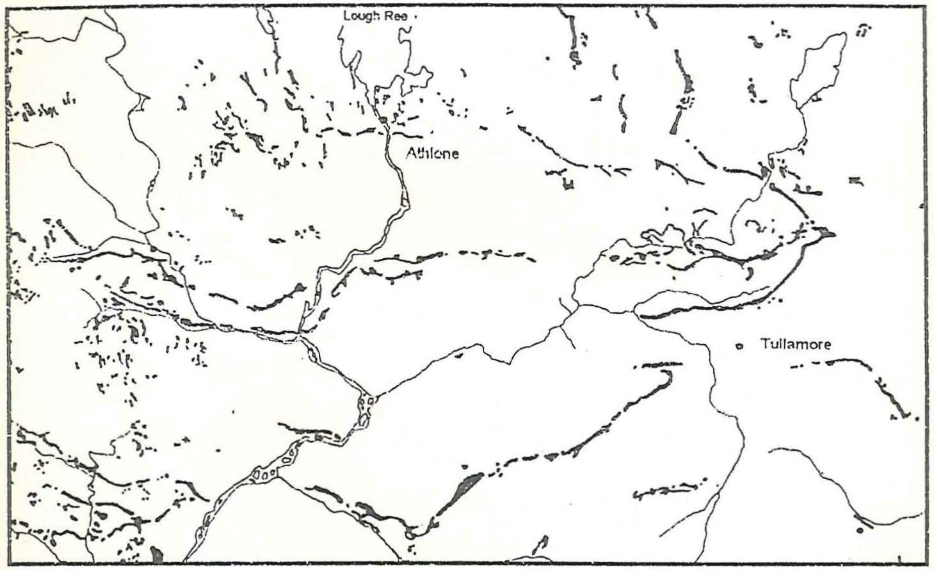
The Quaternary of

THE IRISH MIDLANDS



Sollas' map of the Irish Eskers (1896)

Field Guide No. 21

IQUA

IRISH ASSOCIATION FOR QUATERNARY STUDIES

Bettina Stefanini

Irish Association for Quaternary Studies

The Quaternary of the Irish Midlands

Edited By

Fraser Mitchell and Catherine Delaney

Field Guide No. 21

1997

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PREFACE

This guide has been written to complement a two day field excursion (4th and 5th October 1997) of the Irish Association for Quaternary Studies (IQUA) to the Irish midlands. Ten years ago IQUA ran a similar excursion to Offaly and west Kildare (Hammond *et al.* 1987). The justification for returning to the midlands a decade later lies in the fact that a considerable body of research has been carried out since the 1987 excursion. Much of this work is described, or referred to, in this guide. This excursion will revisit and reinterpret some sites visited in 1987 as well as visiting some new sites which have been the subject of recent and ongoing research.

The sites to be visited are covered by OS sheets 12, 13 and 15.

Please note that the sites referred to in this guide are either private property or state owned property with restricted access (national monuments, nature reserves). Permission should be sought before entering these sites.

OUTLINE OF THE FIELD EXCURSION

The localities are marked on Figure 1

<u>Saturday 4th October</u>

1.1 Clara Esker
1.2 Clara Bog
1.3 Lemanaghan Works, Co. Offaly
1.4 Clonmacnoise Monastery
1.5 Clonmacnoise Early Medieval Bridge

<u>Sunday 5th October</u>

2.1 Co. Westmeath 'Lakeland' Area
2.2 Corlea Trackway Visitor Centre
2.3 Ballymore Esker

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LIST OF FIGURES

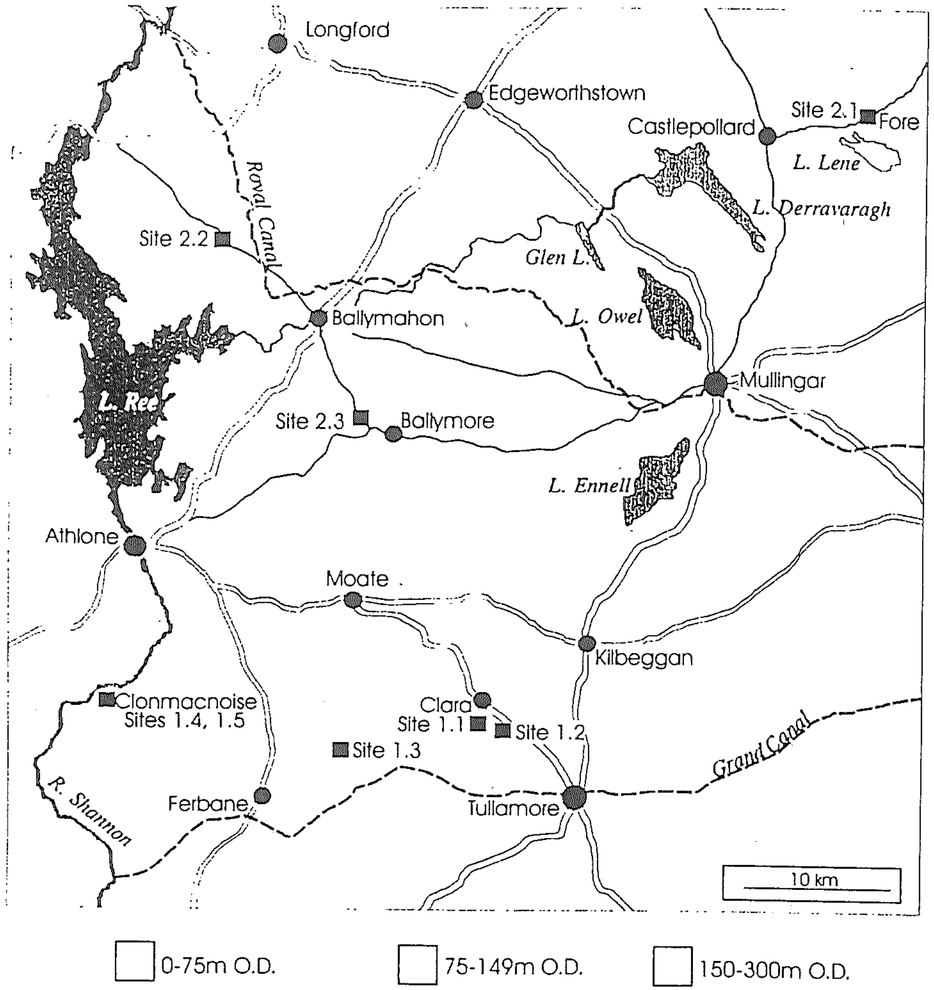

Figure 1: Map of field area, showing sites to be visited

INTRODUCTION

PRE-QUATERNARY GEOLOGY

Catherine Delaney

The bedrock geology of the area to be visited is shown in Figure 2. Whilst the area is dominated by limestone, other rock types do outcrop. The oldest rocks are exposed in the north of the area in a series of inliers of Ordovician and Silurian rocks which protrude through the younger Carboniferous strata. The rocks are sedimentary, deposited within a marine basin from a margin lying somewhere to the south. They are oldest in the Strokestown inlier, where siltstone turbidites with jasper horizons lens out northwards into greywackes and chert siltstones interbedded with mafic volcanics (Holland, 1981). Silurian slates and greywackes are also exposed in the Longford-Down inlier to the north of the field area, and in the Longford and Keel inliers to the south. These older rocks are associated with areas of higher ground.

The Silurian and Ordovician sediments are unconformably overlain by Old Red Sandstone (ORS) clastics, which are exposed around the edge of the Ordovician/Silurian inliers (Fig. 2). The ORS in this area is thought to be almost entirely of Lower Carboniferous (Dinantian) age and consists of sandstones and conglomerates with quartz cobbles and pebbles (Higgs *et al.*, 1988). The sediments were laid down in a fluvial environment.

The ORS is conformably overlain by the main Dinantian limestones. In the north of the field area, along the southern edge of the Longford-Down inlier, the limestones are relatively sandy and are thought to have been deposited in a shallow marine setting. Southwards, these coarser sediments are succeeded by Waulsortian Complex limestones. These are massive limestones, interrupted occasionally by "reef" mounds or mudbanks of very pure, fossiliferous, fine-grained limestones. One such bank is found at Mullawornia, west of Ballymahon. The Waulsortian Complex limestones are thought to have formed in a marine basinal setting. To the east, these relatively pure limestones are overlain by the dark argillaceous "Calp" limestones. These limestones are less pure and are not suitable for karstification.

Lower Carboniferous volcanic activity is recorded from Croghaun Hill, Co. Offaly, at the eastern edge of the area. The volcanics here consist of tuffs and agglomerates (MacCarthy, 1990).

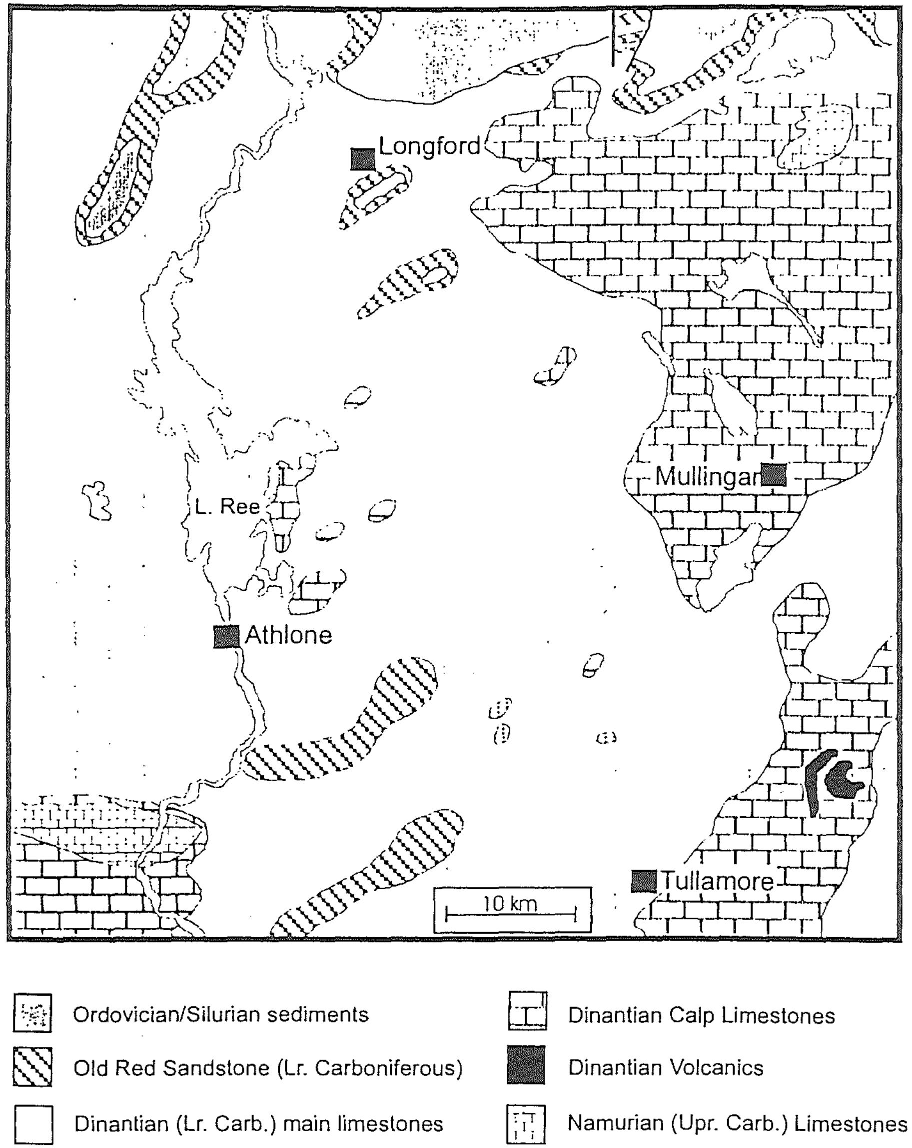

Figure 2: The pre-Quaternary geology of the Central Midlands

The Upper Carboniferous (Namurian) succession, which consists of goniatite-bearing shales and sandstones, outcrops in the eastern part of the area. As with the pre-Carboniferous clastics, these rocks underlie higher ground.

The bedrock surface is exposed in few places in the area. However, borehole records from the western part of the area suggest that the surface is highly variable in relief and was almost certainly karstified during the Tertiary period. Lakes in the area are thought to be dominantly solutional in origin. However, Prof. Frank Mitchell has suggested that the origin of the Shannon basin is more complex, and that Lough Ree may lie within a sag basin formed by post-Carboniferous movement.

QUATERNARY GEOLOGY

Catherine Delaney

Landforms

The landscape of the central Irish Midlands is dominated by an extensive suite of glacial and glaciofluvial depositional landforms. The type of dominant landform varies from north to south (Fig. 3).

Drumlins

The northern part of the area to be visited is dominated by drumlins and elongated streamlined hills, oriented approximately NW-SE, and indicating ice flow towards the SE. Eyles and McCabe (1989) have suggested that the drumlins of the northern Midlands were formed under surging or near-surging ice, caused by the downdraw of ice towards the rapidly calving marine margin of the Irish Sea Glacier.

Hummocky Moraine

A zone of hummocky moraine over 10km in width lies immediately south of the drumlins (Fig. 3). This zone has been interpreted as a zone of 'stagnant ice topography' marking the position of meltout of the Midlandian (Devensian) icesheet (Synge, 1979). More recent work has shown that the zone consists of stagnant ice topography, esker remnants, small eskers (oriented NW-SE and indicating water transport SE-wards), ice thrust ridges, and proglacial outwash. The hummocky moraine was formed by the NW-wards migration of a narrow zone of stagnant ice at the ice margin, rather than by mass downwasting of the icesheet (Delaney, 1995).

Eskers, Kames and Glaciolacustrine Deposits

The area immediately south of the hummocky moraine is dominated by large eskers and kames, lying within raised bog and alluvial deposits, which in turn overlie glaciolacustrine silts and clays. Eskers in this zone are oriented roughly E-W, but converge towards a point east of Daingean (Fig. 3). Sedimentological studies indicate that they were formed both within subglacial tunnels and at the tunnel mouth (Delaney, 1995; Warren & Ashley, 1993). Transport of sediments within the tunnels was eastwards, indicating that retreat of the ice front was broadly westwards. Tunnel mouth deposition took place in standing water, resulting in the formation of deltas and subaqueous outwash fans. Paleocurrent measurements within these deposits vary: at the eastern end of tunnel mouth deposits, transport is eastwards, but around the Lough Ree area, some fans and deltas indicate that transport was southwards, indicating a major change in ice front orientation in this area (Delaney, 1995). The wide distribution of glaciolacustrine deposits indicate that deposition of these sediments occurred into an extensive body of standing

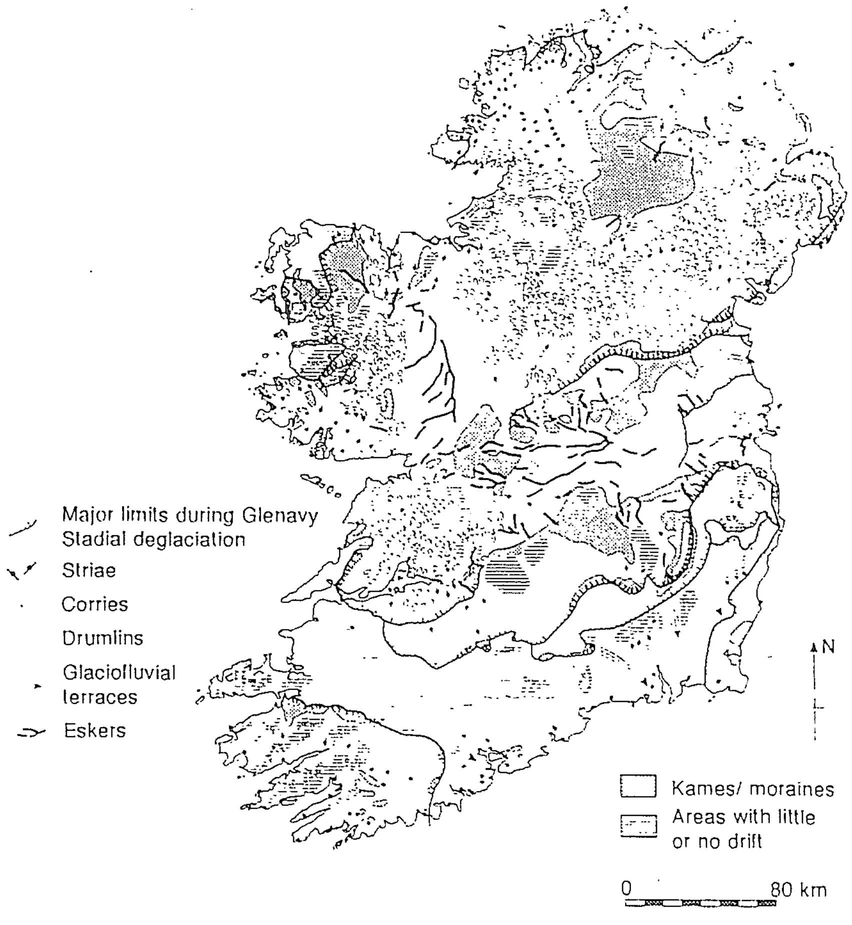

Figure 3: Quaternary geology of Ireland (after McCabe, 1987)

water covering the Midlands. In places, delta surfaces reach 92m O.D., indicating water levels in the lake were above the lowest points in the watersheds between the Shannon basin, and the Liffey and Barrow basins, and that water would have escaped eastwards and southwards through cols east of Tullamore and Daingean. Since no evidence for an ice barrier has been found in the eastern Midlands, it seems likely that lake levels were kept high by relatively high sea-levels in the Irish Sea Basin (Eyles and McCabe 1989; McCabe, 1997).

Stratigraphy

The glacial deposits and landforms of the Midlands are thought to have formed after the maximum of the Late Midlandian glaciation c.24,000-20,000BP (McCabe, 1987), during the deglaciation of the British Isles. However, few attempts have been made to reconstruct the pattern of ice retreat, despite evidence that the alignment of ice margins and ice flow directions were considerably different to those seen during the maximum glaciation (Fig. 4a). Previous workers have recognised at least two ice marginal positions within the Midlands: The Galtrim End Moraine in Meath (A on Fig. 3), a narrow belt of ice-marginal deltas (Synge, 1950, 1970); and the Drumlin Readvance Moraine (termed the Dunany Moraine on the coast; B on Fig. 3) which was thought to have formed during a readvance of ice c. 18,000-19,000BP (Synge, 1969; Stephens *et al.*, 1975). The alignment of the Galtrim end moraine indicates that the ice margin was aligned approximately N-S across the eastern Midlands, an alignment that indicates that ice flow during this period must have come from the west. The E-W alignment of the main eskers, and their convergence on a point east of Daingean also indicate that a curved ice margin retreated westwards, and that the last direction of ice flow in the Midlands is likely to be eastwards (Fig. 4b). The arcuate shape of the margin indicates that ice receded most quickly across the lower, central Midlands around the Brosna, but held on a little longer on the higher ground to either side. It is likely that the rapid retreat in lower terrain was helped by the presence of water at the ice margin, encouraging iceberg calving. Warren and Ashley (1993) have suggested that ice also retreated southwards towards an ice dome centred on the Slieve Blooms; however, no evidence for northward movement of ice is presented, and the evidence for northwards drainage of meltwaters is limited to a narrow zone around the Ballyduff esker.

The position and relevance of the Drumlin Readvance Moraine is also controversial. The inland position of this moraine is doubtful, and has been placed both south of the main esker field (Synge, 1970), and north within the main area of hummocky moraine (Stephens *et al.*, 1975; Fig. 3). The existence of a readvance moraine has also been questioned. However, the reinterpretation of the Dunany Moraine as a glaciomarine pushed morainal bank (Eyles & McCabe, 1989), and the

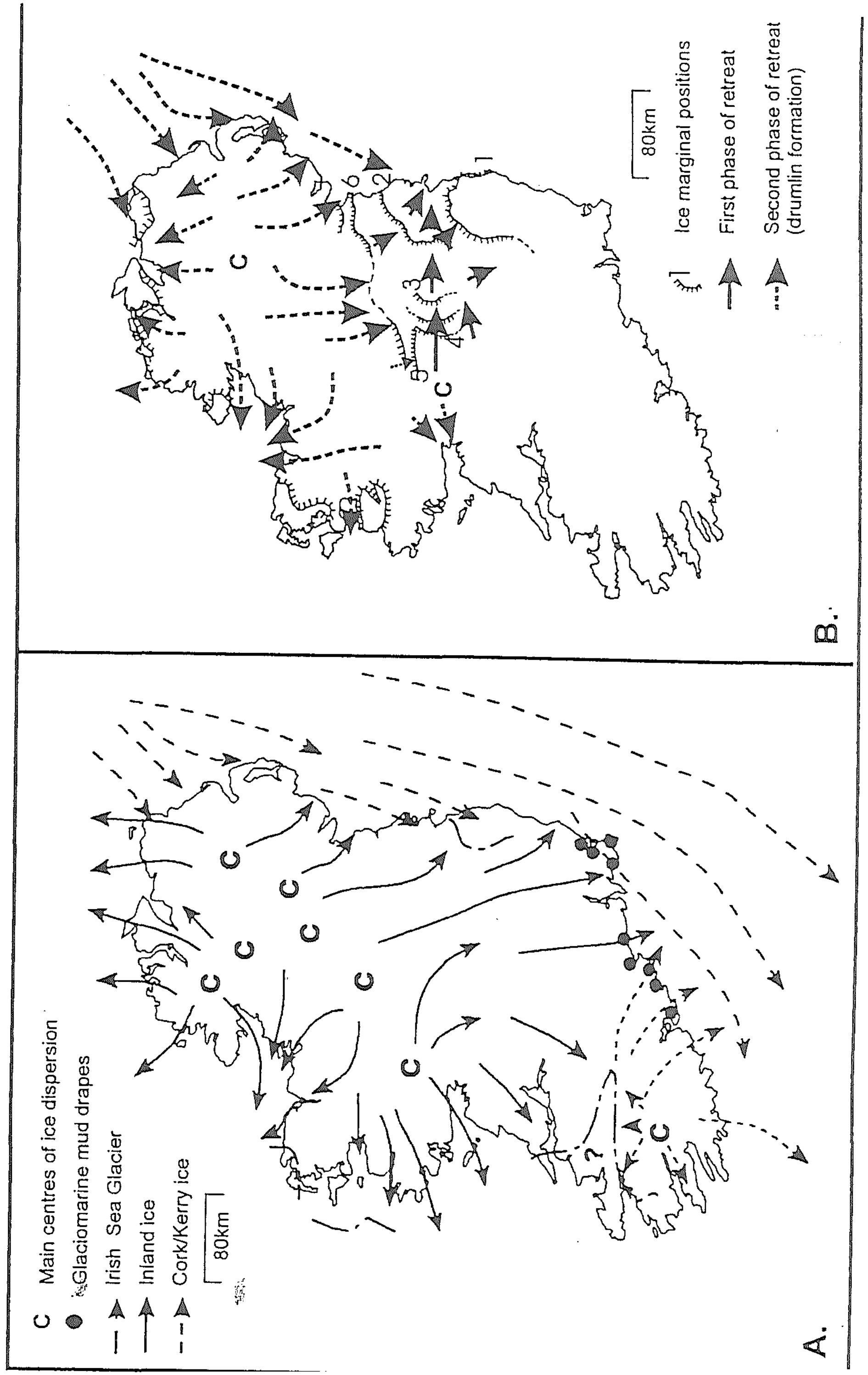

Figure 4: Devensian ice flow directions. A. During the glacial maximum (after McCabe) B.. During recession of the main Devensian ice cap

discovery of evidence indicating a southward readvance of ice in the Lough Ree area indicates that some readvance did occur during deglaciation. The evidence in the region of Lough Ree shows that an ice readvance from the north impinged on the E-W oriented eskers, creating ice-push structures on the northern side of the Athlone Esker, and burying more northerly esker segments in southward-transported outwash (Delaney, 1995). However, this readvance was localised in nature, and ice on the higher ground to the east appears to have retreated continuously, the ice margin veering from a NE-SW orientation to a N-W orientation over time. It is likely that readvance in the Lough Ree area was associated with high water levels in the Shannon Basin, which may have caused limited surging.

It appears that the glacial deposits of the area to be visited were deposited in two stages. The main E-W oriented eskers are thought to have been formed at the end of the Glenavy Stadial, between 20,00-18,000 BP, as the Irish Sea Glacier retreated and drainage in the eastern Midlands became influenced by the influx of sea water up the Irish Sea Basin, drawing iceflow eastwards. Drainage within ice overlying the Midlands was also directed eastwards, and retreat of the icesheet westwards occurred. The second phase of deposition occurred during the Drumlin Event, which took place after 16.5k BP in the northern Irish Sea Basin (McCabe, 1997). During this event rapid drawdown of the ice into the Irish Sea Basin led to destabilisation of the ice cap centred over the northern Midlands, causing rapid ice flow which led to the formation of the drumlins. In the Lough Ree area, readvance of ice occurred, in part destroying the recently formed esker system. After this period of rapid ice flow, progressive northward recession of the ice margin occurred, resulting in the formation of the NW-SE oriented eskers and associated hummocky moraine.

Acknowledgement

I wish to thank Pete Coxon for assistance with drafting the figures.

PALAEOECOLOGY

Fraser Mitchell

The first pollen diagrams from the region covered by this field trip were published in 1951. These were from Clonsast, Co. Offaly, Ballynakill, Co. Westmeath and Grillagh, Co. Longford (Mitchell 1951). Two further diagrams from Clonsast were published by Mitchell (1956) and this gave the first complete Postglacial pollen record for the area. This was supplemented by Michael O'Connell's detailed study of Scragh Bog (O'Connell 1980). None of these pollen diagrams were dated radiometrically but Mitchell (1956) does quote some dates from *Pinus* (pine) wood and *Phragmites* peat.

The early Postglacial at both Clonsast and Scragh Bog is characterised by the early arrival and expansion of *Ulmus* (elm) well in advance of *Quercus* (oak). *Pinus* pollen representation was very low at Scragh Bog but this tree grew on the site at Clonsast. Mitchell (1956) quotes a date of 4150±70 BP for one of the pine stumps at Clonsast. The later Postglacial representation of *Pinus* pollen at Clonsast was low but stumps were found 70cm below the bog surface. A combined radiocarbon date of 1591 BP was proposed for two of these stumps by Mitchell (1956). One of the same samples was re-dated by McAulay and Watts (1961) and returned a date of 1620±130 BP. This is one of the latest fossil pine dates recorded in Ireland (Bradshaw & Browne 1987).

Repeated elm declines and recoveries are beautifully illustrated in the Scragh Bog pollen diagram where *Ulmus* values fluctuate between 2 and 25%. Several anthropogenic indicator pollen types are recorded immediately after the first elm decline, heralding the establishment of Neolithic agriculture in the region. Whilst there is some evidence to support repeated elm declines at Clonsast, the appearance of anthropogenic indicators (*Plantago lanceolata*) was delayed somewhat.

The absence of radiometrically dated pollen diagrams covering the full Postglacial in this region prompted the Midlands palaeoecological Project undertaken by the Botany Department, TCD. Two PhD projects have been completed and are currently being written up, while a third is in progress. Andrew Connolly reports some of his results in this field guide from palaeoecological investigations on and around Clara Bog. Chronologies based on twenty-eight radiocarbon dates from Clara Bog will be reported in due course. Tephra chronologies for the bog currently being undertaken by Queen's University Belfast will provide an addition source of dating. Alyson Heery has completed palynological investigations of two lake sites situated adjacent to eskers. Cornaher Lough, Co. Westmeath contains annually laminated sediment for much of the Holocene (Heery 1997). The pollen data

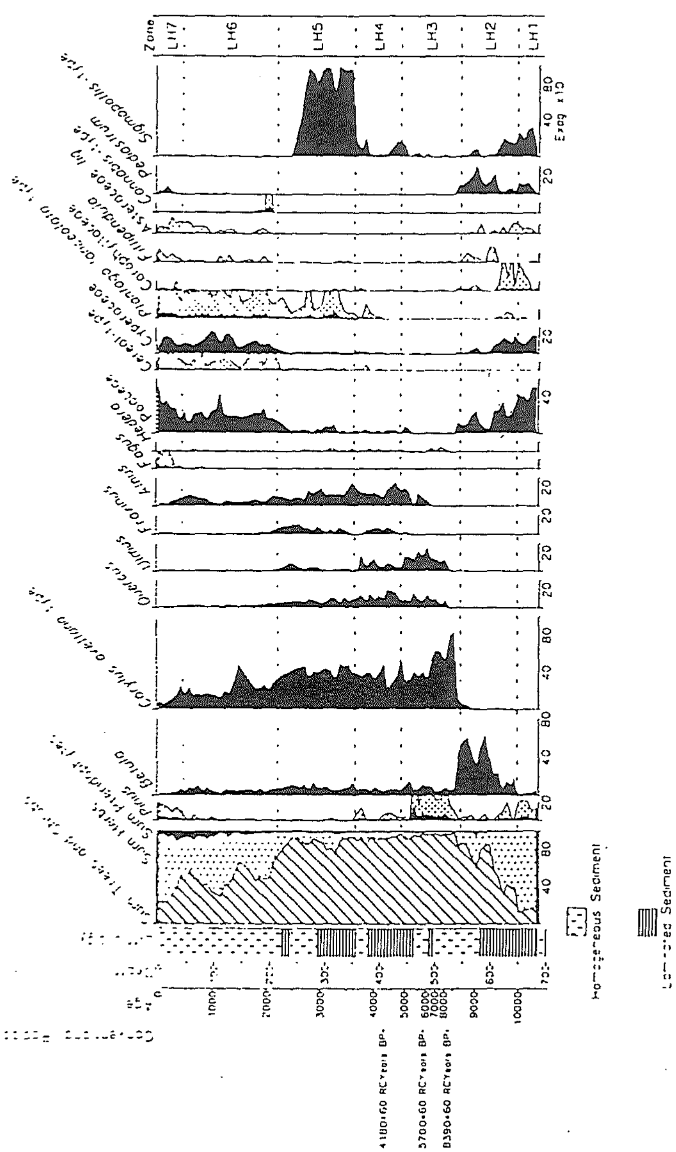

Figure 5. Summary percentage pollen diagram from Cornaher Lough (from Heery 1997)

demonstrate the coincidental expansion of *Ulmus* and *Quercus* in the early Postglacial in contrast to Clonsast and Scragh Bogs (Fig. 5). The local presence of *Pinus* is confirmed by the presence of pine stumps. The pollen records from both Clara Bog and Cornaher Lough illustrate an absence of anthropogenic activity at the time of the initial elm decline. The second lake site at Derryad lies close to Banagher and is outside the field trip area. This site also provides the first detailed description of the Lateglacial from the Midlands (A. Heery unpublished).

Some palynological work has also been completed in association with bog trackway excavations (Caseldine & Hatton 1996; Caseldine *et al.* 1996; Parkes & Bradshaw 1988). Caseldine *et al.* (1996) and Caseldine and Hatton (1996) report short pollen and macrofossil diagrams associated with different trackway constructions from Corlea Bog, Co. Longford. An account of the archaeological excavations at this site appears later in this field guide. The dating of these diagrams will be supplemented by forthcoming tephra data (Caseldine *et al.* in press). The pollen data record anthropogenic activity immediately after the elm decline but fail to detect anthropogenic activity some 300 years later when a trackway was constructed. These apparently contradictory sources of evidence should be borne in mind when interpreting the Neolithic palynological data from Clonsast, Scragh, Clara Bogs and Cornaher Lough described above.

The timing, duration and extent of anthropogenic activity during the Neolithic are variable in the pollen data across the field trip area. The repeated recovery of woodland (especially *Ulmus*) is a constant feature in the pollen data. Sustained agricultural activity becomes a feature of the pollen diagrams at the onset of the Bronze Age and this is broadly consistent with other Irish data.

Palynological evidence for a reduction in anthropogenic activity and an associated recovery of woodland during the Iron Age is evident in all the pollen diagrams that cover this period. This episode is perhaps best illustrated at Clara Bog (Fig. 15). The episode was also detected in a pollen diagram from Mongan Bog (adjacent to Clonmacnoise) (H.M. Parks, unpublished). The upper levels of the Clara Bog diagram, which cover the last few hundred years, illustrate a massive reduction in arboreal pollen taxa (Fig. 15). This is also detected at Scragh and Mongan Bogs and Cornaher Lough. Ongoing research by Edwina Cole (TCD) at All Saint's Bog (near to Banagher), and elsewhere, has also detected this; her project is investigating this period in detail.

Additional palaeoecological work has also been carried out in the field trip area in the form of stratigraphical descriptions of peat profiles. Descriptions of the stratigraphy of Clara Bog were included in the classic paper by Walker and Walker (1961) which demonstrated that raised bogs did not regenerate via a hummock-hollow cycle. Further stratigraphic data are also contained in Hammond (1968) and

Barry *et al.* (1973). The Irish-Dutch bog hydrology project which concentrated on Clara and Raheenmore Bogs has just been completed; a wealth of detailed stratigraphic data from both these sites is currently in press.

Perhaps one of the most enigmatic plants in this region is *Scheuchzeria palustris*, the Rannoch rush. This species is characteristic of continental bogs with permanently high water tables; yet in Britain and Ireland, its present day distribution is confined to Rannoch Moor in the central Scottish Highlands. *Scheuchzeria palustris* was first found in Ireland by J.J. Moore on Pollagh Bog in 1951. Subsequent stratigraphic and macrofossil research demonstrated that *Scheuchzeria* had been present on the bog since early Christian times and had been continuously associated with the soak system (Moore 1955). Pollagh Bog has now been harvested by Bord na Móna but prior to its destruction, J.J. Moore transplanted some plants of *Scheuchzeria palustris* to Raheenmore and Clara Bogs in 1959. The plant was relocated only on Clara a year later but has never been found since and is considered to be extinct in Ireland (Curtis & McGough 1988). Pollagh Bog remains the only Irish location where fossil remains of this species have been found. Barry and Synnott (1970) also report on finds of rare or extinct Irish bryophytes preserved in peat profiles in Kildare.

ARCHAEOLOGY

Eamon Cody

The field trip area, in north-west Leinster, is bounded on the east by Loughs Derravarragh, Owel and Ennell and on the west by Lough Ree on the River Shannon, and lies at the middle of the country; the Hill of Uisnech (N 293 490) at the heart of the area is the anciently supposed centre of Ireland and was a place of sanctity in pagan times (Killanin and Duignan 1967, 101). The nature of the archaeological evidence available for the different eras of human activity in the area down to c. 1200 AD is briefly introduced here.

Human presence in the general area during the Mesolithic period is known from a small number of lake-side sites, which like riverine and coastal locations, seem to have been favoured by hunter-gatherer communities, perhaps because of their considerable food potential (Cooney and Grogan 1994, 12-17). The early Mesolithic, characterised by the production of microliths for use as composite tools for hunting and fishing, is represented by the site at Lough Boora in Broughal townland, Co. Offaly (N 161 181) where hearths, pits and considerable artefactual material, including some two-hundred microliths, the great majority made of chert, were unearthed on excavation along with food remains consisting of hazel nuts and burned mammal, fish and bird bones (Woodman 1978, 323-5). Dates from the site, in radiocarbon years, fall into the range 7,000 - 6,500 BC (O' Brien and Sweetman 1997, 1). Later Mesolithic activity, represented by a lithic industry based on the production of large blades and flakes to the exclusion of the earlier microliths, is known from Lough Kinale in Derragh townland, county Longford (N 38 81) and Lough Derravaragh in Clonava townland (N 39 66), in county Westmeath (Woodman 1978, 316-21).

There is little monumental evidence in the area of the Neolithic farming communities established in Ireland after c. 4000 BC. It lies just south of the great concentrations of megalithic tombs of the period found in the northern third of the country. Evidence of activity in the area during this era largely derives from finds of diagnostic artefacts, in particular, stone axes. The axes, which would have played a major role in forest clearance, have a wide distribution in the area though the relative scarcity of find-spots below 61 m OD (Cooney 1989) denotes a preference on the part of the Neolithic farmers for dry well-drained land. That bog-growth was already posing a threat to some parts of the area is evidenced by the need to construct wooden trackways in Corlea bog, county Longford by the mid-4th millennium BC (Raftery 1990, 11-13).

The succeeding Bronze Age period, c. 2200 - c. 500 BC, is represented in the archaeological record of the area by the products - tools, weapons and ornaments - of the new technology of metalworking, The distinctive burials of the early Bronze Age - single interments of inhumed or cremated remains in, or accompanied by, various styles of funerary pottery - are also quite numerous, especially in Co. Westmeath. The exceptionally large cemetery at Knockastia hill in Coolatoor townland (N 245 433) in that county contained some forty such graves (Waddell 1990, 149-50). Two of the rare settlement sites known from the Irish later Bronze Age, both in lakeside situations, are at Ballinderry Lough in Ballynahinch, county Offaly (N 215 389) and at Clonfinlough (N 030 289), close to Fin Lough, in the same county (O' Brien and Sweetman 1997, 18).

The Iron Age in the area is represented by a small number of artefacts distinctive to the period, such as horse-bits, e.g., the matching pair from Streamstown, Co. Westmeath (Raftery 1984, 28) and also the newly-introduced rotary quern (Caulfield 1977, 131-5), a more efficient device for grinding grain than the earlier saddle-quern. Securely dated structural evidence of the period consists of two stretches, each some 1 km long, of a massive wooden roadway suited to wheeled traffic, which dates to the mid-second century BC, found in bog in the Corlea and Derraghan More areas of county Longford (Raftery 1994, 37-43), part of which is preserved and displayed in the Visitor Centre at Corlea (N 09 63). This is just one of a number of large undertakings in Ireland during the second and first centuries BC which suggest activity on a tribal level (Raftery 1994, 226).

As elsewhere in Ireland the great bulk of surviving monuments in the area date to the Early Medieval period (c. 500 AD - c. 1200 AD), an era of considerable agricultural expansion which seems to have been in train since about 300 AD (Mitchell 1986, 153). Some hundreds of ringforts, the homesteads of farm families whose main economic activity appears to have been the rearing of cattle, were built in the area at this period with very high densities of the type recorded on the good land lying between Lough Owel and the Hill of Uisneach in Co. Westmeath (Stout 1997, 35, 77). In this lakeland region the crannóg, the lacustrine equivalent of the dryland ringfort, is also represented. Following the spread of Christianity during the fifth century an array of new monument types - churches, round-towers, crosses and cross-slabs - enter the archaeological record. Some of Ireland's great monastic sites, which served for centuries not just as places of worship but as centres of art, literature and learning, are found in the midlands. An important early site is the sixth century Columban foundation at Durrow Demesne, Co. Offaly (N 318 308) which is associated with the illuminated Book of Durrow, now in Trinity College Library, Dublin. Among the remains at the site is a fine high cross, probably of ninth century date (Harbison 1994, 55-8). The pre-eminent monastic site in the area is at Clonmacnoise, Co. Offaly (N 00 30), described elsewhere in this field guide.

The visible impact of the outside influences at work in twelfth century Ireland are

represented in the monuments of the area. In the domain of church architecture a doorway in one of the churches at Clonmacnoise was built in the new romanesque style while an abbey at Abbeyshrule, Co. Longford (N 226 588) was one of those established under the rule of the Cistercians, one of the great continental monastic orders (Killanin and Duignan 1967, 99, 171). The initial phase of the Norman invasion led to the construction of a series of mottes, defensive earthworks, in the late twelfth and early thirteenth centuries, a number of which are known in east Longford and Westmeath, e.g., at the town of Moate (Moategranoge townland) in the latter county (N 186 382). These form part of a line of such sites across north Leinster protecting it from unconquered Ulster (Stout and Stout 1997, 54-5).

Acknowledgement

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FIELD SITES

1.1 CLARA ESKER

Mary Smyth

Geology of Clara Area

Carboniferous limestone underlies the Clara region. The bedrock is overlain by glacial drift deposits of 'clayey gravel till' and 'sandy gravel till'(Fig. 6). Topography associated with the till deposits is characteristically undulating low relief, evident to the south of Clara Bog. Till deposits in the region have a maximum thickness of 10m, and are less than 1m in places. Particle size ranges from clay and silt to large limestone boulders up to 3-4m (derived from glacial erosion of the bedrock). Boulders of less than 0.5m are derived from bedrock lithologies to the west of the area, indicating the 'West to East' movement of the ice sheet.

Clara Esker

The landscape of the Clara region is dominated by esker ridges which run along the northern margin of the bog, in a West-East direction. Here the esker morphology does not consist of simple ridge features, but takes the form of a broad elevated feature with undulating topography, composed of sands and gravels. The esker complex ranges in width from 1-1.5km south of Clara town, to 100m wide where the isolated ridge occurs to the west. Characteristic features of the esker complex include kettle holes of various sizes, hill features (broad and pointed) and the classic esker ridge features. The ridge feature appears disjointed in places merging with the undulating topography. Elsewhere it bifurcates to direct itself around kettle-holes. These features of the esker complex reflect meltwater deposition on and in the ice.

Geological History of Clara

The Quaternary geology of the region implies a general easterly movement of the ice sheet. Heavily weathered limestone bedrock was easily eroded providing additional material to incorporate as sediment in the glacier. Bedrock surface topography is irregular consisting of many depressions, due to its highly weathered nature. A large depression is present in the bedrock surface in the area now occupied by Clara Bog. Glacial till deposits, as described above, were deposited by the ice sheet in the area. The till deposits visible on the southern margin of the bog

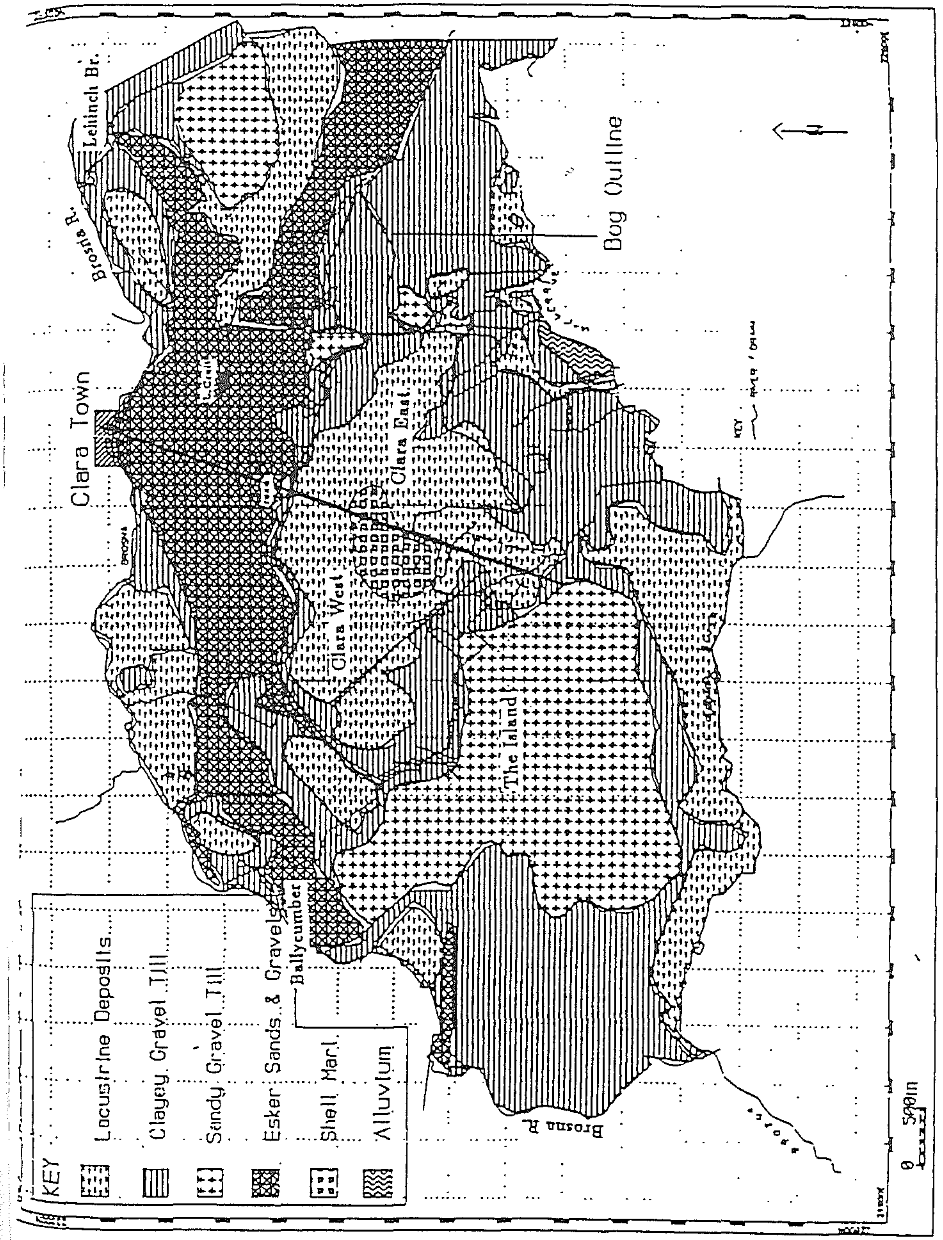


Figure 6. Quaternary geology of the Clara study area

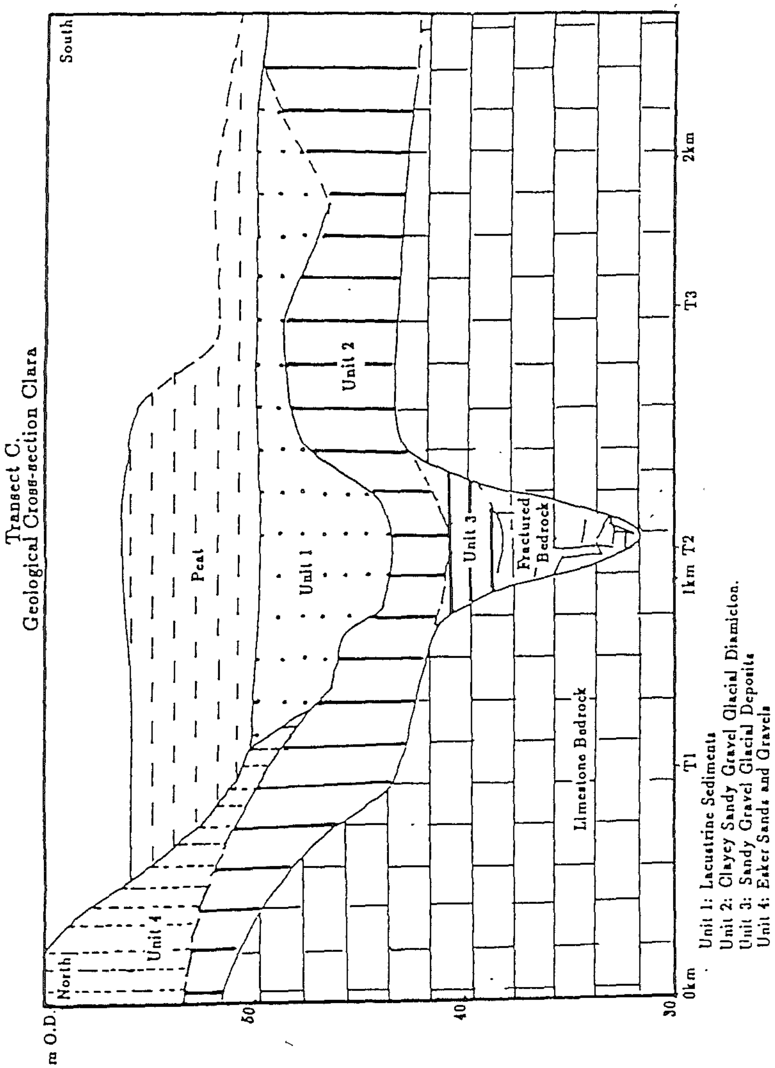
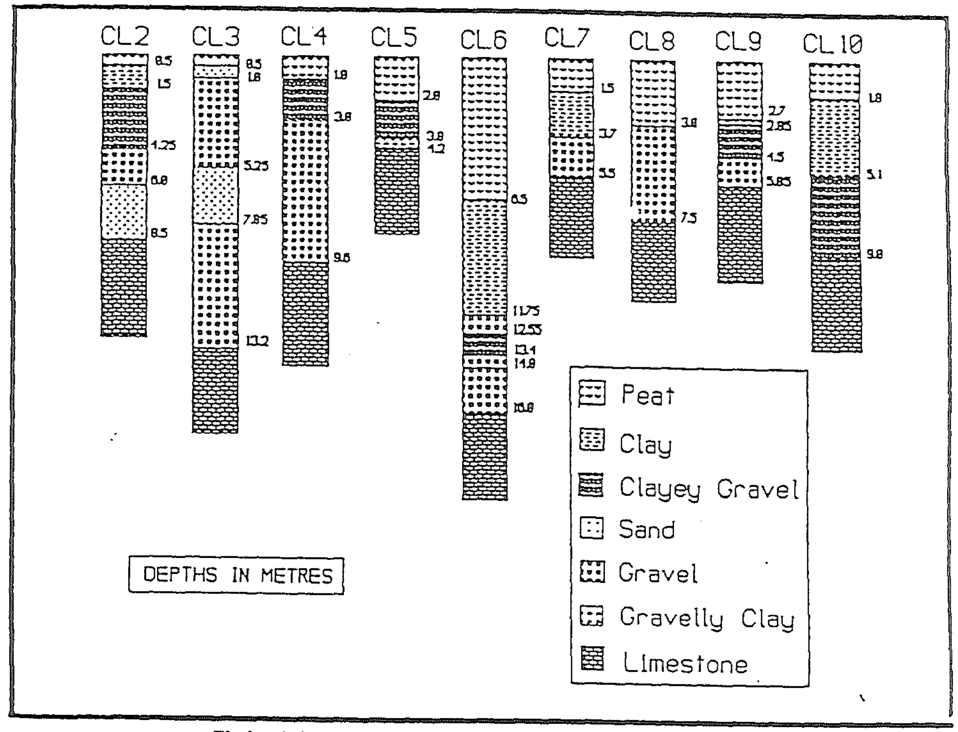


Figure 7. Geological cross-section along transect C, Clara study area



Note.: The borehole lithologies displayed on this page describe samples recovered from the drilling operation. However due to the difficulties of obtaining accurate samples (loss of fines, etc.), the lithologies displayed may not be an accurate representation of the actual lithology. For example, at borehole CL2 the sand and gravel units which underlie the clayey gravel diamicton may contain a significant clay content. This is suggested from geophysical soundings, mapping and pumping tests carried out in the area, but is not reflected in the sample recovered from the drilling. Therefore the geological transects display a clayey sandy gravel diamicton (Unit 2) resting on bedrock in areas where the boreholes may not indicate this to be so. Such interpretations are based on geological mapping and VES carried out in the area.

Unit 3 and 4 on the geological transects are based on geological mapping and VES correlated with the borehole information.

Figure 8. Geological logs for boreholes drilled at Clara

extend beneath the bog. After glacial retreat a mantle of glacial deposits covered the bedrock. Glacial deposition infilled minor depressions in the bedrock surface, however it resulted in a landscape topography which reflected the large underlying depressions of the bedrock in a more subdued form (Fig. 7).

The impermeable nature of the glacial deposits prevented downward drainage of the water into the bedrock, forming a landscape dominated by lakes occupying the topographic depressions. A large lake occupied the depression beneath the present-day bog. Over considerable time, streams transported fine sediment into the lake in suspension. Silt and clay deposits were the chief constituents of these lacustrine sediments, although fine gravel particles occur. Lacustrine deposits accumulated to thicknesses in excess of 6m (Figs 7 and 8).

1.2 Clara Bog

Andrew Connolly

Clara Bog lies south of the village of Clara in Co. Offaly. It extends for 665 ha. and constitutes the largest remaining area of intact raised bog in Ireland. There are no intact raised bogs of similar size and importance remaining in Ireland. The bog was acquired by the Wildlife Service of the OPW and is now a National Nature Reserve.

Clara Bog is located 2 km south of the town of Clara in north Co. Offaly (7°37' W, 53°19' N; grid ref. N 25 30) at an altitude between 56 and 62.5 m above sea-level (Fig. 1). The bog is bisected by a road running south from Clara to the village of Rahan. Clara Bog is bounded to the north by an esker, which runs east to west. To the south the bog was bounded by the Clodiagh and Silver Rivers, but peat cutting and land reclamation have removed the margin of the bog northwards (Fig. 9).

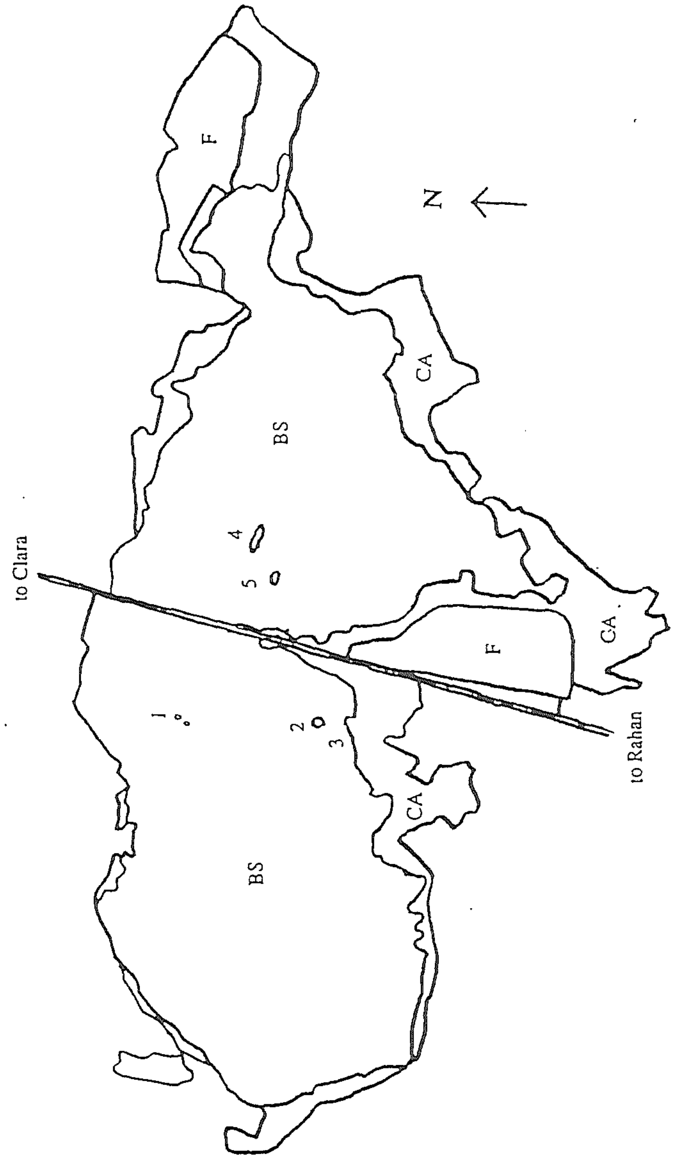
Before the bog was purchased by the OPW, Bord na Móna cut a network of shallow drains on the eastern side of the bog. This work was carried out in preparation for mechanical harvesting of the peat. These drains have been blocked at intervals to prevent drying out of the surface, but they can still be observed. One-third of the bog is privately owned and peat harvesting is actively carried out at the margins of the bog each year, particularly at the southern edge.

Topographical Features of Clara Bog

Clara Bog is of particular interest due to features which are associated with its internal drainage system (soak system). Of particular interest are:

1. Shanley's Lough and an associated *Betula pubescens* dominated woodland on Clara Bog West.
2. Lough Roe and a smaller lough (Lough Beag) to the south of Lough Roe on Clara Bog East.

These sites are atypical of ombrotrophic conditions as they support vegetation which requires a greater concentration of nutrients than is usually available on a bog.



1= Main pollen core site; 2= Shanley's Lough; 3= Clara birch wood; 4= Lough Roe; 5= Lough Beag. CA = Cut-away bog; BS = intact raised bog surface; F = forest.

Figure 9. Clara Bog with coring site and features marked

Vegetation

Most of the intact bog surface supports typical ombrotrophic peatland taxa such as *Sphagnum* species, *Calluna vulgaris* (Heather), *Narthecium ossifragum* (Bog asphodel) and *Menyanthes trifoliata* (Bog-bean). Some areas support vegetation which is more typical of a nutrient rich environment, such as *Vaccinium oxycoccus* (Cranberry), *Betula pubescens* (Birch) and *Molinia caerulea*. An example is the *B. pubescens* woodland on Clara Bog west which can be seen from a distance. The vegetation of Clara Bog was studied extensively by Kelly (1993).

The Development of Clara Bog

The development of Clara Bog was relatively straightforward and was along the lines of the model described by Mitchell (1986). Pollen and sediment analyses were carried out (see Fig. 10) and the results are summarised below:

CL-1. At the beginning of the Holocene, the hollow in which Clara Bog lies was a shallow depression with a lake in the centre. As environmental conditions became favourable for the growth of plants and algae calcium carbonate began to be precipitate out of the water and was deposited on the lake bottom as marl. This period of marl deposition was very short and fen vegetation invaded the lake. The fen peats started to accumulate at about 10000 BP. The fen peat includes *Phragmites* remains, attesting to the minerotrophic nature of the vegetation. Unlike many other raised bogs, there is no record of organic lake mud deposits prior to the deposition of the fen peat. It may be implied from this that the lake rapidly became a fen.

CL-2. Sphagnum peat began to accumulate between approximately 8400 BP and 8000 BP. *Calluna* was also growing at this time. This period of ombrotrophic peat growth was probably due to a local fluctuation in the ground-water table as no evidence for a more widespread change has been reported from other midlands sites.

CL-3. At 8000 BP the fen peat began to accumulate again, and *Phragmites* and sedge remains can be seen in the sediment.

CL-4. At 6300 BP ombrotrophic peat once more began to accumulate as the accumulating fen peat reached the level of the ground-water table. During the period from 6300 BP to the present, the peat forming vegetation expanded to cover an area much larger than that occupied by the original lake. Stumps of pine trees which were rooted on mineral soil and became covered by peat can be seen at the cutaway margins. Well humified *Sphagnum* makes up the bulk of the fossilised

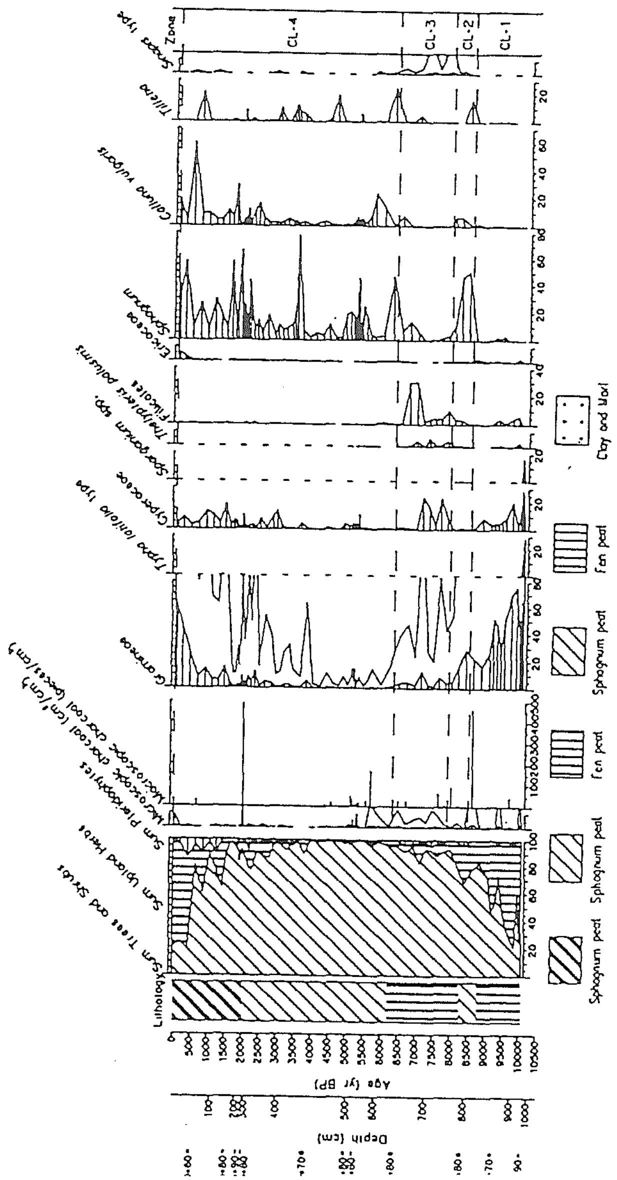


Figure 10. Summary local pollen percentage diagram from the main core on Clara Bog

plant material from 6300 BP to 2000 BP. After about 2000 BP the peat was less humified, indicating wetter conditions on the bog surface, and possibly also in the region. This change in humification occurred during the period associated with the Iron-Age decline in agriculture.

Drainage, particularly that associated with the main road, has been having a significant impact on the bog since the early nineteenth century (Fig. 11). This has resulted in a lowering of the water levels and compaction of the peat, particularly in the area adjacent to the Clara–Rahan road (Daly and Johnston, 1994).

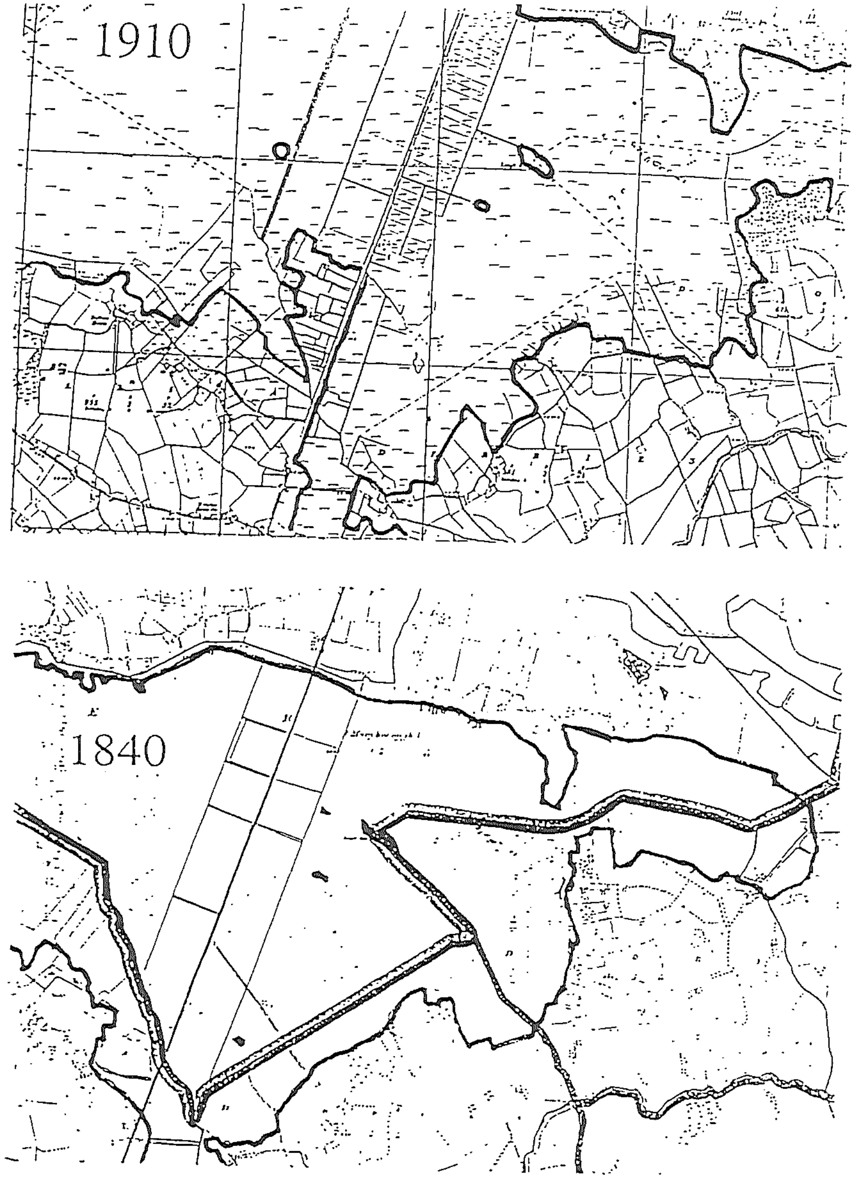
Four relatively large bodies of open water are indicated on Ordnance Survey (O.S.) maps published since 1840. Of these, one was on an area which has since been cut away; two have been infilled by minerotrophic vegetation and no longer have areas of open water, while one waterbody remains open.

Lough Roe and Lough Beag

These two waterbodies, located on the eastern side of Clara Bog (Figs. 9 and 11) were marked on the first O.S. map published. Their origins were investigated by sediment analysis using the Troels-Smith system (Troels-Smith, 1955). Radiocarbon dates were obtained for sediments from Lough Roe. Both Lough Roe and Lough Beag were found to have developed in a similar manner. Their development is summarised as follows (see Figs. 12 and 13):

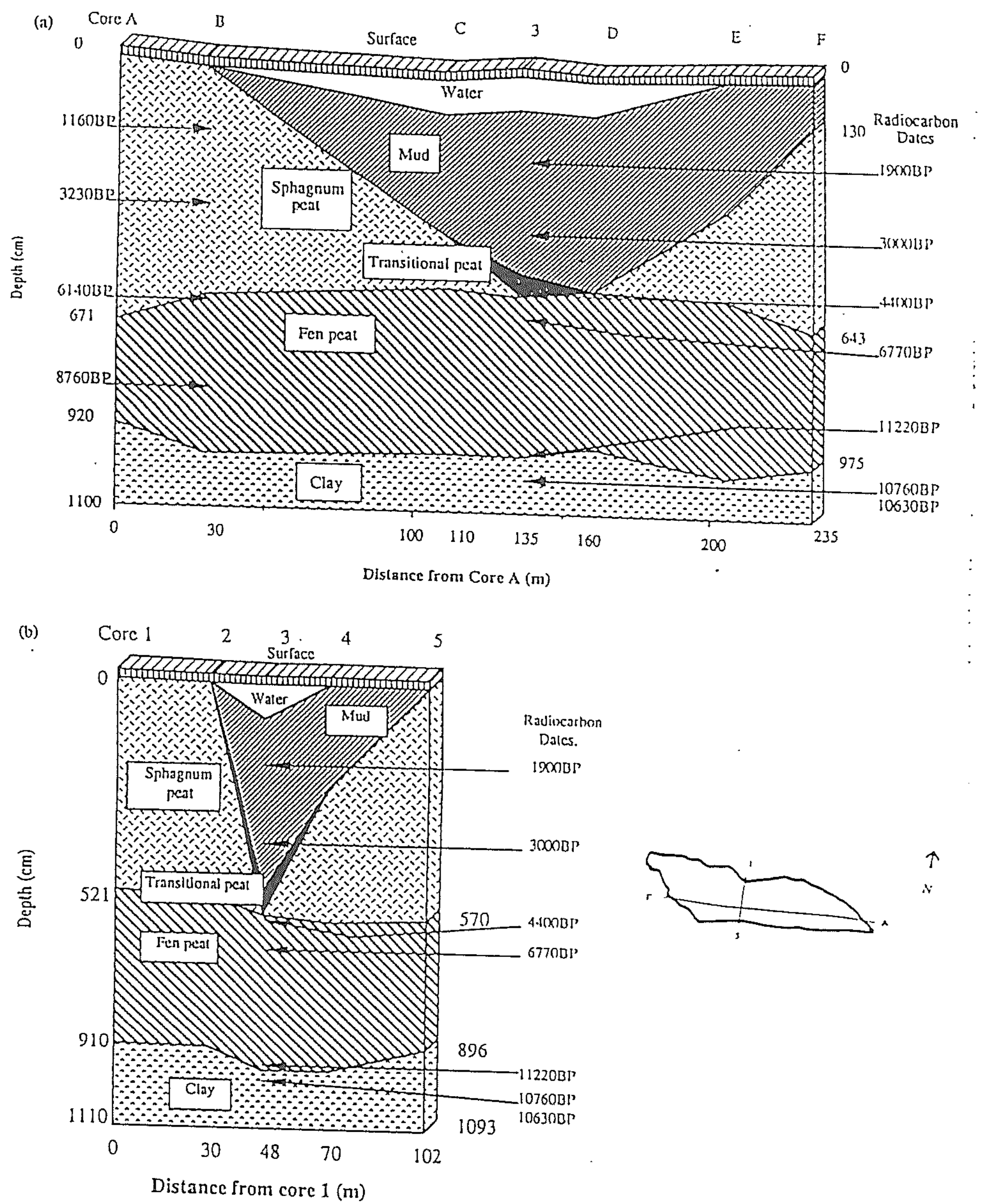
1. Lacustrine sediments were deposited during the late-Glacial and the early Holocene. As in the rest of the central bog area, fen vegetation quickly colonised the lake and fen peat accumulated, along with one episode of ombrotrophic peat accumulation, until about 6300 BP.

2. A small area of a transitional type of peat was laid down amidst the *Sphagnum* peat. The lake area expanded gradually as the surrounding peat accumulated. Radiocarbon dates indicate a delay between the change from fen to transitional peat and the deposition of lake mud in Lough Roe. Gyttja was deposited on the lake bottom, containing highly decomposed *Sphagnum* and other unidentified plant remains. This process continued until the recent past when drains were dug on the bog surface. After this, the lakes began to contract as they were infilled by fringing vegetation. This process can be seen on the series of OS maps produced since 1840. The smaller waterbodies disappeared first, while Lough Roe was not completely infilled until the 1980s.



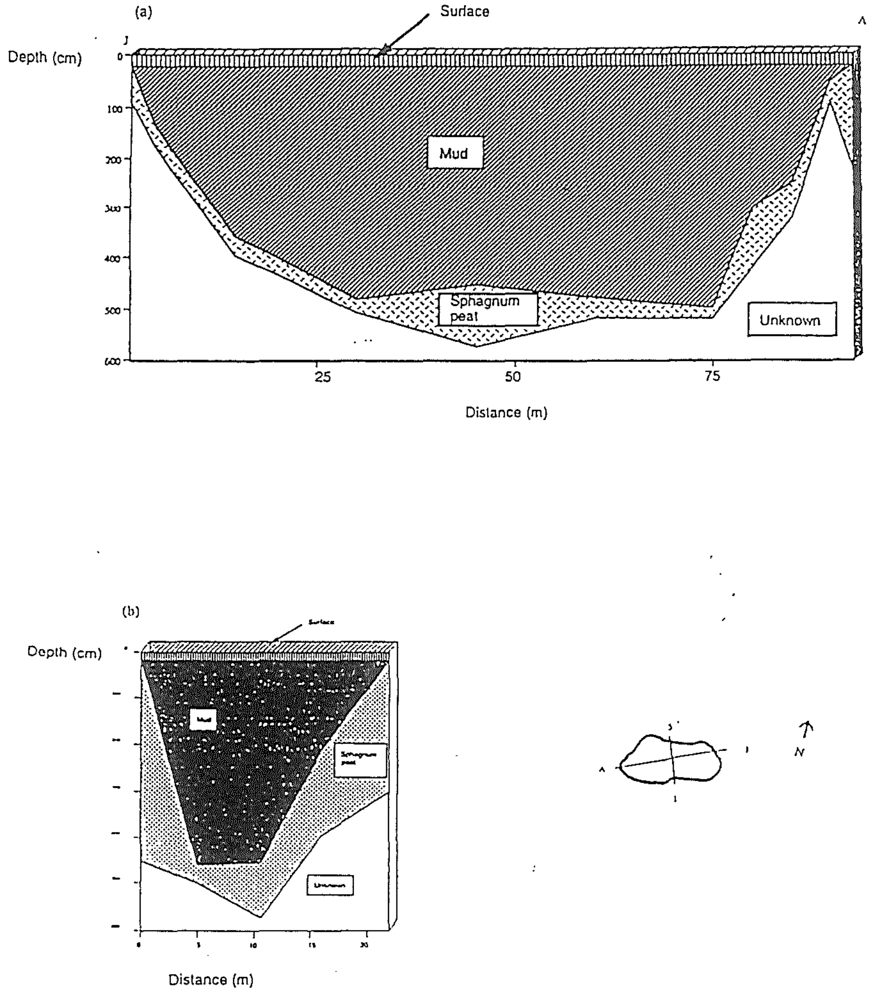
Ordnance survey maps from 1840 and 1910 showing the proliferation of drains on the bog surface and the changes in the soak features. Note the absence of Shanley's Lough from the 1840 map and the absence of birch woodland from Clara West in 1910.

Figure 11. Ordnance survey maps from 1840 and 1910 showing the proliferation of drains on the surface of Clara Bog and the changes in the soak features



(a)= Long axis, cores A–F; (b)= Short axis, cores 1–5.

Figure 12. The stratigraphy of Lough Roe



(a)= Long axis, cores A–J; (b)= Short axis, 1–5.

Figure 13. The stratigraphy of Lough Beag

Shanley's Lough and the Birchwood

Shanley's Lough lies on the western side of Clara Bog. It was first mapped on the 1910 OS map. The Lough was not present on the 1889 OS map. Unlike the waterbodies on the eastern side of the bog there is *Sphagnum* peat on the bottom of Shanley's Lough (Bloetjes and Van der Meer, 1992). The underlying stratigraphy is the same as for the rest of the bog. This indicates that the lough probably originated as a depression on the bog surface.

A stand of *Betula pubescens* exists adjacent to Shanley's Lough. This feature is unusual as it is uncommon to find closed canopy woodland on undrained, nutrient-poor peat. Several such woods are described by Cross (1987). The *Betula* stand is not regenerating and appears to be even aged. A provisional lead-210 date gives an age of approximately 60 years for the increase in *Betula* pollen at the site.

The pollen diagram (Fig. 14) shows the development of the local vegetation in the area occupied by the *Betula* stand.

CB-1 This zone shows a pollen assemblage typical of a normal raised bog surface, i.e., one dominated by *Sphagnum* and heather, with a high regional pollen input.

CB-2 This zone shows increased values for sedge and grass pollen types. The decline in *Corylus avellana* type is due to the clearance of hazel trees from the landscape.

CB-3 There was a large increase in hazel type pollen due to an expansion of *Myrica* bushes on the bog surface. This indicates an increased supply of nutrients at the site.

CB-4 A large and sudden increase in birch pollen marks the beginning of the current closed canopy woodland phase. Lead-210 dating suggests that the birch wood became established about 60 years ago.

It would appear that the woodland originated as a result of human activity on the bog surface which has caused changes in the drainage of the bog to occur. As the drainage continues to change the conditions which allowed the establishment of the stand will disappear and so will the trees.

Regional Vegetation History

In order to put the development of the bog in a regional context, a study of the regional vegetation history was undertaken. A core measuring 958 cm was taken

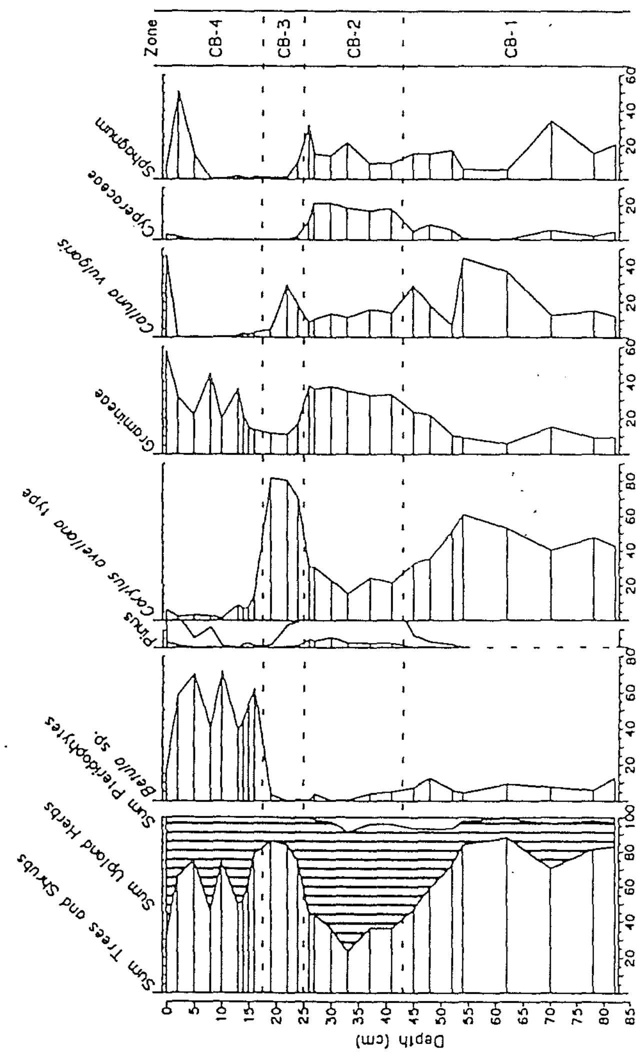


Figure 14. Summary pollen percentage diagram from the birch wood on Clara West

from the western side of Clara Bog for pollen analysis. Radiocarbon dating was used to date events in the pollen and sediment record. The pollen data was zoned using CONISS (Grimm, 1987) and five significant zones were indicated. A regional vegetation history based on these data is given below (see Fig. 15).

Zone CB-1: 958–852 cm. *Juniperus* - Gramineae - *Betula* peak zone (~10070 BP–9140 BP): This zone covers the early Holocene as tree species expanded to dominate the region around Clara. *Juniperus* was succeeded by *Salix* and *Betula* as the landscape changed from being shrub and herb dominated to being tree dominated.

Zone CB-2: 852–648 cm. *Corylus avellana–Pinus* peak zone (9140 BP–6590 BP): This zone sees the expansion of the larger forest trees in the landscape around Clara. *Corylus* and *Pinus* arrived simultaneously and became very important components of the vegetation. *Ulmus* and finally *Quercus* expanded at a later stage and gradually became very important in the region.

Zone CB-3: 648–444 cm. *Corylus avellana–Quercus–Ulmus–Alnus* peak zone (6590 BP–3890 BP): This zone covers 2700 radiocarbon years of relatively stable vegetation in the pollen catchment of Clara Bog. There are few occurrences of herb pollen in this zone, the dominant herb being Gramineae with a value of about 1%. There are declines in *Ulmus* during this zone, including one at 5000 BP. However, none of these are recorded as long lasting or particularly severe. *Alnus* expanded to replace *Pinus* during this zone.

Zone CB-4: 444–56 cm. *Corylus avellana–Quercus–Alnus* peak zone (3890 BP–510 BP): This zone covers the period when large scale human impact on the vegetation became detectable. It covers all of post-Mesolithic time at Clara, until the clearance of the last remnants of forest in the middle ages. Agriculture is detectable at the start of the zone, as *Ulmus* finally declines to low values. Later, at about 2000 BP, there is a lull in agriculture and a recovery in tree pollen percentages during the Iron Age. After about 200 years agricultural indicators re-expanded and the forest tree pollen gradually diminished in importance.

Zone CB-5: 56–0 cm . Gramineae–*Plantago* peak zone (510 BP– -40 BP): This zone starts with the clearance of forest from the landscape. *Corylus* scrub must have been almost totally removed at this time. Gramineae and *Plantago* spp. become dominant, indicating the expansion of agriculture in the landscape. *Pinus* appears in this zone having been reintroduced and *Fagus* is also present.

This history is relatively similar to that of other areas of the midlands (i.e., Mitchell, 1956) although radiocarbon dating indicates that human influence on the vegetation was quite minor until about 3800 BP and that the elm decline was not as marked as in some areas, e.g., Scragh Bog (O'Connell, 1980).

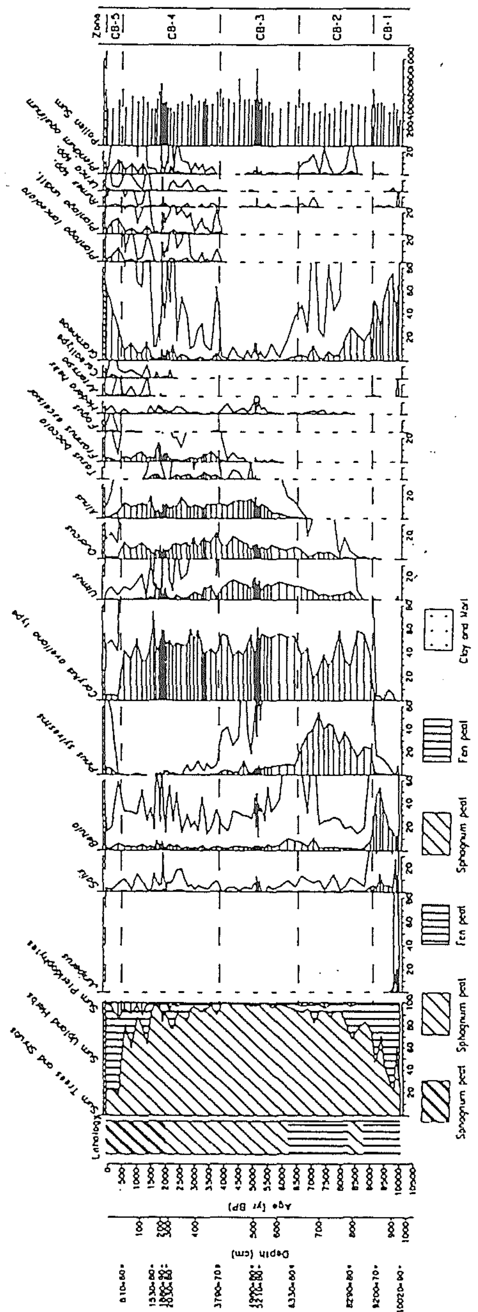


Figure 15. Summary regional pollen percentage diagram from the main core on Clara Bog

1.3 Recently Identified Archaeological Sites in Lemanaghan Works, Co. Offaly

Conor McDermott and Ellen O'Carroll

The Bord na Móna Lemanaghan Works in Co. Offaly covers 1,300 hectares of raised bog. The Works are part of a much larger area of wetlands which include areas of alluvium and callows along the River Brosna (Fig. 16). The open bogland in the Lemanaghan area was much greater than it appears today as many acres of the surrounding farmland are reclaimed peat.

At the centre of these wetlands there is a large dryland island. This was the site of an ecclesiastical centre founded by St. Manchan before his death in 645 AD. Associated with the remains of a Medieval Church are ninth and tenth century cross-slabs and also some Romanesque architectural fragments survive. The ecclesiastical centre is now better known for its associated metalwork - the fragments of the 11th century Lemanaghan Crozier recovered from the bog and the 12th century Shrine of St. Manchan.

The central area of Lemanaghan Works has been worked by B.n.M. since the 1950's. Production was extended into adjoining bogs from the 1970's. The Irish Archaeological Wetland Unit first started work in the Lemanaghan Works in 1993. These Works are composed of the five bogs of Derrynagun, Curraghalassa, Kilnagarnagh, Corrhill and Lemanaghan. Since then further surveys have been carried out in 1994, 1996 & 1997. The survey was restricted to the commercial B.n.M. area as it represents the single largest threat to the wetland archaeology.

To date over 660 new archaeological sites and artefacts have been found. The number of sites from each bog is Lemanaghan 205, Derrynagun 111, Curraghalassa 150+, Kilnagarnagh 19 and Corrhill 175+. This figure when combined with the results of other I.A.W.U. surveys in northwest Co. Offaly brings the total number of sites to over 800. Most of the sites are located in the peripheral bogs where peat extraction started at a later date. Despite this, there are five times the national average number of sightings per hectare in the Lemanaghan Works. This gives Lemanaghan one of the highest densities of wetland archaeological sites known in Europe.

There is a considerable variety in the types of archaeological sites which have been discovered. Some are small deposits of wood used to cross areas of localised

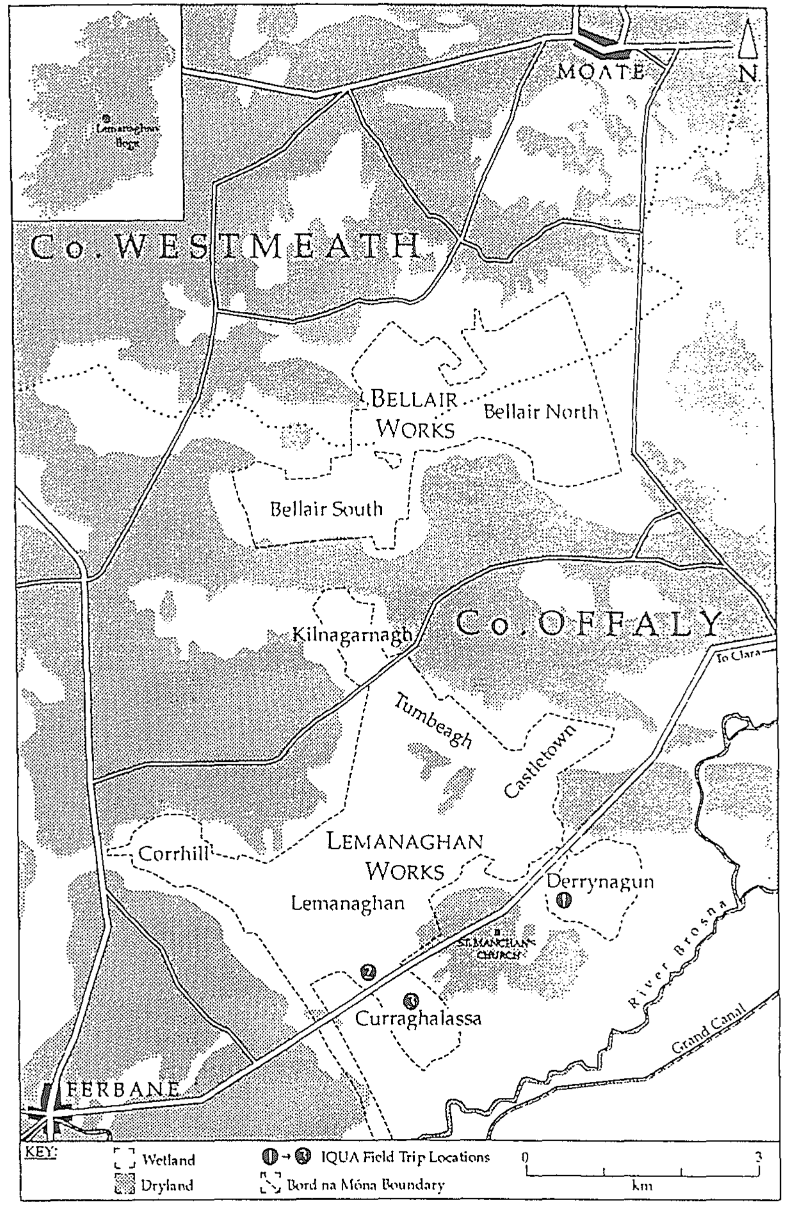


Fig. 16. Location map of Lemanaghan Works

wetness on the bog surface. Others are stake and post rows, sometime several hundred metres long, for which no definite function has yet been identified. Many of the remaining sites are trackways and they vary considerably in construction. They can be constructed of brushwood and/or roundwoods and can sometimes be traced over long distances. Others are longitudinal plank walkways secured by pegs and supported beneath by cross timbers or roundwoods. One such site was excavated by Nóra Bermingham of the I.A.W.U. in Castletown Bog and dated to the late seventh century AD (Fig. 17). The two least common types are made of flagstones/gravel or of hurdles (woven panels). Both of these types have also been found in Lemanaghan.

In some locations in Lemanaghan successive horizons of sites occurred in the drain faces and could be followed for up to 70m along the drain. The densities in which sites sometimes occurred made it impossible to tell where one site ended and another began.

This evidence contrasts with the common perception of bogs as an empty wilderness devoid of human presence. From the Lemanaghan material it appears that in bogs such as Corrhill and Curraghalassa there were extended periods where a structure or structures were constantly present on the bog. Once the archaeological sites were enveloped by the growing peat new sites were constructed in the area. This resulted in the formation of the archaeological horizons presently exposed in the B.n.M. drain faces.

The evidence gathered to date points to a complex interaction between the archaeological sites and the bogs in which they were constructed. In addition the number of sites in the bog would have a considerable impact on the surrounding dryland from which much of the construction material probably originated.

The three locations to visited on the field trip are designed to illustrate the points made above.

Stop 1.3.1 Derrynagun Bog

Derrynagun Bog was surveyed in 1994 and 111 archaeological sites were identified (Fig. 16 No. 1). The site types included a 130m long post row, brushwood and roundwood "puddle toghers", roundwood toghers up to 300m long and the remains of a mid second millennium BC single plank walkway. This bog produced one artefact, a perforated wooden shaft found in isolation on the milled surface.

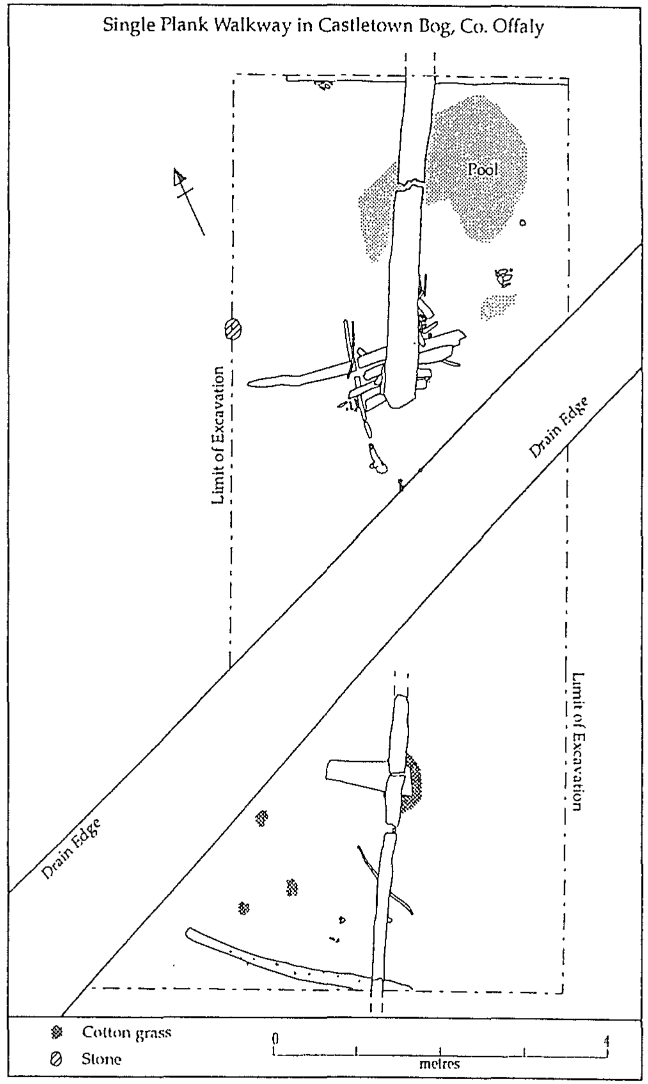


Fig. 17. The superstructure of a single plank walkway in Castletown Bog

During the course of the 1994 survey a trackway was identified to the north-east of Lemanaghan Island in the Bord na Móna bog. It was traced for a minimum distance of 750m. Although not visible in every drain face the track could be traced by the grassy vegetation which grew on the surface of the bog along the line of the site. Several phases of construction were associated with this track and in 1996 the site was returned to and a small excavation was carried out by Ellen O Carroll of the I.A.W.U..

A small excavation measuring 10x2 metres was undertaken on the site. This revealed five phases of construction with some possible phases of abandonment indicated by the development of peat between some layers. Each phase was clearly defined by the use of different construction methods and materials.

The earliest construction phase was a longitudinal plank walkway consisting of three split oak planks. The total width of this structure was 1m and the depth was 52cm. Phase 2 consisted of a layer of redeposited boulder clay situated directly on top of the planks. This deposit was very substantial measuring 3.4m in maximum width and 40cm at its deepest point. Immediately above the boulder clay was a layer of well humified *Sphagnum* peat which may indicate a time when the use of the site was in decline. Phase 3 was constructed above this peat layer. It consisted of split oak planks laid transversely across the site (Fig. 18). A substantial amount of brushwood was then interwoven in and around these planks. Directly above Phase 3 was another layer of *Sphagnum* peat which may also indicate a period of decline. Phase 4 was composed of redeposited boulder clay on a much smaller scale than Phase 2. It was up to 2m in width and 10cm in depth. The final phase constructed (Phase 5) consisted of a flagstone layer up to 2.16m wide and 20cm deep. These flagstones were very flat sandstone slabs and would have made a very even walking surface.

Dendrochronological dates from two of the phases of construction indicates that this site was in use for over 600 years. The first phase of construction has been dated to AD 653± 9 (Q9281). The second date was from a split oak timber of Phase 3 which dated to AD 1158 (Q9282).

The first phase of construction, the plank walkway, is broadly contemporary with the establishment of the monastery by St. Manchan in 645 AD on the dryland. It may therefore be associated with the monastic site but as the trackway continued in use it probably became part of major network across the large expanses of bog in the midlands.

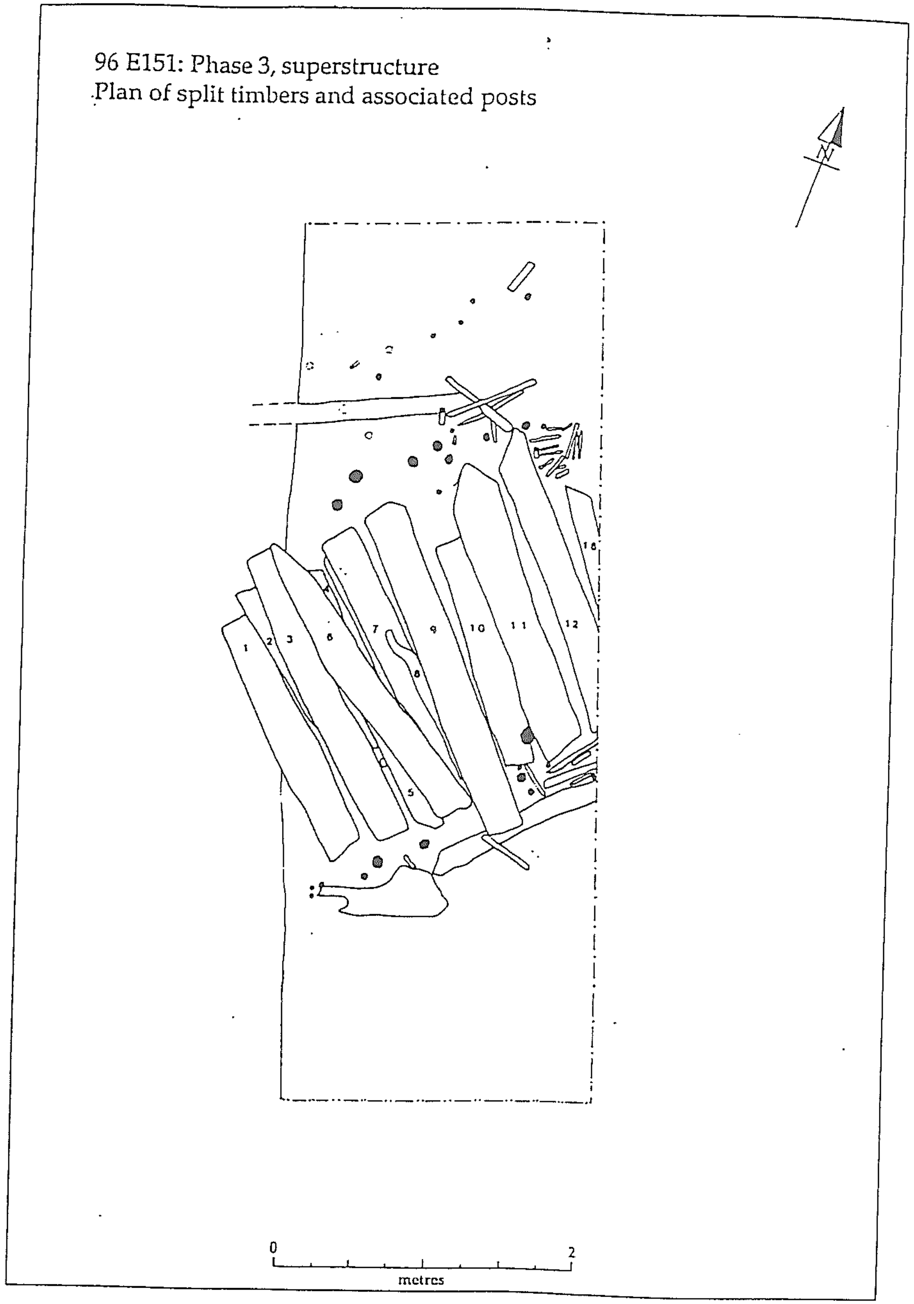


Figure 18. Phase 3 of the roadway in Derrynagun Bog

Stop 1.3.2 Lemanaghan South

In 1993 a number of archaeological sites were identified near to the northern side of the road running from Lemanaghan to Ferbane (Fig. 16 No. 2). One of these sites was a multi-phased construction of flagstones, gravel, planks and brushwood similar to the site excavated in Derrynagun. In one location, at the eastern side of the Bord na Móna owned area, extremely disturbed material was traced along a B.n.M. drainage ditch for a distance of 170m. The adjacent drains 15m away on each side were examined and no archaeological material was observed. This indicated that the site was likely to be trackway running almost parallel to the drain and cut by it. Fragments of stone and wood were noted on the field surfaces beside the drain. Although some of this material appeared to be *in situ*, it was difficult to distinguish it from debris upcast by ditching.

At one point along this stretch of the site (LMN South 3) a number of oak timbers were noted below the disturbed material. A small test trench 0.5x2m was opened across this part of the site which revealed 4 layers of construction with peat accumulation between the phases. The maximum depth of material recorded was 85cm. The uppermost layer was composed of three tangentially split planks arranged longitudinally and some outlying roundwoods. Layer 2 consisted of a dense deposit brushwood on the northern side and roundwoods to the south. It measured 1.7m in width and 30cm in maximum depth. Layer 3 consisted of a this band of gravel 90cm wide and 5cm in thickness. The lowest layer was of gravel and stone measuring 1.25m wide and 35cm in maximum thickness. Due to flooding it was not possible to excavate deeper.

One of the planks in Layer 1 produced a dendrochronological date of 1219±9 AD (Q9252). This indicates that peat has been removed from over the site at this location and it is not known if this contained further archaeological layers.

A second test trench was opened on a very similar structure 220m to the northeast. The composition of the site and the depth of stratigraphy were the same and it is likely that these are two sightings of the same structure. When both of these were projected towards the dryland to the east a linear feature covered by grass was noted in private land. This was traced for approximately 100m and at two locations flagstones were visible on the field surface.

This site on the western side of Lemanaghan island has produced a date that is remarkably similar to the excavated site in Derrynagun Bog and at the very least

they were broadly contemporary. The similarities in construction materials and the multi-period nature of the sites make it seem likely that they formed parts of a continuous routeway. The ecclesiastical site would then have been a stopping point on an important communication network rather than a place of isolation.

Stop 1.3.3 Curraghalassa Bog

The 1996 survey started in Curraghalassa Bog and over 150 sites were recorded as well as a number of artefacts. Although the drainage ditches have been cut in this bog no milling has taken place and some surface vegetation remains. Towards the centre of the bog there are two small, tree covered gravel knolls that stand above the bog. The sites were widely spread across the bog to the north of these knolls and for a short distance to the south of them. Site types recorded included small deposits of worked wood and toghers constructed of planks, roundwoods and brushwood. A delicate hurdle that was almost completely destroyed was also recorded.

Of particular note were areas with high site densities identified during the survey (Fig. 19). Some drain face exposures had horizons of archaeological material up to 1m in depth which clearly continued below the base of the drain. Although the survey identified the areas of highest site density it was clear that a considerable number of sites remain to be found. Seven sites from a number of locations in the bog that were recorded near the drain bases were dated from the latter half of the sixth to the first half of the seventh centuries AD. In the absence of excavations and considering the complexity of the material the classification of many of the sites in this bog is regarded as provisional.

Two leather shoes were recovered from this bog. One was from a disturbed context and is Medieval in date while the other, which was found close to the remains of the hurdle, is post-Medieval. A number of other leather fragments were recovered from disturbed contexts. A cluster of wooden artefacts was uncovered below the base of a drain among the timbers of a damaged site. The site was part of a horizon of structures one of which, 60cm above, has been dated to the seventh century AD. The artefacts included the lid and base of a stave built vessel, fragments of a possible second vessel and a dressed and perforated wooden beam. Elsewhere part of another perforated shaft was uncovered which had been incorporated into the structure of a site.

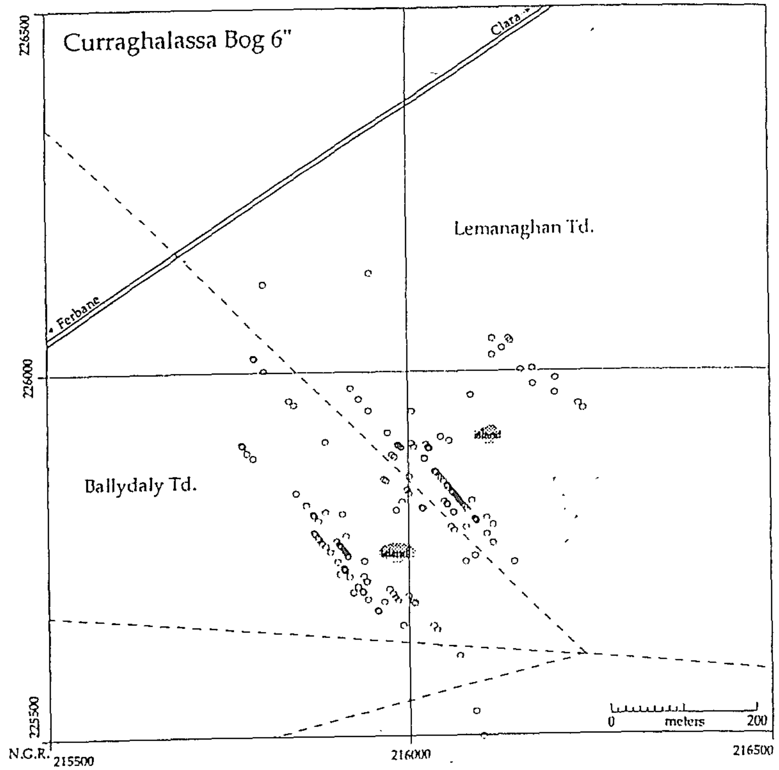


Fig. 19. Plot at 1:10560 showing the density of archaeological sites in Curraghalassa Bog

1.4 Clonmacnoise Monastery

Conleth Manning

A considerable amount of research has been done on the archaeology of Clonmacnoise in recent years especially within the last decade. Naturally enough much of this work has still to be fully published and in this short contribution I merely intend to give a brief summary of what work has been done under different headings, with references to what has been published. For a general account of the site see the official guidebook (Manning 1994a).

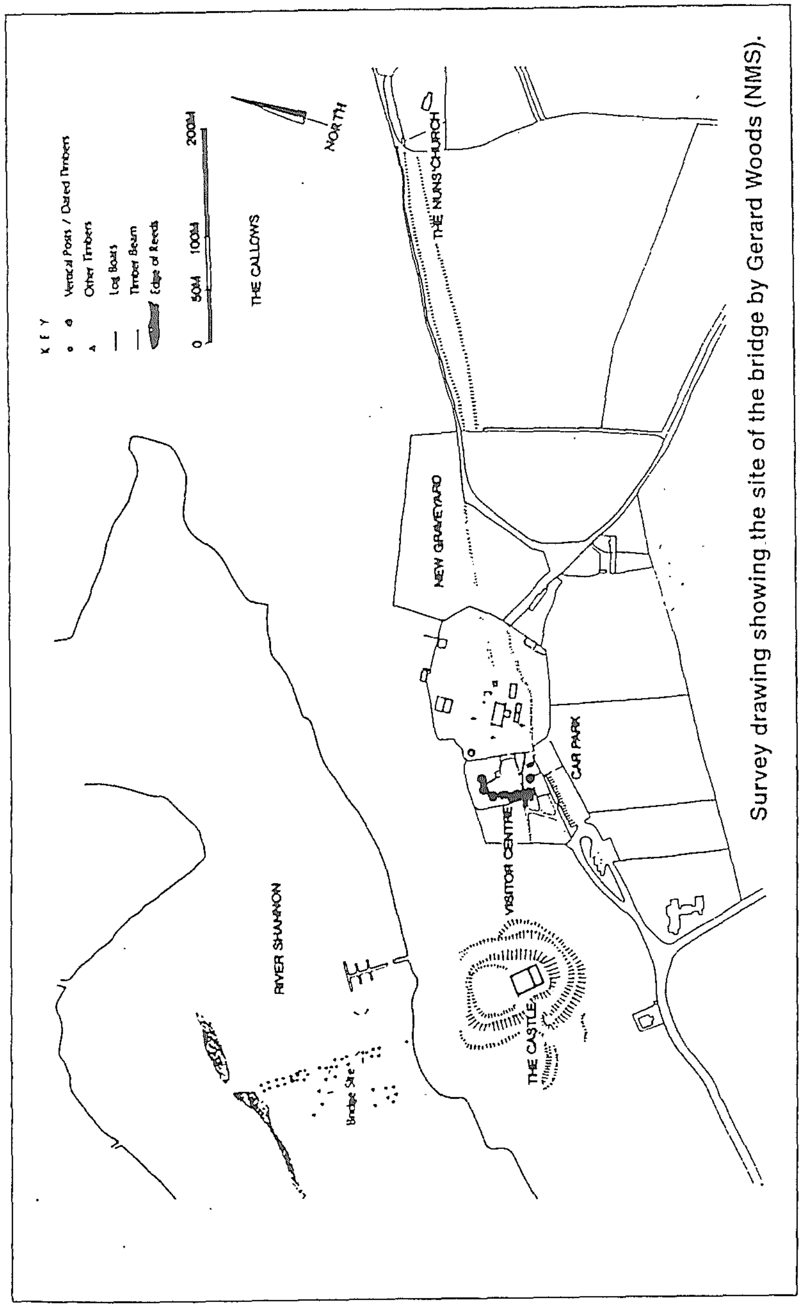
Excavation

The first of the recent series of excavations was that carried out by the National Museum under the direction of Raghnall Ó Floinn in 1979 in the playing pitch of the National School (Fig. 20). A hoard of Viking coins was found when holes for new goal posts were being dug and a small archaeological excavation was undertaken which confirmed that this area was part of the settlement in the 11th century (Ó Floinn 1987-8).

A series of larger excavations was undertaken by the National Monuments Service under the present writer's direction in 1985 and 1989-90 in advance of the building of the Visitor Centre within what was then known as the Steeple Garden. The north and south ends of the garden were on east/west gravel ridges with a hollow, sloping down to the west between them. In this hollow the build-up of archaeological deposits and garden soil was as great as 2m at the centre while on the gravel ridges the undisturbed sand was just below the sod in places. Structures found included a gravel roadway, a kiln and stakeholes of buildings and fences. Evidence was also found for both bronze and iron working and some limited garden cultivation in one phase. The use of this area continued into the 13th century and one pit produced a coin of King John (Manning 1986, 1990, 1991).

The most recent series of excavations have been directed by Heather King of the National Monuments Service and consisted of a major rescue excavation of the north-west corner of the new graveyard, prior to use for burial, and excavation beneath and around each of the three crosses in the main graveyard in connection with the removal of the originals into the Visitor Centre.

The excavation in the new graveyard is of great importance in that it has uncovered the layout of houses and yards in association with a roadway giving us for the first time a view of what part of the domestic area of one of our more important early



Survey drawing showing the site of the bridge by Gerard Woods (NMS).

Figure 20. General map of the entire site including the bridge

ecclesiastical sites might have looked like. The evidence for the houses takes the form of stone-revetted platforms. A boat docking area, a river-side embankment, corn-drying kilns and metal working areas have also been recorded. The activity in this area centres mainly around the 8th-10th centuries and a large collection of artefacts has been uncovered including bronze pins and other decorated objects, antler combs, bone trial pieces and many stone and iron objects (King 1991, 1992a, 1992c, 1993, 1994a, 1995, 1996).

Excavation under the South Cross and the Cross of the Scriptures gave indications that these crosses were preceded by wooden crosses in the same locations. Early burials were also uncovered around the Cross of the Scriptures (King 1995).

The Crosses, Cross-Slabs and Ogham Stone

The crosses have been the subject of much published research and debate in the last twenty years but there are still conflicts of opinion on a number of issues especially the dating of the Cross of the Scriptures, the identification of a number of the panels on it and the dating of the cross fragment with the confronted lions (Hicks 1980; Henry 1980; Edwards 1984; Edwards 1986; de Paor 1987; Stalley 1990; Richardson and Scarry 1990; Harbison 1992; Fitzpatrick 1993). Excavation around the base of the North Cross in 1990 showed that it was a reused millstone and that it formed part of a composite base like examples recorded from Iona in Scotland (Manning 1992). This would tend to confirm the early date of around 800 AD normally assigned to this cross.

The collection of cross-slabs with over 600 complete or fragmentary examples is the largest in Ireland or Britain. Further examples have been coming to light almost every year, recently, during excavation and other work in and around the site. There is need for a major recording programme and study of this internationally important collection. Probably the oldest inscribed memorial of them all, the ogham stone, was recovered from the new graveyard in 1990 (Manning and Moore 1991).

The Buildings

Recent research combining a detailed physical study of the fabric of the Cathedral with a new evaluation of historical references to it and of the history of Clonmacnoise generally has thrown much light on the building history of this enigmatic structure (Manning 1995 and forthcoming). The original building was erected in 909 by the Flann, king of Tara, and the abbot of Clonmacnoise, Colmán. Most of the surviving north wall and much of what is left of the east and west walls belong to the first phase and consist of roughly coursed sandstone masonry with

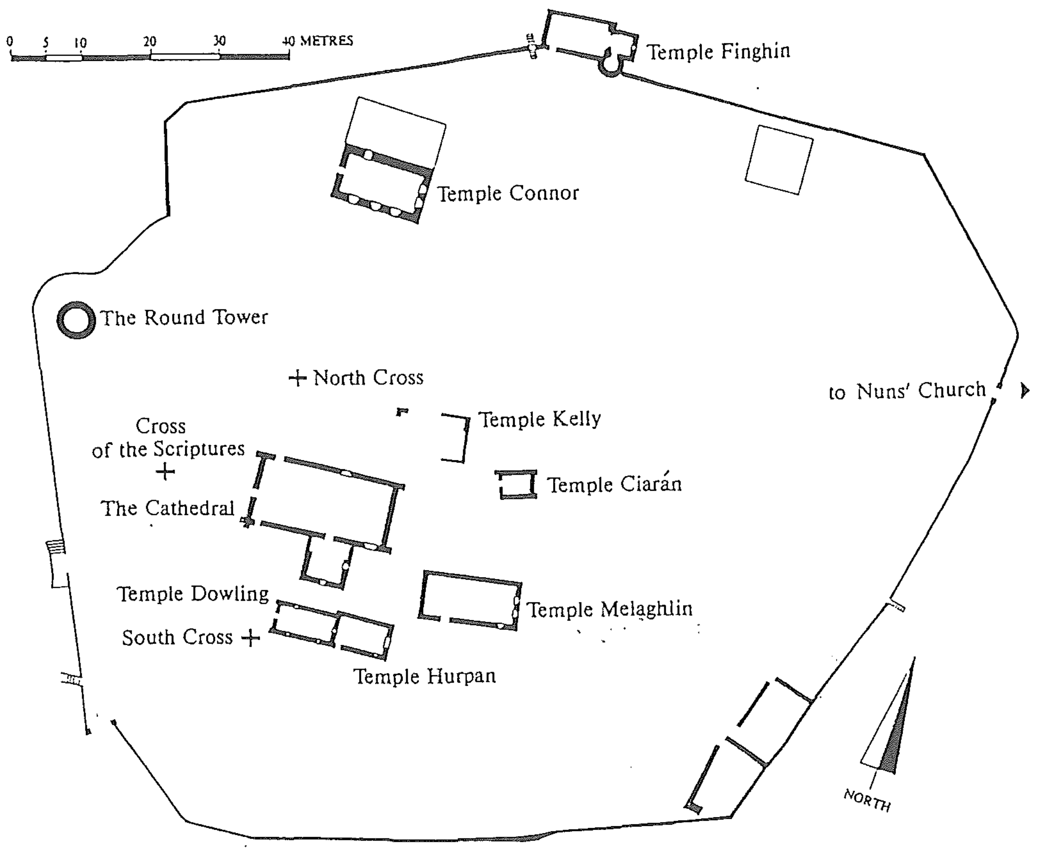


Figure 21. A plan of the graveyard showing the main monuments

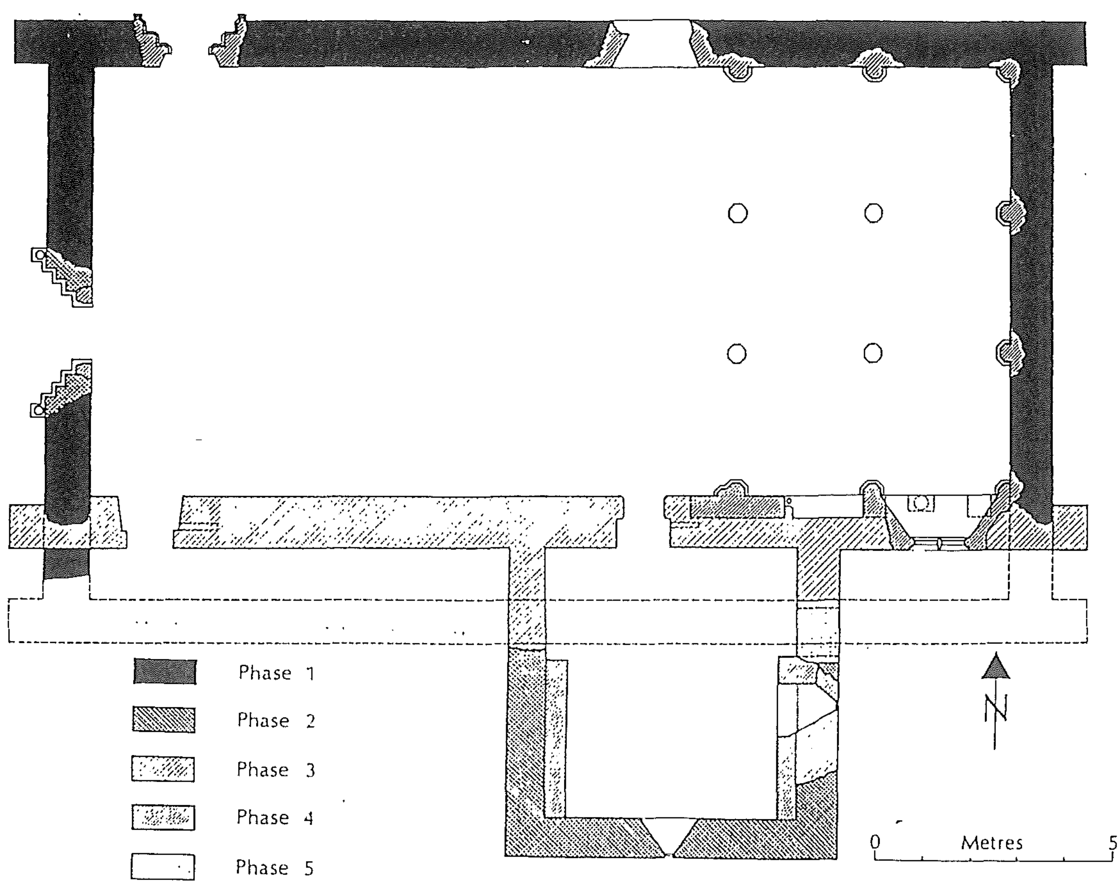


Figure 22. A plan of the cathedral showing the building phases and the line of the missing phase-1 south wall

putlog holes penetrating the wall (Fig. 22). No other features survive apart from the antae projecting from the ends of the north wall. The original south wall was two metres further south. It was taken down and rebuilt north of its original line around the late 13th century (Phase 3) and this simple fact explains why the west doorway is excentrically placed in the present west wall. This elaborate doorway with its pointed arch is a Transitional Style (Phase 2) replacement of the original. The original sacristy building was also added to the south during this phase and the walls of the nave were heightened. In contrast to phase 1 the phase 2 masons used mostly limestone. This work may date from 1207. The latest major phase of work on the building dates from the mid 15th century and included the vaulting of the east end of the church and the sacristy, the provision of accommodation above both and the building of the beautiful north doorway.

The round tower, often misnamed O'Rourke's Tower and often misrepresented as being of 10th-century date, was in fact completed, as the Annals tell us, by Toirrdelbach Ua Conchobair, king of Connacht, and the abbot of Clonmacnoise, Gillachrist Ua Maoileoin in 1124 AD (Manning 1997). Only at 95% probability does the radiocarbon date range (780-1150 AD), got from mortar from the tower, include its true date.

The smallest of the churches, Teampall Chiaráin, appears to be contemporary with the cathedral to judge from the exactly similar sandstone masonry and the use of putlog holes and deep antae. The doorway, of which only half survives was round headed and appears to be original. The cross fragment with the confronted lions was found reused in the original north jamb of this door, a fact that gives strong support to the earlier dating of around 800 for this cross. Radiocarbon dating carried out on the mortar of this church (Berger 1995, 169-70), which gave at 95% probability a range of AD 660-980, would support an early 10th-century dating for the building (Manning forthcoming).

1.5 UNDERWATER EXCAVATIONS OF AN EARLY MEDIEVAL WOODEN BRIDGE AT CLONMACNOISE, CO. OFFALY

Donal Boland and Aidan O'Sullivan

Underwater archaeological sites are only now beginning to appear on the Irish archaeological landscape. Despite the abundant potential in our lakes, rivers and coastal waters, it is only really in the last few years that archaeologists have been trained in scuba techniques. Some underwater divers, themselves vastly experienced in diving our midland lakes and rivers, have also become interested in being involved in the archaeological investigation of crannogs, fording places, bridges and other features. Recent archaeological survey and excavation in the River Shannon at Clonmacnoise have lead to the discovery of a substantial Early Medieval wooden bridge on the riverbed. Other finds include nine dug-out wooden boats, four Early Medieval iron woodworking axes, a large Early Medieval decorated bronze basin, iron slag, a whetstone, animal bone and a Mesolithic chert core. The bridge, boats and metalwork can be interpreted in terms of the regional politics and urban economy of the monastic town of Clonmacnoise, Co. Offaly.

Archaeological, Geophysical and Palaeoenvironmental Investigations 1994-97

The bridge was first discovered in summer 1994, when two local underwater divers began underwater survey on the riverbed of the River Shannon at Clonmacnoise, convinced that riverine structures relating to the monastic site could be located there. The divers, Donal Boland and Mattie Graham, supported by the National Monuments Service and its archaeologist Fionnbarr Moore, were also armed with a peculiar annalistic reference from the *Annals of Clonmacnoise* for the year 1158 AD, which reads as follows.

"There was a conuocation of all the clergie in Ireland at Breyuick Teige. The bishops of Connaught with the archbishop, Hugh o'Nosyn, tooke their jorny to come thither, & as they were passing towards Clonvicknoise with 2 of the cowarbs of St. Queran in theire company, and as they were comeing to the joysts or wooden bridge over the Syenn at Clonvicknos called Curr Clwana, they were mett by the rebell Carpreach the swift and his kearne, whoe killed two laymen and robbed the clergie."

When the divers reached the medieval castle, they encountered a large vertical post driven into the soft silt of the riverbed just off the Offaly bank. A search line was then laid directly across the river from this post. Underwater search along this line then revealed several other vertical posts and horizontal beams on the riverbed, especially well exposed on the Roscommon shore where the water is quite shallow (Fig. 20). In 1995, a two-week underwater survey was carried out on the riverbed, funded by the National Monuments Service and carried out mostly by local IUART divers, supported by a number of archaeologists and the NMS surveyor Gerry Woods. Over 200 dive hours were spent in the water, searching an area of 10,800 square metres.

This lead to the discovery of 100 timbers spread over an area 140m by 60m. It was evident that this was a linear wooden structure of paired posts, with some in-situ timbers and large numbers of timbers that had drifted downstream. Finds included six dug-out boats, two Early Medieval woodworking axes and a whetstone. Dendrochronological dates of 804 AD were obtained from the vertical oak posts by David Brown, Palaeoecology Centre, Queen's University Belfast. This indicated that the structure far from being medieval (as suggested by the twelfth-century AD annalistic reference and its proximity to the Anglo-Norman castle), was actually contemporary with the Early Medieval monastic town of Clonmacnoise itself.

The results, while exciting, were also immediately enigmatic. What was the function of this structure? Was it a jetty (it was not then traced completely across the river), a ship barrier or a bridge? The complex carpentry, the scale and arrangement of the timbers strongly suggested that it was indeed a bridge, built of paired posts with transverse beams set inside joints in the verticals that suggested a substantial upper-structure. There were still many remaining questions. How was the bridge assembled, where was the walkway, how was the bridge supported in the soft riverbed and what was its lifespan?

It was decided by the National Monuments Service that more detailed, multi-disciplinery archaeological investigations were needed. In Spring 1997, Kevin Barton of University College, Galway carried out, with the authors assistance, a week's remote sensing on the river. Side-scan sonar and GPR technology was employed to search the dark gloom of the riverbed. Chris Blythe of the Coastal Resources Centre, University College, Cork carried out palaeoenvironmental investigations, clarifying the stratigraphy of the riverbed, as well as the Roscommon callow and the Offaly esker sands. In the summer of 1997, a six-week underwater archaeological excavation was carried out on the structure. A team of five archaeologists, divers and boatmen prepared scale drawings, took photographs and carried out sampling of the wooden structures. Despite the cold, dark and difficult visibility, the first major underwater archaeological excavations in Ireland proved to be highly successful. The bridge was traced across the entire span of the river. Considerable detail on its construction and carpentry was obtained. In particular, deep excavations were carried out around several posts and a single large vertical post was lifted, along with its beams and planks, onto the project barge and there recorded in detail.

Site Description and Interpretation

The Early Medieval bridge is situated on a relatively narrow part of the River Shannon (about 160m), but its location is more likely to have been caused by proximity to the monastery (Fig. 20). The esker slopes quickly down here to the river bank on the Offaly side, but on the Roscommon side there are several miles of raised bog before drylands is again reached. Interestingly, a gravel togher has been found in this bog, oriented directly at the bridge. This togher (Coolumber twd), composed of gravel, clay and stones and measuring about 3m in width, is almost certainly also Early Medieval in date. The river itself is fairly shallow at this point, although it never could have served as a natural ford (the riverbed is composed entirely of very soft, silty clay). The deepest part of the channel is about 60m out from the Offaly bank, where it drops quickly to a depth of 5m. The riverbed then slopes gradually up again to the north-west, reaching a water depth of 1.5m, from where it runs level into the reed-beds and up to the callows beyond. Intriguingly, the archaeology of the structure (see below) would suggest that the Early Medieval riverbed is presently mostly exposed at the bottom of the river. Reconstructing the original water depth is more difficult, but it is unlikely to be very much higher than that of today.

The bridge was constructed by driving two parallel lines of posts vertically into the river clays to a depth of 3.5m. This was accomplished by arranging the posts in pairs, the upstream and downstream posts being about 4-5m apart and each pair spaced at 5-6m intervals across the river. Our discovery of several narrow, sharpened roundwood posts beside these massive verticals indicates that the alignment of the bridge was first marked out by quickly driving in a line of hazel and alder saplings across the river. The large vertical posts were all of roundwood oak (diameter about 40cm) which had been hewn to a square cross-section, leaving sapwood along the edges. The verticals were sharpened to a blunt point with iron axes. The tips of these points had two augur holes drilled through them, for as yet unknown reasons.

The posts were prevented from sinking into the deep semi-liquid clays by an ingenious system of individual baseplates. Each vertical post held a transverse oak beam in a mortise. These beams projected out either side of the vertical and themselves held two cleft oak planks in mortises (Fig. 23). These planks were arranged so that each was joggled tightly up beside the vertical. These planks and beams acted as a baseplate, so that the vertical as it was driven down, halted its descent when the planks touched the riverbed. Although this is the common theme, the arrangement of timbers through the verticals varied. In particular, on the Roscommon side, the baseplate was crudely made. Only a single hewn trunk was rammed through the mortise, it being hoped that this would suffice. It didn't. In each case where only a single hewn beam was used, it broke or tilted, dragging

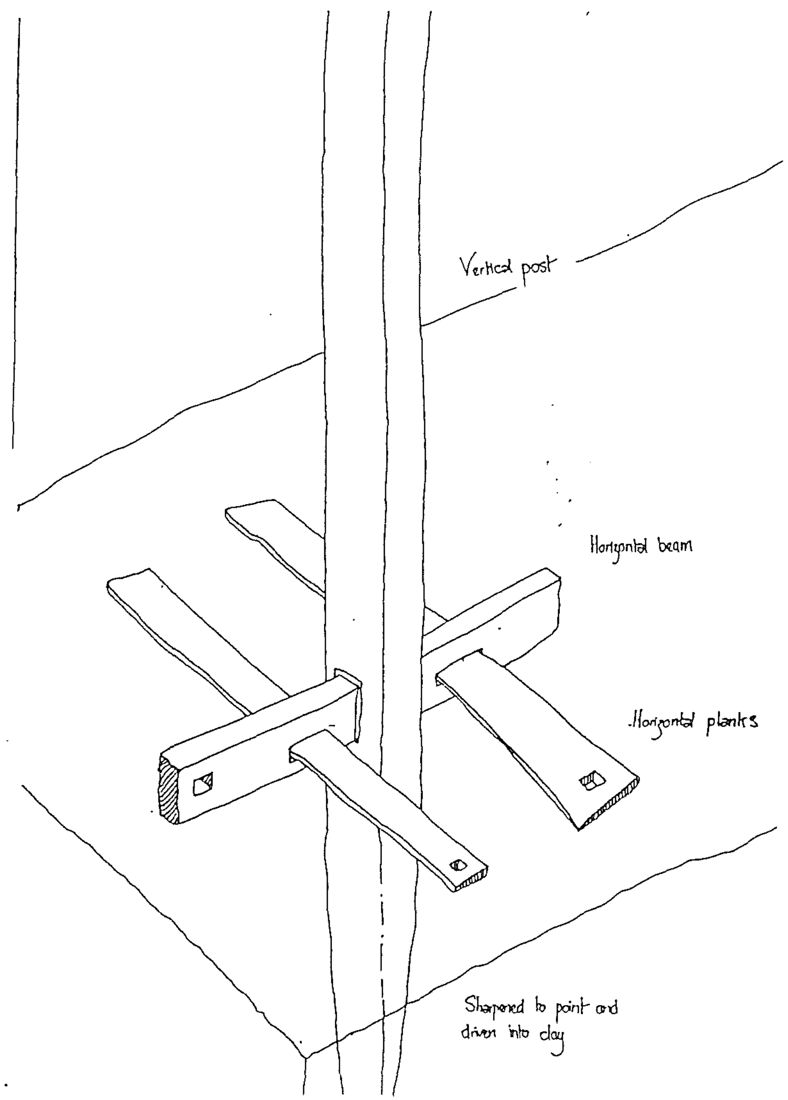


Figure 23. Reconstruction of vertical posts with beams and planks

the broken transverse down into the soft clays.

Reconstructing the upper structure of the bridge will be a slightly more difficult interpretative task (Fig. 24). Fortunately, the upper portions of some of the vertical posts are lying on the riverbed. One horizontal oak timber measures 13m in length. It has a number of broken out mortise joints which can be used to reconstruct the location of transverse beams and other features. However it seems certain that the structure had a plank or wattle walkway on the upper part. The posts probably projected high above this walkway and there may have been a simple handrail. The structure will be informative about Early Medieval construction techniques, woodmanship and timber supply, carpenters and their tools, tree-felling, cleaving, hewing and joinery techniques. It seems likely that the oaks used were slow-grown, knotty and poor in quality. This may indicate that good-quality oaks were in short supply. The bridge probably measured about 4-5m in width at the walkway level, being well suited to the passage of herds of cattle, wheeled vehicles and large bodies of armed warriors. It makes sense that the bridge was constructed to allow such traffic, ordinary pedestrians could have crossed using boats or rafts.

There appears to be little evidence for repair or the construction of a second bridge at this point. The life-span of exposed timber bridges is typically reckoned to be about 50 years. Without repair, their life-span is even shorter. Major repairs are often required after 10-15 years, these being mostly confined to the upper deck. After about 25 years the structure is generally considered unsafe. The vertical posts typically rot after 20 to 40 years. Whatever the arguments about these details, it seems likely that this Clonmacnoise wooden bridge was out of use by the mid-ninth century AD. Where then, are the other bridges at Clonmacnoise, where indeed is the 1158 AD bridge? Undoubtedly there are further bridges, waterfronts and boat slip structures to be discovered on this short stretch of river.

Dug-out Boats, Metalwork and Other Finds

The underwater surveys and excavation have uncovered a range of other finds on the riverbed. There are at least nine dug-out boats along the line of the bridge, and both upstream and downstream of it (Fig. 25). These dug-outs, originally carved from whole roundwood trunks with axe and adze, vary in form. Several are found in close association with the bridge timbers and probably also date to the early ninth century AD. They survive in length from 5.5m to 3m, with a typical surviving width of 60cm. There are also some interesting details. One dug-out boat found beside a vertical bridge post has repair patches at its end, where the boat cracked in antiquity and was fixed by nailing small carved oak planks into the internal floor. Another dug-out boat found by a vertical post had two separate wooden ribs nailed

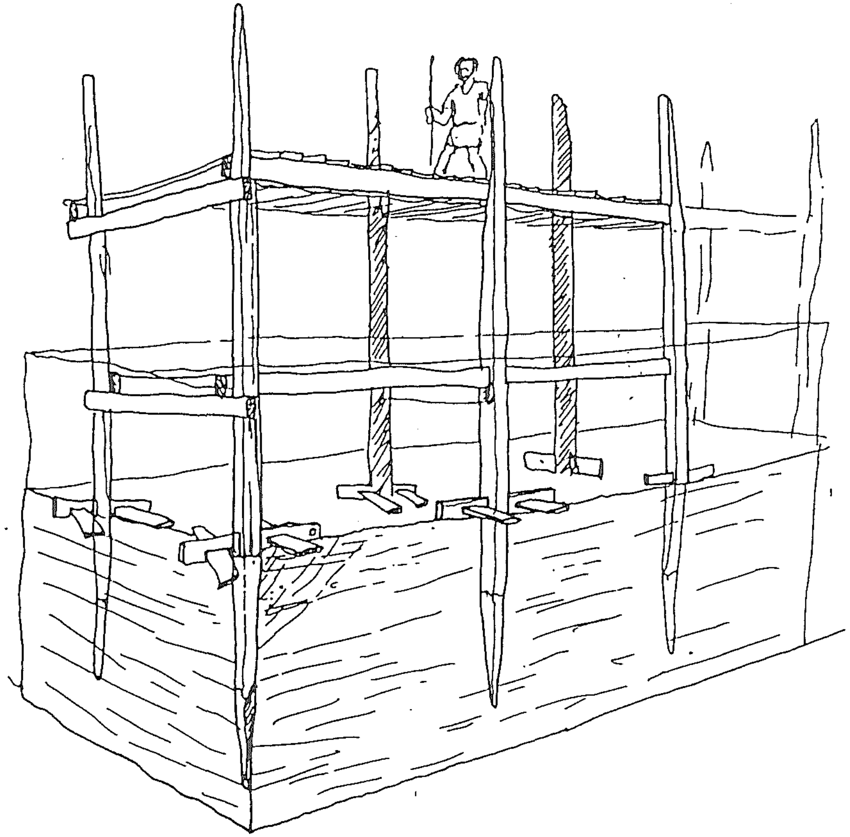


Figure 24. Preliminary reconstruction of Early Medieval bridge

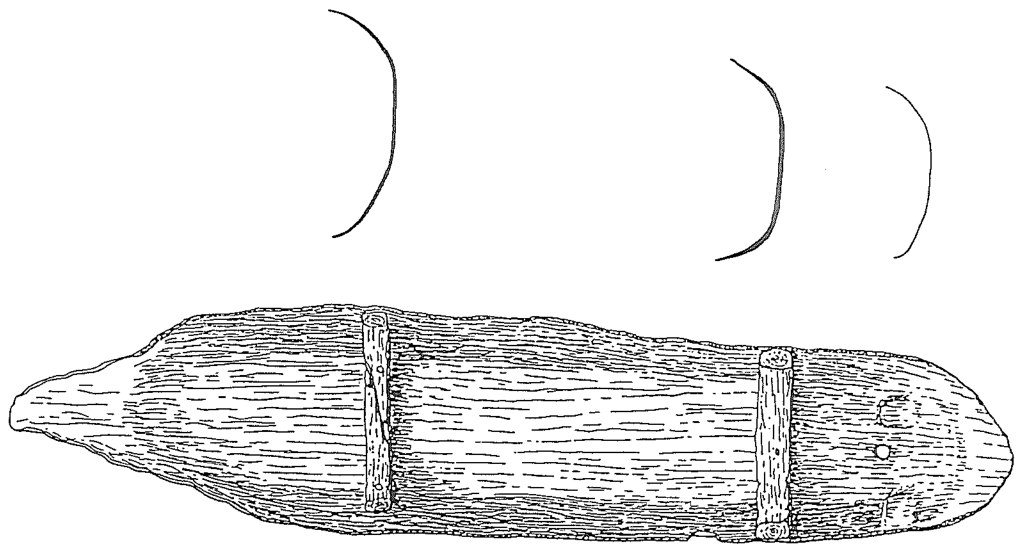


Figure 25. Dug-out boat found beside bridge, length 3.80m

and dowelled into the floor. A third dug-out found by a vertical post had two Early Medieval woodworking axes (a felling axe and a general-purpose carpentry axe) lying in the floor. These iron axes had parts of the wooden handles still in the sockets. Another dugout boat produced an Early Medieval iron axe on the floor, yet another had a whetstone for sharpening axes. Iron was common in another form on the riverbed, as large blocks and fragments of slag. This was probably dumped into the river from nearby ironworking areas.

Perhaps the most exciting artefactual find was a large decorated bronze basin of eighth-ninth century AD date. This basin was found lying in the river silts, beside a vertical post of the bridge. It is remarkably similar in size, shape and decoration to examples found in the Derrynaflan hoard, Co. Tipperary, as well as those from Derreen, Co. Clare, Thomastown, Co. Kilkenny and from a crannog on Lough Lene, Co. Westmeath. Otherwise this artefact type is more common from Viking graves in Norway. It may have had some function in the liturgy of the early Irish church, such as holding wine or in the washing of the hands. It has damage along its sides, evidently from a series of violent blows. The archaeologist is tempted to reach for the documented raids on the monastery by Irish kings and by Viking pillagers in the ninth century, as a means of explaining the loss of this valuable item in the river.

An Early Medieval Bridge at Clonmacnoise

The Early Medieval monastic town of Clonmacnoise was one of the wonders of early Ireland. The bridge would have been itself a wonder to behold, no doubt the largest wooden structure that anyone at the time could have seen. Clonmacnoise is situated at the junction of the River Shannon, itself a major nautical routeway through the country, with the Eiscir Riada which was the east-west routeway through the country. The bridge should be viewed as part of this national routeway (the original M1). However it was by no means a 'bypass bridge', because building this structure across the river meant that the Clonmacnoise monastery could control, or at least had access to, a major communications networks across the midlands. Wooden trackways have been found in the nearby bogs by the Wetland Unit, one excavated example at Bloomhill (a few miles to the north) has been dated to the thirteenth-century AD. Incidentally, there are also annalistic references to Early Medieval bridges elsewhere on the River Shannon, particularly at Athlone.

At 804 AD, Clonmacnoise was under the patronage of the overlords of Connaught. In the years ahead, it also came under the hegemony of the Clann Cholmain kings of the southern Ui Neill. Like Hiberno-Norse Dublin, Clonmacnoise was strategically placed on the border between provinces. However it was primarily a Connaught monastery, being perceived as the entrance to that province. A bridge

was an obvious construction given that it is technically in the territory of Mide. In the eighth-ninth centuries AD, the monastic town was expanding. Domestic structures and industrial working areas have been found in the vicinity of the modern graveyard by Heather King and elsewhere by Con Manning. The monastery was starting to become a centre for learning and art, with the production of such manuscripts as *Lebor na hUidre*, the high crosses, church building and fine metalwork. The bridge was undoubtedly part of this confident expansion in population and works, with an added important role in physically linking the monastery with its political hinterland.

Acknowledgements

The authors are grateful to many people for their help with the Clonmacnoise project, particularly Fionnbarr Moore, Gerry Woods and Conleth Manning of the National Monuments Service, the underwater excavation team of Brian MacAllister, Aisling Collins, Mattie Graham, John Riddeley, Colin Breen and Eddie MacPhillips and the specialists named above. The final report on the Clonmacnoise bridge will be published as a monograph in early 1998.

2.1 LANDFORMS AND HYDROLOGY OF THE CO. WESTMEATH 'LAKELAND' AREA

David Drew

The extent to which the limestones of the central lowlands of Ireland have been karstified has been the subject of speculation for several decades. Such karstification is thought to have been most likely during the Tertiary The presence of deposits of this age (determined palynologically) infilling fissures or hollows that are presumed to be karstic in origin, is the main source of evidence for the existence of such ancient karst (Coxon and Coxon 1997). The extent and character of any Tertiary karst landscapes is wholly unknown. It is assumed that during Pleistocene times karst landscapes were subject to erosion, to burial under till deposits and to periodic re-activation in warmer periods (Drew 1991).

The Area

An area of some $100km^2$ on the Co. Meath - Co. Westmeath border exhibits landforms and a hydrologic functioning that might be interpreted as diagnostic of a palaeokarst which is to some degree being reactivated. The area corresponds to the Westmeath 'lakeland' and consists of a series of distinctive isolated hills located to the east of the course of the River Inny in a band oriented northeast-southwest bounded by Lough Sheelin and Slieve na Calliagh to the north and extending to just southwest of Lough Owel (Fig. 26). To the west of the River Inny the hills cease abruptly and the terrain is almost completely flat as far as the River Shannon. Literature relevant to the area is almost wholly lacking, what there is being anecdotal and travelogue in style rather than scientific, for example Sheehan (1982) and Wallace (1987).

Landforms and Geology

The location of the highest of the isolated hills (an arbitrary height of >140m is used) is shown in Figure 27. There are some 37 such hills present in the area. Typically the hills are steep sided though the northern flanks are often blanketed by till and/or fluvio-glacial deposits (e.g. Mullaghineen, south of Lough Sheelin) obscuring the original topography. Vertical rock faces are widespread, for example on the hill south of Fore, on the Rock of Curry and on Knockeyon on the south-eastern shore of Lough Derravaghara though the cliffs are found with all orientations.

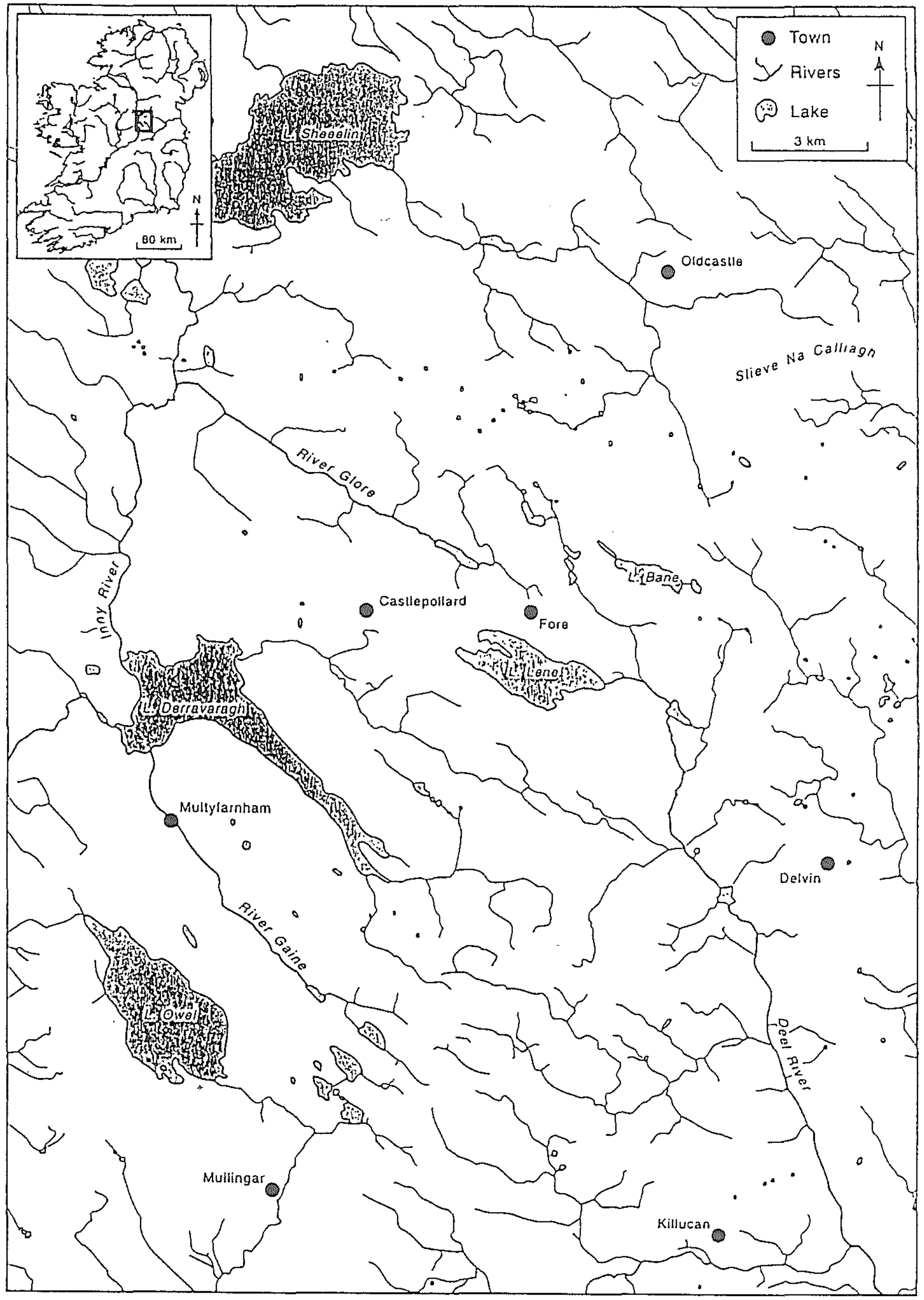


Figure 26. Surface drainage in the Co. Westmeath 'Lakeland' area

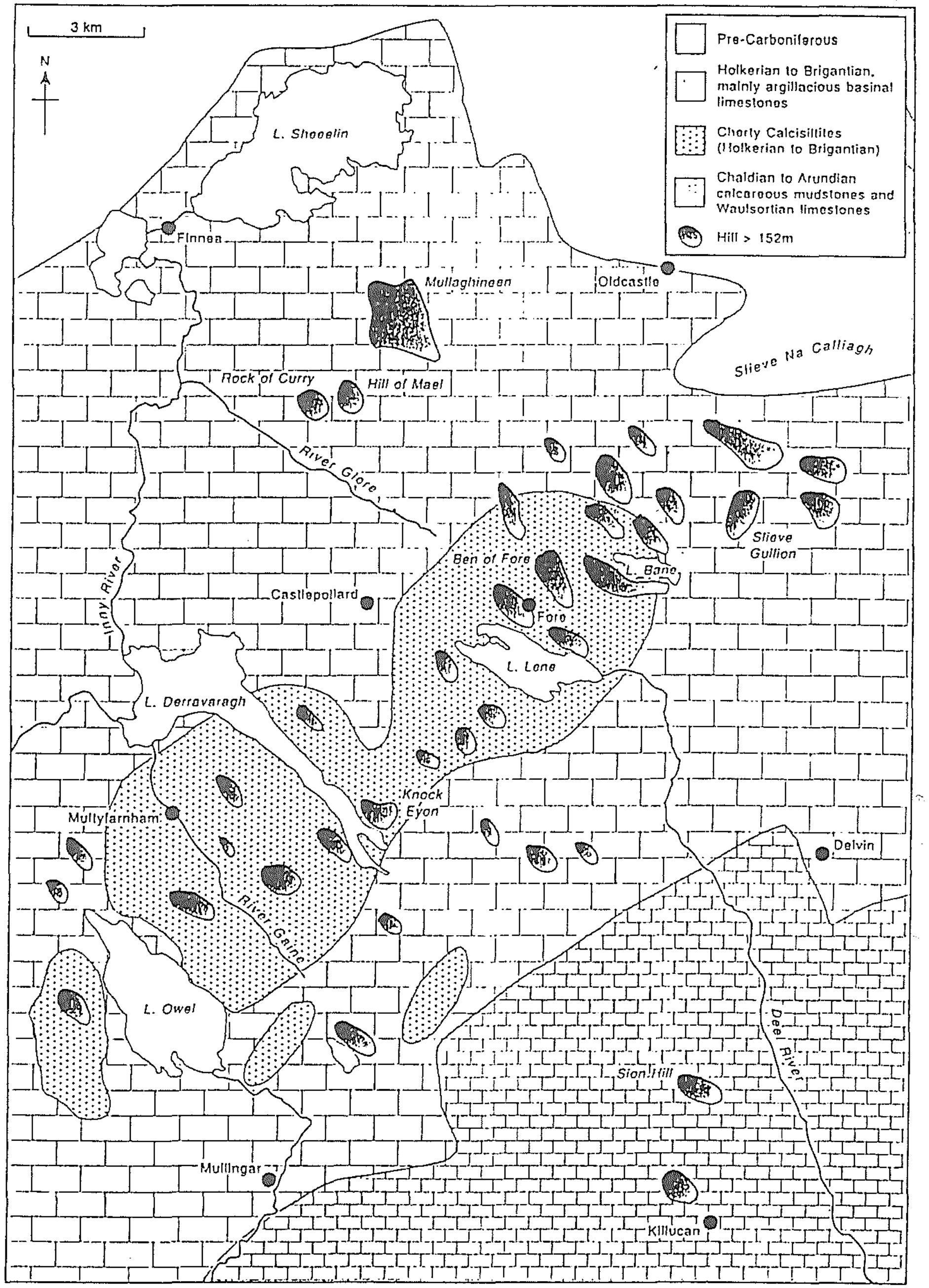


Figure 27. Geology and topography of the Co. Westmeath 'Lakeland' area

There seems to be no obvious geological explanation for the occurrence or the morphology of the hills. Figure 27 also shows the bedrock geology of the Carboniferous limestones, comprising in this area the older calcareous mudstones and Waulsortian limestones and the argillaceous limestones of Holkerian to Brigantian age (Chevron Mineral Co. 1992). The isolated hills are largely absent from the older limestones with the exception of isolated hills (calcareous mud banks?) such as Uisneach, Mount Dalton and Knockastia, all 150-180m in altitude and located to the southwest of Lough Ennell. The great majority of the hills are located in the younger limestones. It was originally considered that the chert-rich limestones, differentiated on Figure 27 might correspond to the area in which the hills occur, due to the resistance to both mechanical and solutional erosion of the cherts. In fact some 55% of the hills are located on the cherty limestones and 45% on the other basinal limestones. Similarly, the occurrence of the hills does not seem to be related very obviously to geological structure. The Hill of Mael and Mullaghineen are developed in gently dipping limestones whereas at Knockeyon the rocks dip at 80^0. Thus there does not appear to be any straightforwardly geological determinism to account for the topography.

Only the elevated portions of the bedrock terrain are visible, the areas between the hills being blanketed with unknown depths of glacial (and other?) materials. An origin for the hills due to glacial erosion of the intervening rock seems unlikely in the Irish Midlands and as has been seen a strictly geological origin is also doubtful. However, it is arguable that the terrain is comparable to that of residual karst hillocks (hums or towers) found in many lowland karsts world-wide. The presence of hill-foot caves at the Rock of Curry (Simms 1991) and fossil phreatic caves high on the hills, for example Poll na gCat (Dowds 1987) reinforces this hypothesis.

Other areas with similar isolated limestone hillocks are found in Ireland. The Stradbally Hills east of Portlaoise are developed in a variety of limestones but are similar in morphology to the Westmeath features. The Doons area south of Lough Gill in Co. Sligo has similar forms developed in impure limestones. All three of these groups of hills are located within a few kilometres of the junction between the limestone and non-calcareous rocks.

Hydrology and Hydrogeology

The lakes that dot the area are generally oriented northwest-southeast, as are some of the uplands. Charlesworth (1963) regards many of them as being dammed by glacial deposits to some degree with only Lough Ree to the west showing features that might be interpreted as flooded dolines. Many of the lakes are effluent, having no surface inflows of water but some outflow (Loughs Lene and Owel for example), whilst others have no surface inflow or outflow (Bane and White Lough).

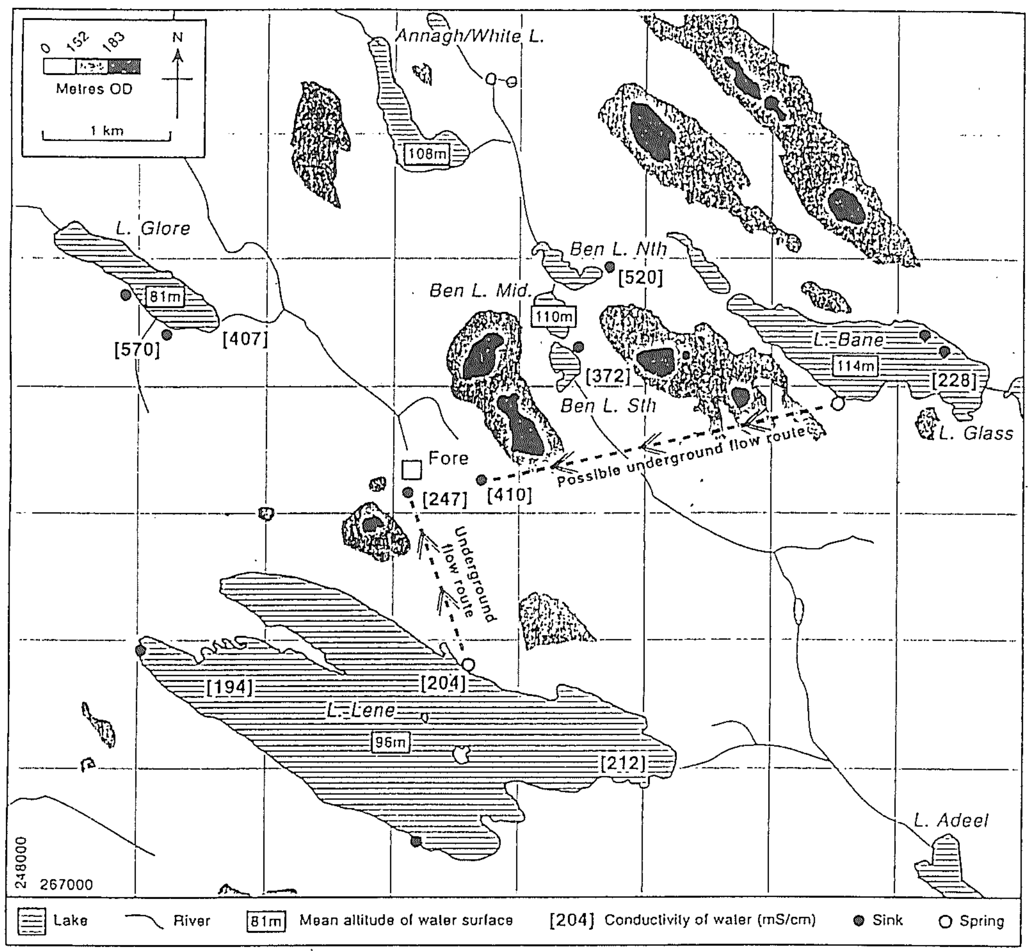


Figure 28. Surface and groundwater hydrology of the Fore area

The lakes straddle the watershed between the Inny (Shannon) and Deel (Boyne) catchments and early reference was made by Piers in 1682 (Vallancey 1771) to the fact that Lough Lene drains via a surface channel eastwards to the River Deel and subterraneously via sinkholes to (it was assumed) springs in the settlement at Fore to the north and hence flowed both to the Atlantic and to the Irish Sea. This assumption was reiterated by Coleman (1965). A hydrological study which included water tracing by McDonald (1988) demonstrated that underground flow from Lough Lene to the southerly spring at Fore did take place with a flow rate of 80m/h. Mean outflow from the sinks and at the spring was 100 litres/sec compared with a surface outflow of 80 litres/sec. The sinks and spring dry in late summer suggesting a high level connection only, the floor of the lake presumably being impermeable.

There are other springs in the area, some of them in the lake beds. The location of the lakes in the Fore area, the altitude of the water surfaces and the conductivity of the spring and lake waters (August 1997) are shown in Figure 28 together with proven and inferred underground drainage. There appear to be two distinct bodies of groundwater: short residence water with conductivities of 190-240µS/cm and longer residence time waters with conductivities of >400µS/cm. For example, there are two springs in Fore, the spring deriving from Lough Lene having a low conductivity, a temperature related to ambient and a flashy flow regime. The second spring, some 300m distant (Toberfaolagh) has a conductivity of 410µS/cm, a constant flow (135 litres/sec and a constant temperature 10.5^{0}C). It seems that concentrated underground flow of water is at least as important as surface flow in this area and this may also be considered as evidence of karst conditions.

Conclusions

It may be suggested that the existence of present day shallow underground drainage and numerous springs is evidence for a degree of present day active and probably Postglacial karstic drainage. The presence of large springs with stable flow regimes and apparent long residence times may be evidence of more mature, ancient, fossil conduit systems that are being reactivated to some degree. The isolated hills may represent residual features of a former mature karst landscape. These are obviously hypotheses only and require compilation of additional evidence before being accepted or rejected.

2.2 CORLEA TRACKWAY VISITOR CENTRE

Details of the Corlea Trackway excavations and associated research have been published by Raftery (1996). Timbers from the trackway have been preserved and are on display in the Corlea Trackway Visitor Centre. The Centre also hosts an exhibition detailing aspects of trackway construction and use.

2.3 THE BALLYMAHON ESKER

Catherine Delaney

The Ballymahon Esker is aligned NW-SE across the major hummocky moraine zone east of Lough Ree (Fig. 3). The esker is continuous, apart from a short beaded section at the northwestern end. The main ridge is composed of alternating zones of narrow, relatively sharp crested ridge which widen downstream into broad, flat-topped or gently undulating areas which generally widen and become lower and less well-defined distally (Fig. 29).

Small exposures are found along the length of the esker and have allowed reconstruction of the formation of the esker. These show that there is a close correspondence between the morphology of the ridge and the type of sediment and sedimentary structures found below. Narrow, sharp-crested, steep sided ridges are associated with coarse-grained (to boulder size), poorly sorted sediments, crudely stratified. Sediment sorting is so poorly developed that sediments frequently have a polymodal size distribution, with pores between large clasts infilled by a matrix of fine pebble to clay sized material. Sedimentary structures include crude cross-stratification indicating transport broadly parallel to the esker alignment, and horizontal bedding with crude clast imbrication. At one point backset bedding is found, consisting of irregular foresets dipping NW-wards (upstream), and is thought to have been formed during antidunal flow conditions (Johannson, 1975; Delaney, 1995). These deposits are thought to have been laid down in subglacial tunnels (see below).

In contrast, the wider, flat-topped and gently undulating parts of the esker are underlain by well-sorted gravels and sands. Beds of ripple-laminated and normally graded massive sands containing fine laminae of silt and clay are thought to have been deposited in a glaciolacustrine environment. Well-sorted, cross-stratified pebble and cobble gravels are usually found towards the top of the sequence, indicating the progradation of large bedforms into standing water. These areas are interpreted as ice-marginal deltas or subaqueous outwash fans which were laid down in standing water at the mouth of the ice-walled channel.

The esker therefore consists of a series of tunnel-to-ice-margin segments, arranged one after the other, and becoming younger NW-wards. This indicates that both the esker and the hummocky moraine in the area were also deposited time-transgressively in a narrow ice-marginal stagnant zone which retreated northwestwards.

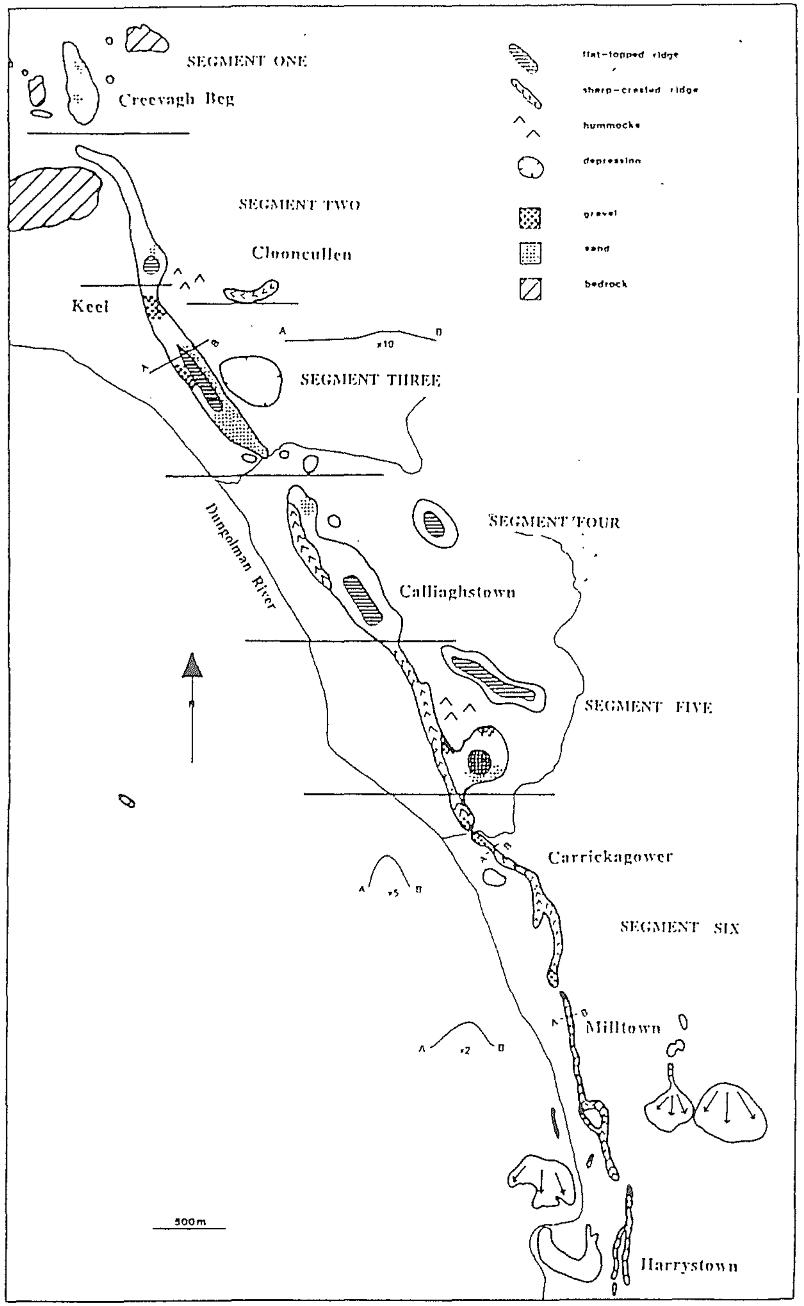


Figure 29. Morphological map of the Ballymahon Esker

Carrickagower Borrow Pit

A small borrow pit in a section of narrow, steep-sided ridge provides exposure in coarse grained, poorly sorted cobble gravels, usually with a polymodal matrix. Clasts throughout are coated with a film of silt and clay A sketch of the section is shown in Figure 30. Sediments in the lower part of the section exhibit crude horizontal stratification, caused by the occurrence of thin, discontinuous openwork horizons. This type of bedding is commonly associated with fluvial deposition of longitudinal bars in high velocity streams with fluctuating discharges (Eynon & Walker, 1974; Steel & Thompson, 1983).

These bedded sediments are overlain by a unit of polymodally sorted, matrix and clast-supported boulder and cobble gravels. Bedding in this unit is indistinct; however, the presence of clusters of imbricated clasts, variations in grading, and the occasional occurrence of thin units of laminated sands, silts and clays indicates that this unit is composed of a series of internally massive clasts. Where distinguishable, individual beds show inverse and normal grading. At the base of some beds large (boulder-sized) clasts show b-axis imbrication, while cobble sized clasts within the beds show a-axis imbrication.

These coarse grained sediments are thought to have been deposited from a series of highly concentrated water-sediment flows, mostly turbulent in nature, but occasionally with sufficiently high sediment concentrations to dampen turbulence and cause shearing and plug flow to occur. Sediment concentrations in such flows lie between 40% and 80%, compared to less than 20% in normal turbulent stream flow. Such flows are termed hyper-concentrated flood flows (Smith, 1986), and have much in common with sediment gravity mass flows such as turbidity currents and grain flows. Such flows occur where the occurrence of sudden, high velocity floods is associated with the availability of large quantities of sediment, and have been recorded in connection with recent jökulhlaups and volcanic lahars (Pierson & Scott, 1985; Maizels, 1991).

In such flows, almost all clasts are carried in suspension initially. Polymodal size ranges occur because sediment concentrations are too high and/or the distance sediment was transported too little to allow separation of sediment into different size ranges (Smith, 1986). The beds show some variation in sediment concentration must have occurred. Clast-supported polymodal gravels are thought to form when sediment concentrations are low enough to allow the larger clasts to drop from suspension first, trapping the finer sediments in pore spaces between. Matrix-supported gravels occur when the concentration of finer sediment (granule to clay size) is high enough to support coarse material through a combination of buoyancy due to the trapping of pore waters, cohesion due to the presence of clay, and due to the banging of grains together in the flow. Lower sediment

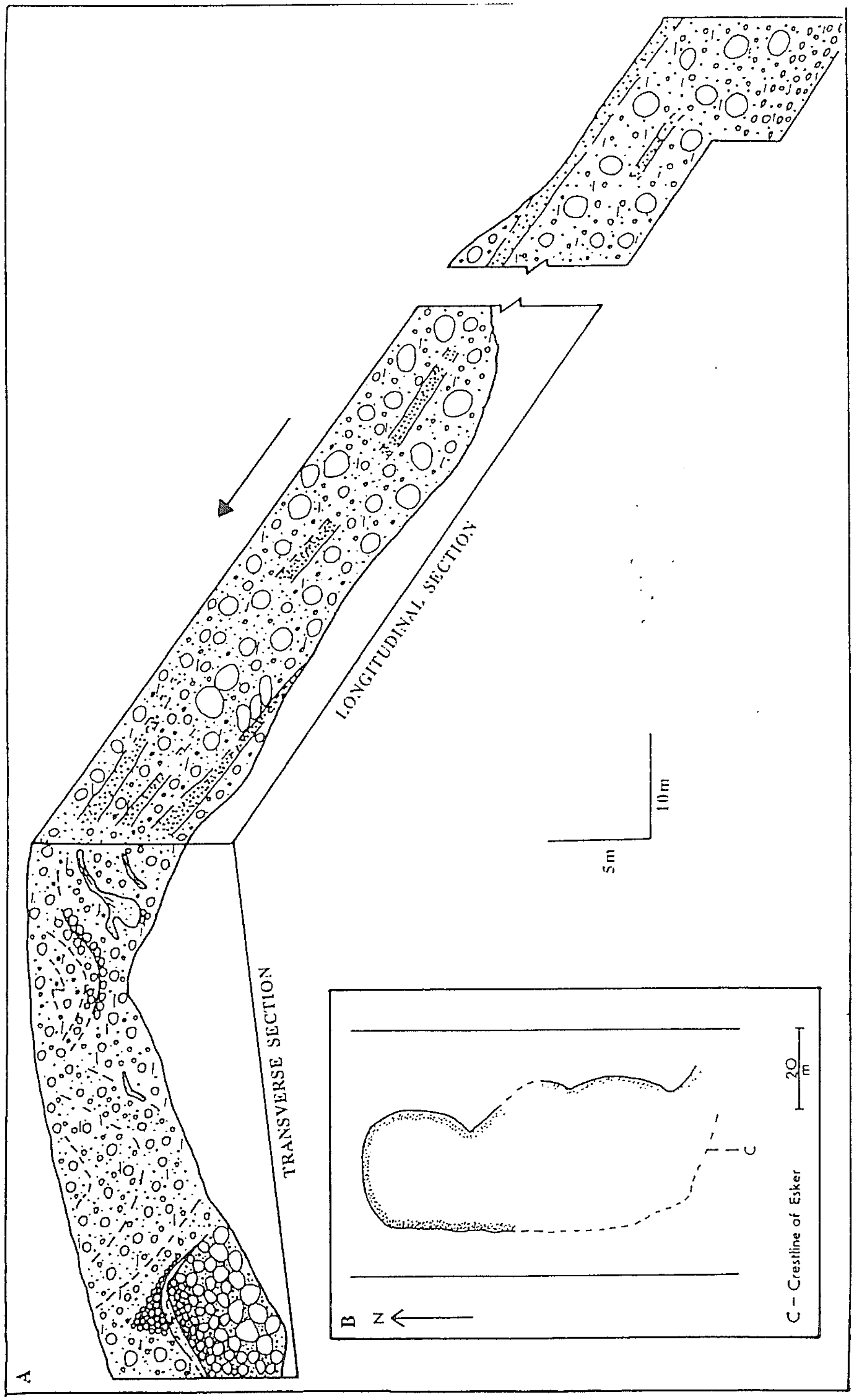


Figure 30. Sketch of exposure, Carrickagower Borrow Pit

concentrations are also indicated by the presence of normal grading as sediment concentration is low enough to allow some size sorting. In addition, b-axis imbrication, indicating rolling of clasts, may occur as larger clasts are rolled along the bed by the shearing of the flow above (Lowe, 1979). Higher sediment concentrations are indicated by inverse grading, caused by migration of the coarsest clasts away from the zone of maximum shear, and by a-axis imbrication, which occurs when the banging of clasts together causes the longest axes to be pushed parallel to the flow direction (Smith, 1986).

The thin beds of fine grained sediments overlying these coarse sediments are thought to form during the final waning of flow. They are in part eroded, and at one point have been squeezed upwards and downstream into the overlying sediments. This is thought to be a water escape structure formed by the dumping of masses of sediment onto the wet sands and silts.

The occurrence of these beds within the esker is thought to be associated with the occurrence of sporadic floods down a sub-glacial tunnel. Such floods are likely to have occurred in a number of ways: seasonal floods associated with the melting of winter snows, floods due to the trapping of meltwater in a sinkhole or crevasse on the glacier surface and subsequent release into the tunnel system; the occurrence of a sudden storm in the catchment area. For example, Russell *et al.* (1990) observed that discharge fluctuations followed by temporary damming of proglacial channels by ice debris dams are associated with ice-rich flood fronts with characteristics of sediment-rich flows, including lack of surface turbulence, and zones of plug flow. The resulting deposits may be inversely graded and are classified as hyperconcentrated flood flows.

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