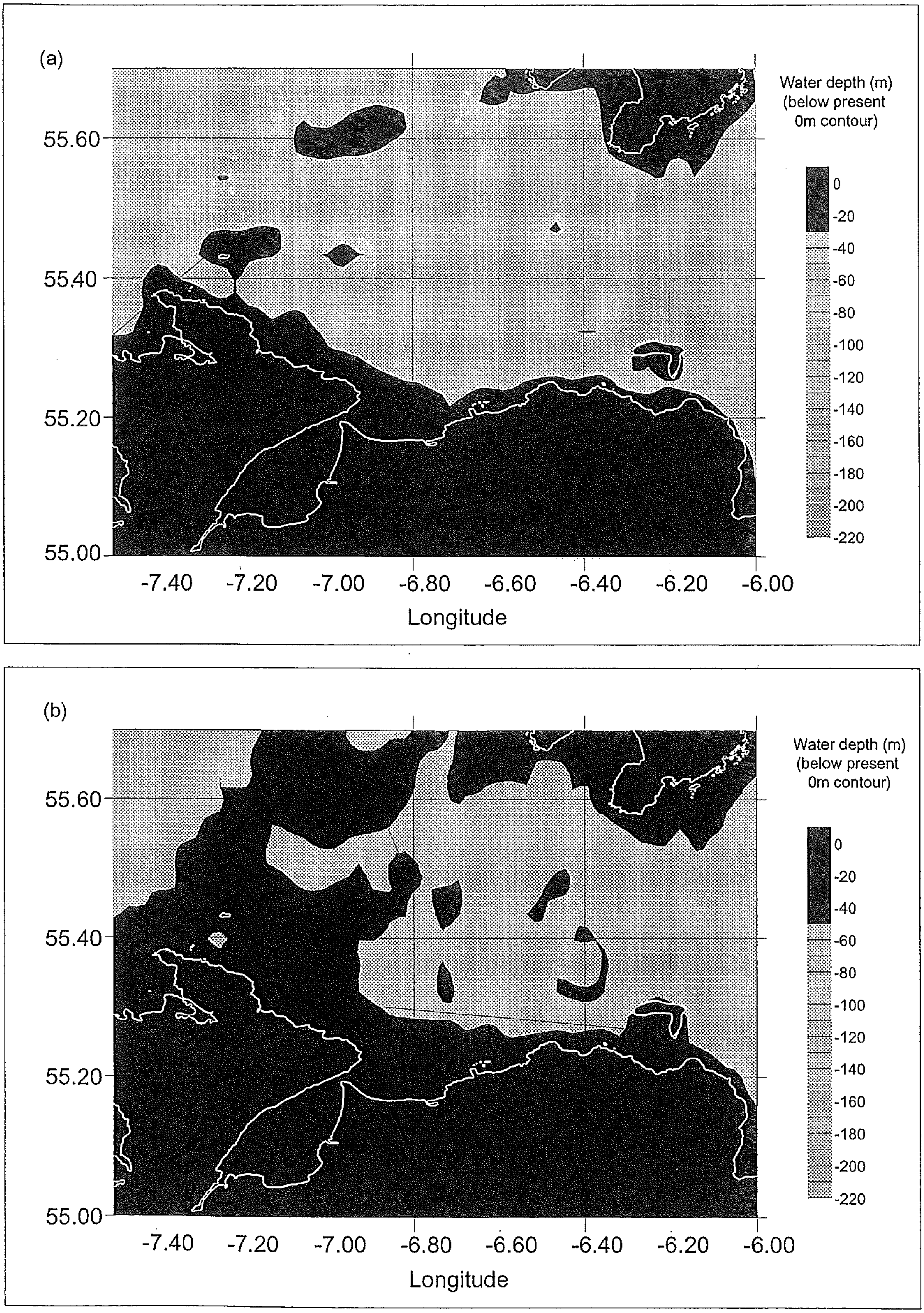


Fig. 31. Possible landbridges between Ireland and Scotland using (a) –30m and (b) –50m isobaths.

Analysis of sea floor sedimentary facies from side-scan sonar data off the north coast of Northern Ireland

Declan Lawlor and Andrew Cooper

Introduction

The north coast and inner shelf of Northern Ireland is exposed to energy inputs from high energy Atlantic swell waves and tidal currents which accelerate as the tidal wave propagates through the North Channel. Shelf and coastal sediment is derived largely from reworking of relict glacial deposits of Irish and Scottish origin. Contemporary terrigenous sediment supply is believed to be minimal. Recent investigations of the north coast inner shelf seafloor environment using side-scan sonar data reveal the existence of several distinct sea floor facies, defined on the basis of sediment texture and bedform morphology. These facies may be tentatively linked to the prevailing energy regimes.

Geomorphological and sedimentological investigations of the seafloor are a largely neglected element of scientific research in Ireland. Such studies, however, have the potential to elucidate the link between beach and nearshore sedimentation, the nature of shelf sediment dispersal, and understanding Quaternary history.

Bedform classification

Bedforms may be classified in terms of their scale, morphology, orientation and relationship to present-day processes (Pantin 1991). Komar (1976) refers to bedforms as irregularities in the particulate substrate of a fluid flow, and suggests that bedforms more often occur in associations, hierarchies, and in hierarchical associations. Other definitions of bedforms include the identification of regularly spaced mounds and hollows of sediment, which form on the seabed under different flow conditions (Open University 1978). However, the suggestion by Pantin (1991) to classify bedforms by their relationship to present-day processes appears to be an important aspect of bedform classification for many authors. Nielsen (1994) indicates that if current flow is too weak the present bedform topography will be largely dominated by relict bedforms from previous, more vigorous events and, in the absence of such events, then bottom sediments will be dominated by bioturbation.

There is some disagreement as to whether unidirectional currents or wave orbital motions are most important to sediment transport on the worlds' continental shelves. Evidence suggests that wave action can cause bottom sediment stirring to depths of > 125m on high-energy coasts (Carter 1988). At shallower depths, sediment transport becomes much more complex, in that one must consider the combined effects of wave action along with superimposed unidirectional currents (Reinick and Singh 1973).

Modes of bedform behaviour

Whether bedforms are developed by wave action alone, by unidirectional flow, or by a combination of the two, most bedforms will fall into two main categories. (1) Those that are orientated across the flow direction (transverse bedforms) such as sand waves and megaripples. (2) Those that are orientated parallel to the mean flow direction (longitudinal bedforms) such as sand ribbons and streaks. Swift and Ludwick (1976) attribute these two basic patterns to two basic types of flow field; (i) a transverse pattern in which zones of scour and aggradation alternate down the flow path; and (ii) a longitudinal pattern in which zones of scour and deposition alternate across the flow path.

The facies approach

To identify and describe the morphology of the north coast inner shelf, a facies approach was adopted. This approach is essentially a descriptive one based on observational, descriptive and interpretative techniques, which aim to reflect the combined depositional processes and depositional environment(s) that characterise the north coast inner continental shelf. In the following section, distinctive surface facies types are identified and described, and their spatial distributions mapped on the basis of sediment type, sediment structure, sea floor topography and water depth.

Surface facies types

A series of ten surface facies types was identified from the set of north coast side-scan sonar records or sonographs. A summary facies description table is shown in Table 1, which compares different facies characteristics. Examples of different bedform facies are shown in Fig. 32.

Facies 1 – large sand waves

This facies type consists of large asymmetric sand waves with amplitudes of 8m and wavelengths of approximately 150m. The sand waves are found in the sea depth range 70-100m, with net movement apparently orientated from west to east with an 80° bearing. Sand wave crests are sinuous to straight, creating a two-dimensional bedform with crests up to 600m long. A second-order of symmetrical ripples with crest orientations running 30°- 210° from north, is superimposed on the larger scale features. These are identified as wave ripples.

A third-order of asymmetric current ripples appears to parallel the first features. These ripples have wavelengths of approximately 25m and are orientated toward the east at around 80°. They appear to be climbing onto the larger features and are probably current ripples.

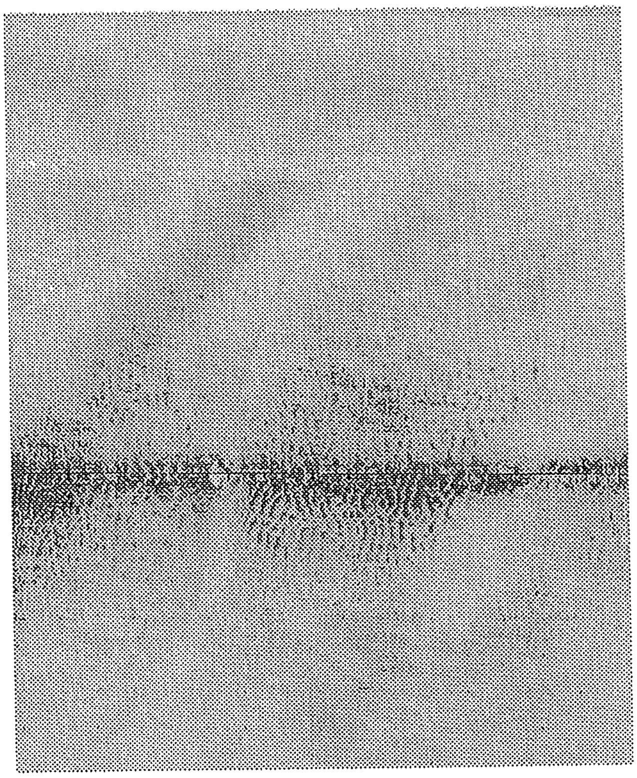
Facies 2 – small asymmetric sand waves

Termed small asymmetric sand waves, this facies type is found in areas where water depth exceeds 75m. Large areas of uniform planar sand are evident with an extensive development of asymmetric sand ripples. Ripple dimensions include wavelengths of around 12m and low amplitudes of around 1m. The geographical extent of this facies appears to be centred in the area between Ramore Head and Benbane Head, with occurrences further inshore than that of the large sand waves (facies 1).

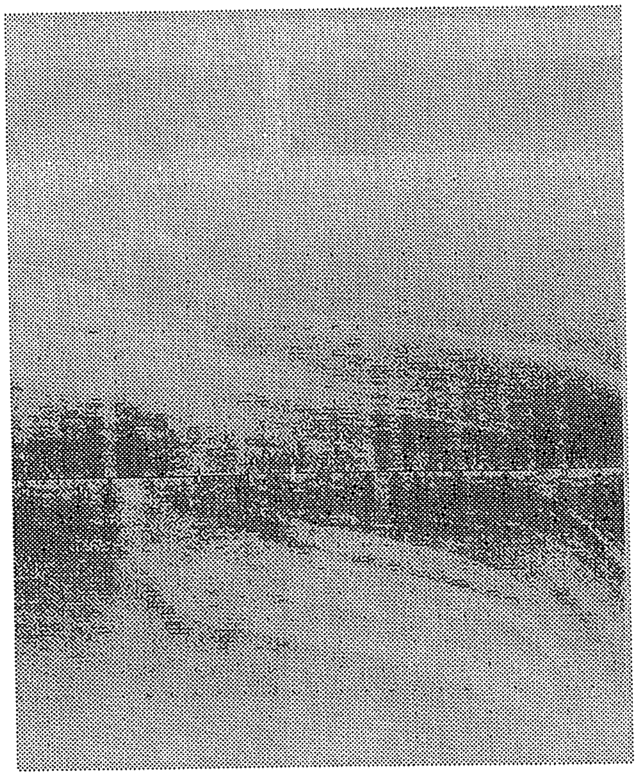
Table 1: Facies types of the north coast inner shelf

Facies	Facies description	Water depth (m)	Sediment type	Bedforms	Bedform dimensions (m) amplitude (A), wavelength (L)
1	Large asymmetric sand waves with superimposed current ripples	70-100	Sand	Sand waves, ripples	A=10m, L=150m (sand waves) A=2m, L=25m (ripples)
2	Small asymmetric sand ripples	70+	Sand	Sand ripples	A=1m, L=12m
3	Asymmetric sand waves with superimposed ripples (smaller than facies 1)	c. 150	Sand/gravel	Sand waves, ripples	A=8m, L=50m (sand waves)
4	Gravel surface with rock pinnacles	130+	Gravel/bedrock	Gravel patches	-
4b	Solid bedrock	40-60	Bedrock	(none)	-
5	Flat gravel surface with rippled sand and linear streaks	30-65	Gravel/sand	Sand ripples, linear streaks, wav rippled gravel	A=3m, L=10m
6	Flat gravelly sand or sand	20-35	Gravel/sand	(none)	-
7	Planar sand	<30	Sand	(none)	-
8	Large sand accumulation (localised)	20-30	Sand	Small sand ripples, larger sand streaks, 3D sand deposits	A=1m, L=8m A=3m, L=20m A=5m, L=25m
9	Large sand ridges over gravel (localised)	15-20	Sand/gravel	Sand ridges	A=12m, L-350m

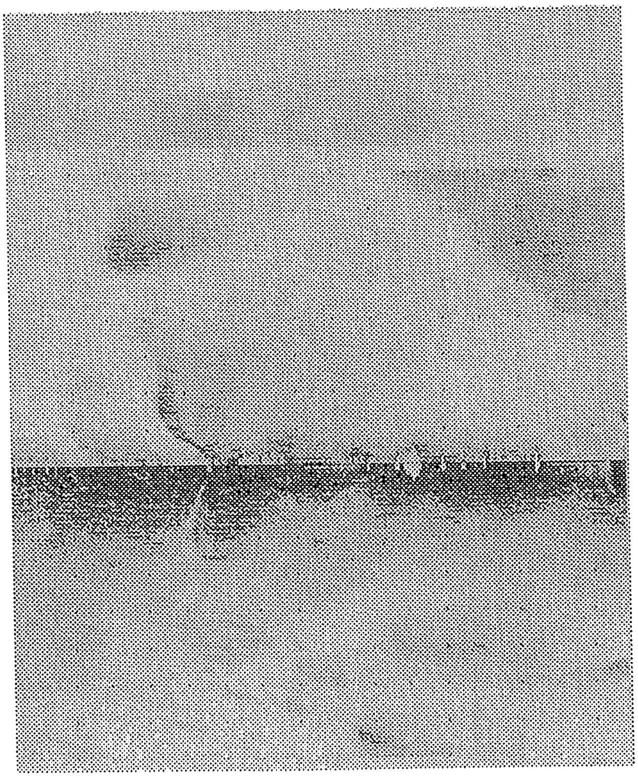
Facies 1 Low relief sinuous crest



Facies 5 Example of linear sand streaks



Facies 8 Ballycastle Bay Hierarchy



Facies 9 Gravel ridges off Ramore Head

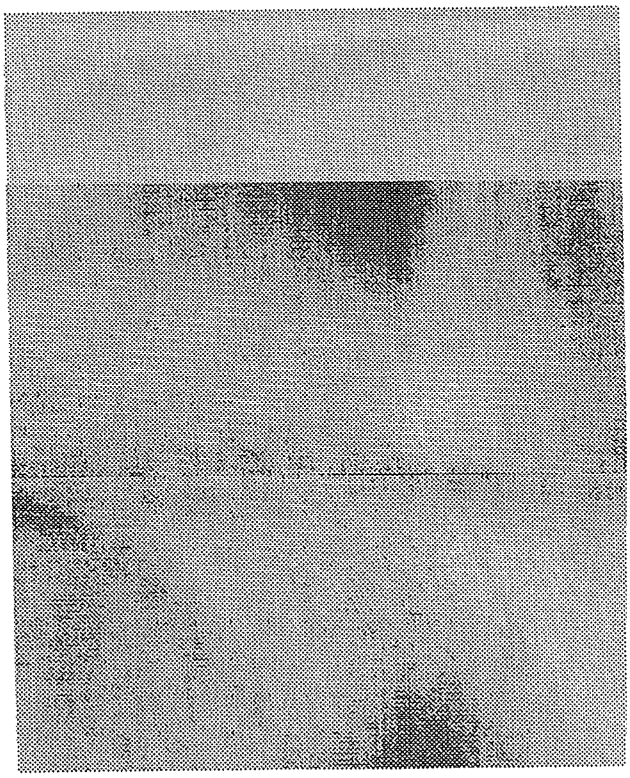


Fig. 32. Examples of different bedform types, north coast. Tick points are 25m apart.

Facies 3- small asymmetrical sand waves with ripples

In water depths typically around 150m, a facies similar to Facies 1 occurs. The generally smaller bedform dimensions however, allow for a separate classification (small asymmetric sand waves with ripples). These sand waves have an amplitude of around 10m and wavelength of 50m. These features are often straight-crested and can be found to the northeast of Ramore Head, on the outer-most track-lines surveyed. As in the case of facies 1, there appears to be a secondary order of wave-induced ripples, with a possible shore-parallel orientation, superimposed on the larger features.

Facies 4 – gravel with rock pinnacles

This facies typically occurs in water depths in excess of 130m. This facies type consists of an essentially flat gravel surface with occasional rock outcrops or pinnacles. Some of these rock pinnacles extend to 25 metres above the seafloor, with the result that the rock outcrops have different water depths on either side. A water depth of 120m to the west of the outcrop and 175m to the east suggests erosional scour on the eastern edge and deposition against the western face. This facies extends into a relatively shallow water depth of 12m near Church Bay, highlighting the intense nature of the hydrodynamic regime surrounding Rathlin Island and North Channel approaches.

Facies 4b – gravel/scoured bedrock

Although this group bears a close resemblance to the previous group, certain subtle characteristic differences allow it to be distinguished as a sub-group of facies 4. Consisting largely of a solid bedrock substrate or a scoured gravel/rock surface, the gravel and scoured bedrock facies tends to be concentrated in shallow water areas relative to facies 4 (generally between 40-55m depth). The main differences between facies groups 4 and 4b, are that surface facies 4b lacks the distinctive rock pinnacles found in facies 4, and the surface reflects a more smooth finish which may be attributed to the results of wave motion. From observation alone, it is probably impossible to account for the apparent differences; however, it is very likely that both form part of a larger relict glacial facies unit.

Facies 5 – rippled sand/sand streaks

A mainly flat gravel surface of low relief occurs in a central zone between the inner- and outer-most tracklines in the west of the study area in water depths between 30-65m. Linear indentations are filled with rippled sand orientated approximately NW-SE. Linear streaks appear continuous and are parallel or sub-parallel to lineations in the gravel. It is possible that these streaks may be longitudinal furrows, but the origin of such furrows is unclear. They could also be evidence of iceberg plough marks or contemporary shelf processes. Wave-rippled gravel also appears occasionally on the surface.

Facies 6 – flat gravelly sand

Flat gravelly sand, or sand, occurs in water depths greater than 10m and less than 35m, with little relief. Asymmetric ripples are evident with amplitudes of about 1m and wavelengths of 5m. This facies usually occurs in close proximity to the previous group, facies 5. The main difference between the two is the lack of linear streaks in facies 6. The geographical extent of this facies is concentrated again to the western sector of the study area, fringing the flat gravel platforms.

Facies 7 – planar sand

This facies usually covers extensive areas inshore. It is found in areas adjacent to beachs and dune complexes such as off Benone, Portstewart Strand and White Park Bay in water depths typically less than 20m. Its features include a flat and featureless sandy floor with possible ripples in isolated areas. It occupies an extensive area of the nearshore between Ramore Head and Inishowen Head, incorporating the Tuns Bank.

Facies 8 – Ballycastle Bay hierarchy

This facies type occurs exclusively in one area, in Ballycastle Bay. Water depths are in the range 20-30m. Its features proved to be one of the most complex of all the identified facies, with a series of initial small scale sand ripples, leading onto much larger ripple features, followed eventually by a cluster of three-dimensional features. The presence of this facies association with an apparent bedform hierarchy suggests the fashioning of large volumes of sand by a strong tidal flow regime. The three-dimensional morphology of this facies indicates a complex interaction between the overall flow field and substrate.

Facies 9 – Ramore Head ridges

This facies type is another isolated example. It can be summarised as a localised area of sand or gravelly sand over a gravel surface, resulting in a set of large gravelly sand ridges located to the north of Ramore Head. Two large ridges are present, with one smaller ridge. The amplitude of these features is approximately 12m, with wavelengths exceeding 350m. A substantial volume of available sediment appears to be present in this locality just as in the case of the Ballycastle Bay features. The Ramore Head ridges appear to be orientated in a westerly direction, which differs from the normal easterly direction, indicated by surrounding sand and gravel bodies in the study area. Due to the large scale of this isolated example, it was justified to create a separate facies type.

Discussion

Inspection of the data collected throughout the north coast inner continental shelf enables an assessment of the regional distribution of sea floor facies and a preliminary interpretation of their origins. Shelf and coastal sediment on the north coast is derived primarily from the reworking of relict glacial deposits by contemporary waves and tidal currents, and in the inner-most parts of the shelf, by the Holocene transgression. Recent evidence (Cooper *et al.* 1998) indicates that the low-stand shoreline in the region was between 30-35m below present. Present terrigenous sediment supply at the north coast is considered to be minimal, with the late-glacial sediments generally lying on a solid rock surface in the region.

In the nearshore areas such as at Downhill and Benone, the dominant facies comprises planar sand with minimal surface bedforms, to water depths of 20m. This facies reflects swell-wave dominance with orbital wave velocities producing a planar seabed. Further seaward, the shelf surface is composed of asymmetric sand waves (amplitude 5m) which indicate net easterly sediment transport. There is a general seaward increase in the distribution of gravel. This is evident along the outer-most track lines, where facies types 4 and 5 are prominent. Towards the eastern part of the region, the dominant facies becomes increasingly gravelly on a rock surface, reflecting the high intensity of tidal currents on the approaches to the narrow North Channel. The net easterly sediment transport as previously described does not prevail in this area, and it appears to accumulate or cease in a depression. The shelf surface near the headlands of Kinbane and Benbane comprise a basalt rock outcrop with gravel edges, scoured of sediment by either contemporary or relict processes.

A localised series of large gravelly sand ridges (12m amplitude) indicates net westerly sediment transport in an area off Ramore Head, probably caused by coastal configuration-derived tidal eddies, away from the main tidal stream pathways. A series of associated hierarchical sand deposits occurs in Ballycastle Bay, in an area otherwise largely devoid of sediment. These features indicate a substantial amount of available sediment in this local area, with the tidal current regime lacking the intensity to greatly influence the features.

Conclusions

On the inner shelf of the north coast, recent investigations reveal the existence of several distinct sea floor facies, defined on the basis of sediment texture and bedform morphology. The area is a relict glacial landscape with large accumulations of gravel to the north and east, and a lack of available sediment supply to the northwest. A large sand body is present between the entrance to Lough Foyle and Portstewart, to a depth of 20m. The absence of any real bedforms on this facies suggests minimal tidal current influence. Localised pockets of sand accumulations also occur along the coastline, such as at White Park Bay. It is possible that these localised sand sediment supplies in the inner shelf area form a transgressive inner shelf, unlike the gravel areas further seaward which have not been subaerially exposed at previous sea-level low-stands.

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