Irish Association for Quaternary Studies

South Central Mayo

Field Guide No. 22

Cumann Staidéar Ré Cheathartha na hÉireann

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Irish Association for Quaternary Studies

Maigh Eo Láir Theas
South Central Mayo

á eagrú ag/edited by

Kevin Barton and Karen Molloy

Treoir Allamuigh Uimhir 22
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Barton, K. and Molloy, K. (eagarthóirí/editors)
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Cover Plate: Levallinree and Derryhick Loughs from south to north in centre of *turlough* landscape, with Lough Cullin in the background (Photo C. Lawless).

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Preface

An intergal part of the activities of IQUA, the Irish Association for Quaternary Studies is the Annual Field Excursion. The 1998 excursion (10-11 Oct.), organised on behalf of IQUA by Kevin Barton and Karen Molloy, visits the area of South Central Mayo. This area was chosen in order to highlight the considerable body of research, much of it on-going, in the fields of geology, geomorphology, palaeoecology, geophysics and archaeology. As is usual several sites/areas of interest will be visited. In this regard this meeting is unusual in that many of the contributors are members of the local community involved in research, some independently, in their home areas.

This Guide is intended to complement the Field Excursion. It is hoped that it will provide a useful information on research in this area. For the first time we have produced a Field Guide with colour diagrams. It is not advisable to expose these diagrams to prolonged precipitation!

The localities to be visited are covered by the 1:50,000 Discovery Series Maps 30, 31, 38 and 39.

Please note that the localities referred to in this guide are private property or state owned property with restricted access. Permission should be sought before entering these sites.

Localities to be visited on the Field Excursion (see map)

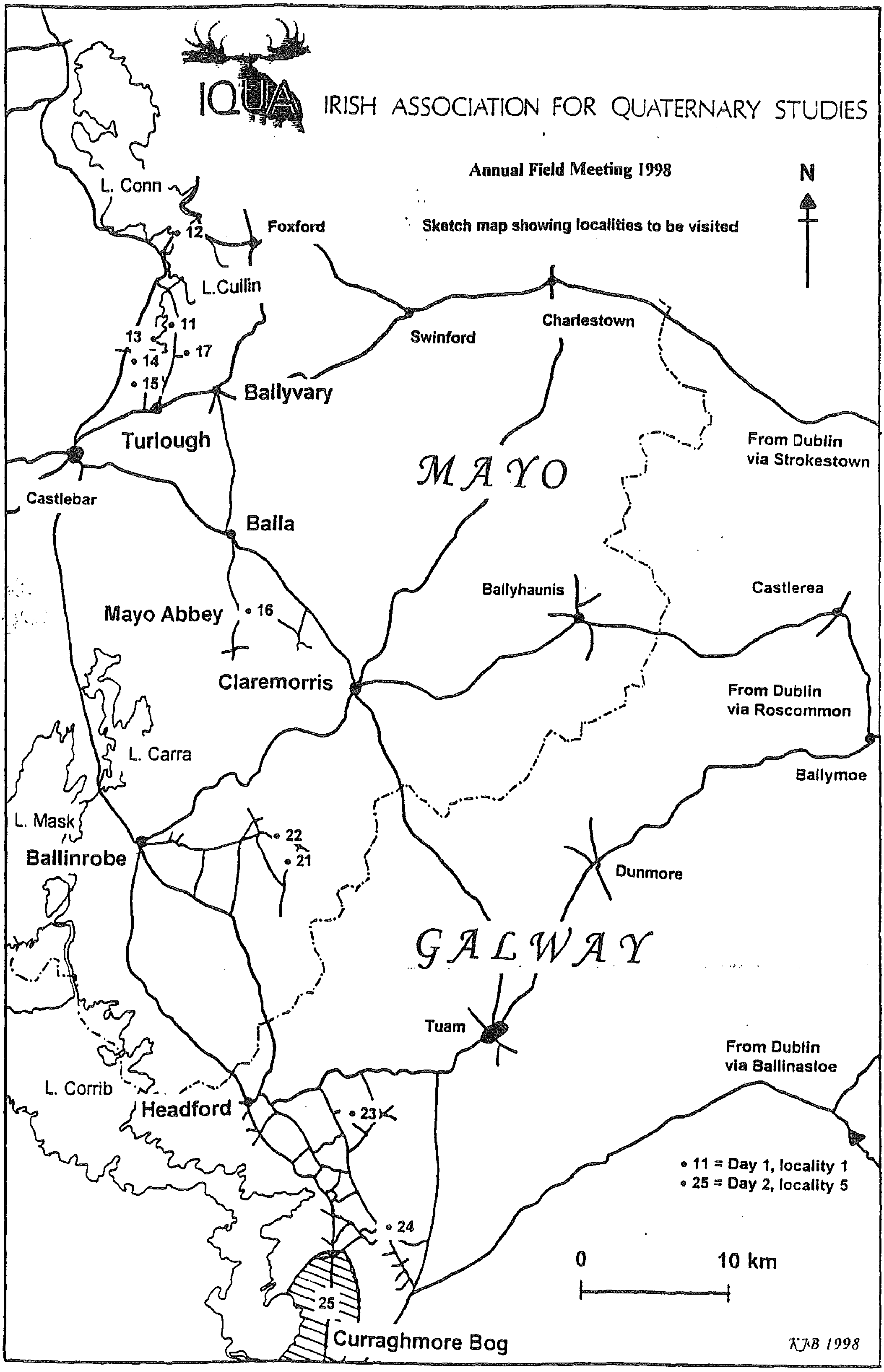
Saturday 10th October

1.1 Derryhick Hill
1.2 Pontoon Bridge
1.3 Levallinree
1.4 Garraghill
1.5 Cloonkesh
1.6 Mayo Abbey
  - Famine Church, video and exhibition
  - Early Christian grave slabs
  - Monastic enclosure
  - Pollen evidence
  - Geophysical evidence

1.7 Lack East *fulachta fiadh* - old and new

Sunday 11th October

2.1 Greaghans
2.2 Kilglassan
2.3 Pollnahallia
2.4 Auclogeen Spring
2.5 Curraghmore Bog


IQUA
IRISH ASSOCIATION FOR QUATERNARY STUDIES
Annual Field Meeting 1998
Sketch map showing localities to be visited
N
L. Conn
12
Foxford
L.Cullin
11
13
14
17
15
Swinford
Charlestown
Ballyvary
Turlough
Castlebar
MAYO
From Dublin
via Strokestown
Balla
Ballyhaunis
Castlerea
Mayo Abbey
16
Claremorris
From Dublin
via Roscommon
L. Carra
Ballymoe
L. Mask
22
21
Ballinrobe
Dunmore
GALWAY
Tuam
From Dublin
via Ballinasloe
L. Corrib
Headford
23
• 11 = Day 1, locality 1
• 25 = Day 2, locality 5
24
0
10 km
25
Curraghmore Bog
KJB 1998

The geology of south Mayo – a brief review

John Madden

Introduction

South Mayo forms part of the now fragmented Caledonian–Appalachian orogen, the most intensively studied of all ancient orogenic belts. However, after two centuries of endeavour, many problems remain unsolved. What is certain is that the area forms part of the Laurentian margin to the Iapetus Ocean.

In detail, south Mayo exposes a very varied geology from Pre-Cambrian metamorphics to Carboniferous limestones with periods of minor intrusions extending into the Tertiary. A complex Quaternary history is evident in many parts but is not considered here. This stratigraphic account of the geology of south Mayo is merely a brief summary of some of the major groups and their formations, their tectonic significance and any other notable feature.

Dalradian Rocks of Connemara

These rocks underlie the region to the south of Killary Harbour and extend east to the southern shores of Lough Mask. They consist of pelites, semi-pelites, psammites, marbles, amphibolites and thin-bedded cherts. Way up criteria are uncommon and are represented mostly as graded bedding, particularly in the Kylemore and Ben Levy Formations. The correlation of the Lower part of the Connemara Dalradian sequence with the Scottish lithostratigraphy is firmly established (Harris and Pitcher 1975). In the Ben Levy Formation around Kylemore, the pelites are seen to contain cordierite, andalusite, staurolite, garnet, muscovite, quartz and biotite.

The disposition of the major stratigraphic formations in the Connemara schists is predominantly controlled by F3 and F4 folds, with F2 folds also being significant. These folds predate the disposition of the Silurian rocks of north Connemara and south Mayo. In general, the regional metamorphism increases southwards in Connemara.

Clew Bay Pre-Bay Silurian Rocks

Rocks of a pre-Silurian age outcrop in an elongate belt that extends from Clare Island in the west to Islandeady, near Castlebar (M 078 869). They comprise of the Deer Park Complex (pelites, amphibolites and serpentinites) to the south and low-grade meta-sediments of the Ballytoohy and Killadangan formations to the north. Varying hypotheses have been proposed to explain the tectonic significance of this region. Bailey and Holtedahl (1938) argued that the rocks of south Mayo are along strike from the Midland Valley of Scotland and that the serpentinites marked the continuation of the Highland Boundary Fault. Philips *et al.* (1969) suggested that the Deer Park Complex is probably pre-Dalradian basement. Philips (1974) pointed out that these rocks were associated with a post Carboniferous faulting. The rocks of this zone and those of another to the north of Clew Bay, the Achill Beg fault zone, are associated with a magnetic linear that can be traced across Ireland to Fair Head and into the Highland Boundary Fault of Scotland.

On the mainland, the Deer Park Complex is dominated by talc carbonates and serpentinites. They crop out along the northern shores of Croagh Patrick. The exact age of the complex is unknown. The Ballytoohy Formation (>550 m in thickness) consists of low-grade metasediments and is in tectonic contact with the Deer Park Complex.

Ordovician rocks

Rocks of known Ordovician age are represented by three different successions, namely the Lough Nafooey succession, the Tourmakeady succession and the main Murrisk succession. These successions have limited overlap in time. The Bohaun Volcanic Formation and the rocks of the Ballyhean inlier are likely to be Ordovician in age. These areas can be termed domains in that they contain distinctive stratigraphies, which cannot be readily related to those of adjacent domains. In common with Ordovician rocks elsewhere along the Laurentian margin, the Ordovician rocks of south Mayo display evidence for active vulcanicity of diverse compositions, locally rapid subsidence rates, flysch sequences and numerous conglomerates indicative of considerable relief. In general terms, a destructive plate margin, with associated volcanic arcs can be inferred.

The Lough Nafooey Group comprises the oldest known Ordovician rocks in the region and outcrops in an east-west belt that extends from Derry Bay on Lough Mask to Currarevagh (L 957 590) at the head of Lough Nafooey. It is dominated by the products of basic and ultrabasic vulcanism and was recognised by Ryan *et al.* (1980) to consist of four formations.

The Tourmakeady Volcanic Succession, outcropping along the northwestern shores of Lough Mask, contains a sequence of Arenig volcanic and associated rocks. The lithology and stratigraphy have only been described in detail by Gardiner and Reynolds (1909).

The Murrisk Group outcrops over a large part of south Mayo. A continuous succession, over 6-km thick, outcrops on the northern limb of a major open, east-west syncline, the Mweelrea Syncline. The division of the group into 9 formations follows the work of Dewey (1963). With a total thickness of over 10 km, the group consists mainly of sandstones, slates and conglomerates. Its base is only exposed in the Partry Mountains where it rests unconformably on the Tourmakeady Volcanic Succession.

The Ballyhean Inlier is pre-Carboniferous and exists to the south of Ballyhean with its northern margin formed by the post-Carboniferous Erriff Valley Fault.

Silurian rocks

The Silurian strata of south Mayo are displayed in three distinct successions which are geographically and, or, tectonically separated. The three successions are the Clare Island – Louisburgh, Croagh Patrick and Killary Harbour – Joyces Country successions. These Silurian sequences differ from those in the Ordovician in that their relationship to the basement is clear. Maximum preserved thickness is much less than for the Ordovician and the presence of active Silurian subduction as an influence of their formation is not obvious.

The Louisburgh – Clare Island Succession is a distinctive group of sedimentary rocks, at least 1.5 km thick. They outcrop on the southern part of Clare Island and on the mainland near the town of Louisburgh. On the mainland, the succession is fault-contacted with pre-Silurian basement rocks but on Clare Island, the basal beds rest unconformably on rocks of the Deer Park Complex. The succession is made up of five formations consisting of conglomerates, siltstones and sandstones.

The Croagh Patrick succession is an east-west belt of lower greenschist metasediments exposed in the Croagh Patrick area. The four formations consist of cross-bedded marbles, fossiliferous siltstones, quartzites, psammites and semi-pelites.

The Killary Harbour - Joyce's Country Succession extend ESE from south of Killary Harbour to Joyce's country and disappear under the Carboniferous rocks of Lough Mask and near Cong. They rest with marked unconformity on the Connemara schists. The succession has been divided into 6 formations consisting of various sandstones, mudrocks and breccias and conglomerates.

The dating of the Silurian rocks has been based on both graptolite and shelly faunas.

Devonian rocks

Both Lower and Middle Devonian rocks of Old Red Sandstone facies crop out to the east of Clew Bay. These Devonian rocks are affected by a series of open to close folds, which do not affect the overlying Carboniferous rocks.

The Lower Devonian outcrop, belonging to the Graffa More Formation, are dominated by bedded conglomerates with subordinate sandstone, and can be seen to rest unconformably on strata which indisputably belong to both the Dalradian and Ordovician in the Clew Bay area. This constrains the timing and positioning of any major transcurrent displacement.

Most of the Devonian sediments are interpreted as representing alluvial fan deposits. All the Devonian rocks, as indeed do the Silurian, show no major volcanic accumulations to rival those of the Ordovician strata. However, volcanism was widespread, with tuffs reported from various levels in all Silurian successions and extrusive rhyolites in the Devonian Graffa More Formation.

Carboniferous rocks

If the Appalachian orogen covering most of south Mayo is the most extensively studied of all ancient orogenic belts, then as one moves east into the Carboniferous limestones (as at Mayo Abbey), the amount of published material is almost negligible. Richard Symes of the G.S.I. in the 1870's was the first and only man to map all the Carboniferous of south and southeast Mayo. He favoured a simple division into Coal Measures, Carboniferous Limestones and Carboniferous Sandstones. Moore (1970) in a report for IBM developed a subdivision, which is dealt with in the section on Mayo Abbey's geology (Madden, this Field Guide). Although many details of the Lower Carboniferous stratigraphy await study, it is clear that there are significant facies changes, which appear to show the effect of basement structures.

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Models of ice flow in south central Mayo, a summary

Colm Jordan

Co. Mayo has been the focus of a great deal of study by Quaternary geologists since the late 19th century. The abundance and complexity of landforms and exposures has stimulated geologists to produce an array of models in an effort to explain their genesis. The interest shown by IQUA in the form of this field guide and excursion indicates the necessity to re-evaluate previous interpretations as our knowledge and understanding of environmental processes develops.

Models of Ice Flow

Initial models of Quaternary ice flow patterns in Ireland were derived from patterns of erratic distribution and the morphological expressions of landforms which were believed to be aligned either parallel to flow, *e.g.* striae, drumlins and roche moutonnées, or transverse to flow, *e.g.* recessional moraines. The models proposed by Close (1867), Kinahan and Close (1872) Hull (1878) Lewis (1894) Sollas (1896) Cole & Hallissy (1914) Charlesworth (1928, 1963) and Warren (1992) are all of this school, while subsequent models integrated the technique of lithostratigraphy into the modelling process, Synge (1969), Eyles, Eyles and Miall (1983), Eyles & McCabe (1991), Hoare (1991), and Warren and Ashley (1994).

The first model, produced by Close (1867) included a small scale map of Ireland outlining overall patterns of ice movement derived from drumlin long axes, striae orientation and the direction of glacially transported erratics. The model recognises a complex pattern of ice movement in the northwest and west midlands and interpreted this as the result of the convergence of at least two great ice sheets, one centred in the west of Ireland, and the other in the north midlands. In central Mayo, from Lough Mask to Lough Conn (and beyond, to Killala), Close had no doubt that the ice flowed from south to north. It was also postulated that ice flowing onshore from Clew Bay converged with this ice mass and added to the northerly flow.

Although Kinahan and Close (1872) developed this model to include two directions of ice flow in Clew Bay, to the east in the north of the Bay, and to the west in the south of Bay, they did not alter the model of a major ice stream flowing in a northerly direction from Lough Mask to Killala Bay.

However, Hull reinterpreted the data in his 1878 paper when he proposed a simplified model involving a single ice mass extending towards the southwest from Lough Neagh into the north midlands and west central Ireland (Figure 1 A). Furthermore, it was suggested that this 'Great Central Snowfield' acted as the single source from which the ice radiated to cover all of Ireland including ice flow across County Mayo, and offshore through Clew Bay. Subsequent work was based on Hull's model of 1878, while Close's hypothesis of 1867 was largely forgotten.

Synge & Stephens (1960) wrote a summary of the thoughts on the Quaternary period in Ireland at that time and although little of the discussion relates directly to central Mayo, accompanying maps of the patterns of glaciation indicate flow from south to north from Lough Mask, through Lough Conn to Killala Bay.

In his 1967 paper on the glaciation of Connemara and south Mayo, Orme reviewed the work carried out by Synge and Stephens (1960) and Mitchell (1957, 1960) on the directions and extents of ice streams in the area and found them to be exactly similar. These models confirm the preceding ones which indicate ice flowing towards the north from Lough Mask with a stream diverging towards the west, to exit out of Clew Bay. Subsequently, Synge (1968, 1969) saw no reason to alter this model. A similar pattern of glaciation was proposed by Farrington and Stephens (1964) and by Sissons (1964) with the slight difference that ice flowed in a southwesterly direction up the Erriff Valley, suggesting that there was no ice source (or ice cap) in the Mweelrea Mountains, but that it all originated from the Great Central Snowfield.

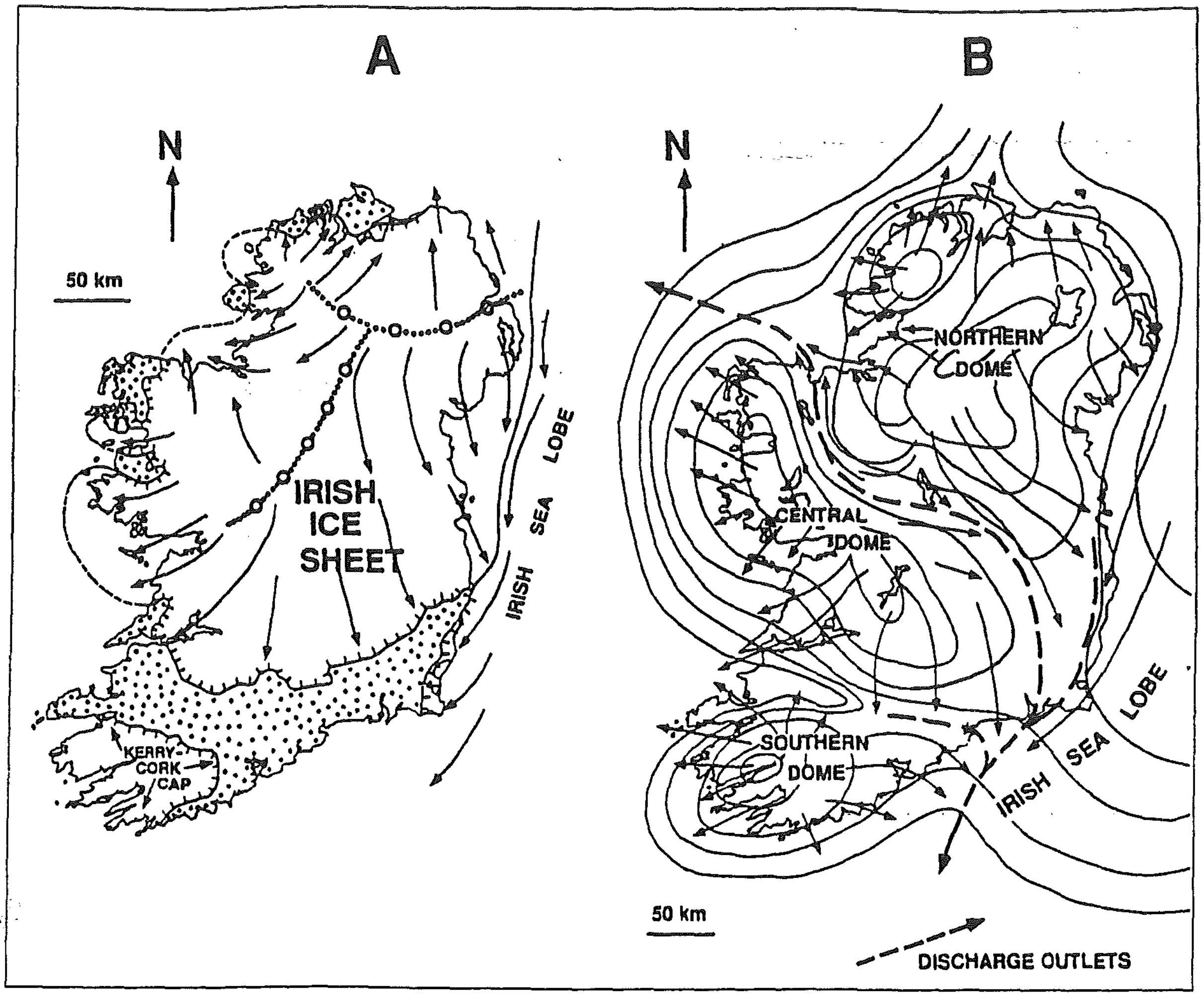

Figure 1. Comparison of the models for the most recent Irish glaciation. A) Great Central Snowfield model. B) Model comprising several synchronous ice domes. (After Warren & Ashley, 1994).

In the next decade a French working group from the Centre National de la Recherche Scientifique (1977) conducted an extensive bibliographic search relating to the west coast of Ireland and followed this by some detailed fieldwork. They reconstructed the supposed contours of the ice dome at its maximum, starting with the preconception of a single ice mass spreading from the east. This study also indicates that ice flowed towards the west, out of Clew Bay, extending its maximum limits further west into the Atlantic Ocean than any previous study. In the same year an INQUA Guidebook (Bowen 1977) with section leaders Orme and Synge, persisted with the contemporary model of ice flowing in a northerly direction from Lough Mask through to Killala Bay, and in a westerly direction offshore through Clew Bay.

A lithostratigraphic approach was adopted by Coxon and Browne (1991) whose research was carried out in central and western Ireland. The authors reached the same conclusion as McCabe and Hoare thirteen years previously, advocating the existence of a single ice dome in the north of the country. They named the two last glaciations, the Munsterian and the Midlandian, and identified the single northern ice dome as the source for both of these. The model changed little in the following years with Synge (1979) McCabe *et al.* (1986) Kenyon (1986) McCabe (1987) Eyles and McCabe (1991) and Warren (1991) proposing various scenarios where the flow of ice was towards the north in central Mayo, and to the west, out of Clew Bay.

More recently, Warren (1992) has advocated a return to the complex flow patterns of Close's model of 1867 when drumlin orientation, striae alignment, roche moutonnées and erratic carriage were used to infer the patterns of ice flow for the last glaciation in Ireland (called the Fenitian by Warren). Warren substantiates Close's model by suggesting that ice radiating from Connemara merged with ice flowing in a clockwise loop from the north Midlands to flow in a northerly direction through the area covered by this field guide (Figure 2).

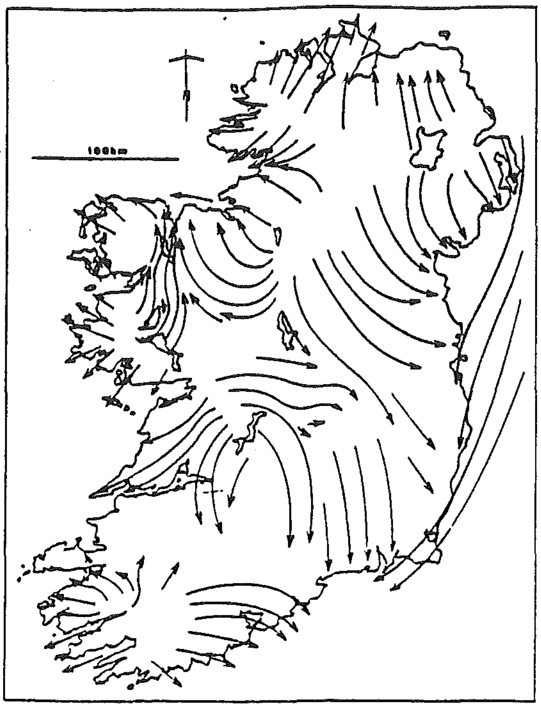

Figure 2. Pattern of ice movement inferred from drumlin alignment, striae orientation and erratic distribution. (After Warren, 1992).

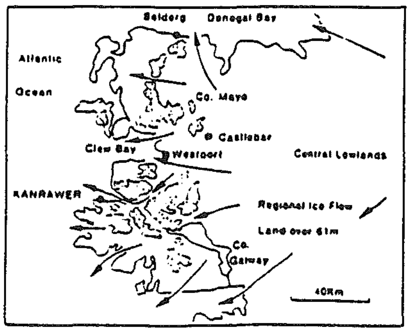

Figure 3. Postulated ice flow pattern in County Mayo. (After McCabe, 1993; and McCabe & Dardis, 1994).

This more complex model encompassing multiple synchronous ice centres was not accepted by McCabe (1993) as shown by his work on drumlins and Irish ice dispersions. McCabe persists with the Great Central Snowfield theory, which included ice flowing from the midlands directly towards the west and offshore through Clew Bay (Figure 3). Of note in the diagram accompanying this model is that the ice is shown flowing in a generally westerly direction across Mayo, rather than in a northerly direction as in all the other models.

In 1994 Warren and Ashley, while writing about the eskers of Ireland, developed Warren's 1992 model to postulate the location of the domes which affected the island of Ireland (Figure 1B). This elucidated the concept of the Connemara ice sheet, discussed in Warren's paper two years earlier, and shows the location of a discharge outlet for the glaciofluvial meltwater running between the northern dome and the central dome through central Mayo to the east of Loughs Conn and Cullen.

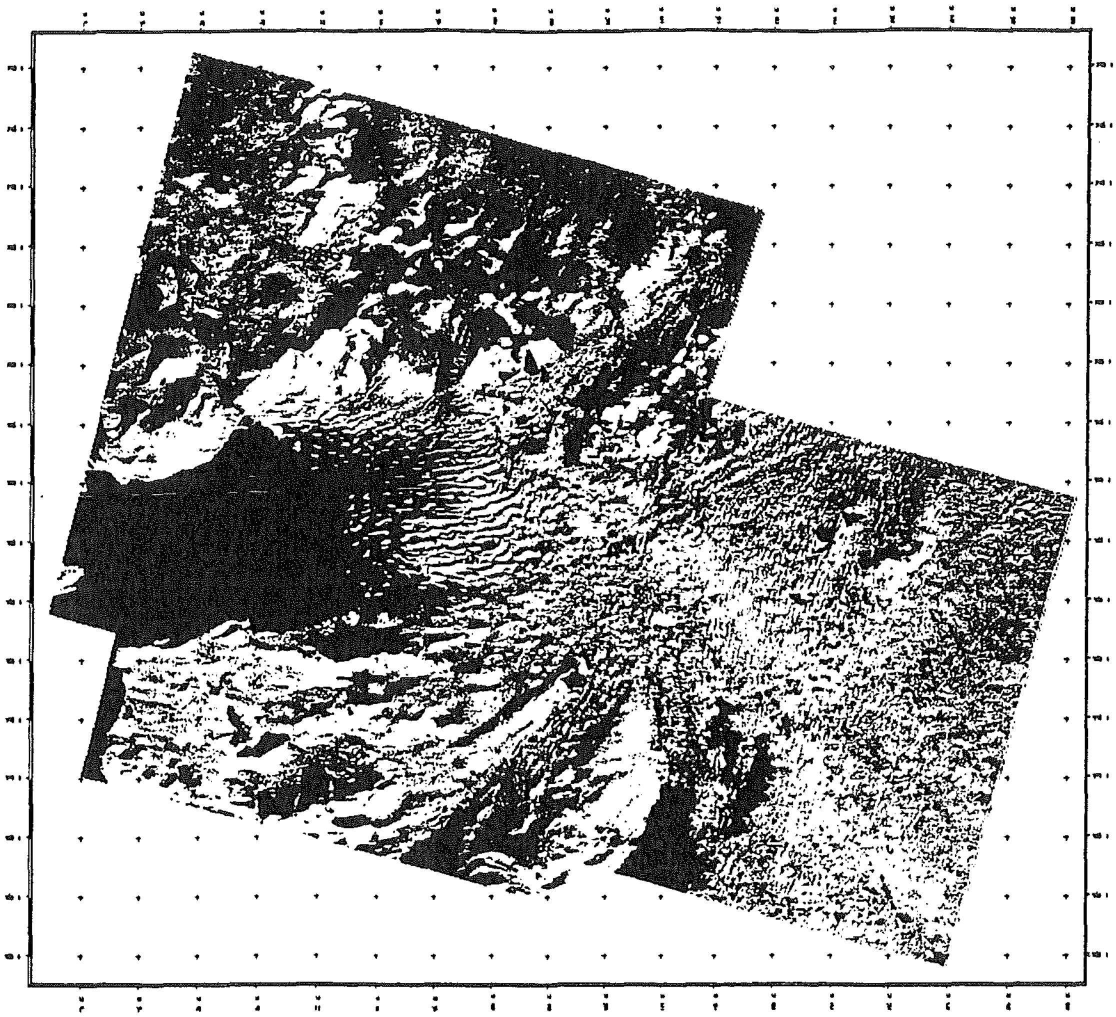

Figure 4. Landsat-5 Thematic Mapper satellite image of western and central Mayo, processed to reveal morphology and soil moisture variations. The Irish National Grid has been overlaid.

Knight and McCabe (1997) produced a paper on the drumlin alignments of Donegal Bay, and maintained faith in the Great Central Snowfield model, including a map showing ice flow in a westerly direction across Mayo from the midlands and offshore through Clew Bay.

It appears that the Great Central Snowfield model became pervasive in the literature since it was first proposed by Hull in 1878 and has remained generally accepted, appearing recently in papers such as McCabe and Clark (1998) and in textbooks such as that by Benn and Evans (1998) advocating a single ice mass moving westwards across the Midlands and Co. Mayo, exiting through Clew Bay. The earlier and more complex model of Close (1865) postulating that ice could in fact have flowed onshore from Clew Bay to merge with the main mass of northerly flowing ice in central Mayo had largely been ignored and rejected until recent work by Warren

(1992, 1994).

Most of these models agree on the direction of ice flow for the area encompassed by this field guide, *i.e.* from south to north through central Mayo. However, it is at the fringes, where the morphology and sedimentology become more complex that the variations in interpretation lie, and the different schools promote opposing ice flow directions. An holistic approach involving both the traditional mapping techniques of sedimentology, lithofacies analysis, erratic carriage mapping, till fabric analysis, deformation structure analysis, and striae location along with state-of-the-art techniques comprising digital image processing of satellite imagery and GIS was undertaken to map much of the area which is to be visited on this IQUA field trip (Jordan 1994, 1997). The satellite imagery (Figure 4), and derived lineation map provide excellent synoptic views of this area and enable the ice flow patterns to be objectively determined, when interpreted in combination with systematic sedimentological field mapping. This has corroborated the previous interpretations of ice flow towards the north, from Lough Mask to Killala Bay, with input from the north midlands, and from the west. Unfortunately, it is to the west, beyond the remit of this field guide, where current interpretations are in conflict, that the most interesting data has been uncovered!

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Introduction to the bedrock geology of the Ox Mountains inlier and particularly the SE flank of the Central Ox Mountains

Barry Long

General

The Ox Mountains inlier (Figure1) is an elongate composite geological structure of mainly Precambrian rocks surrounded by rocks of Carboniferous (Dinantian) age. It ranges northeastwards from near Newport (Co. Mayo) for approximately 104km (65 miles) to beyond Manorhamilton (Co. Leitrim) with a maximum width of about 12km (7.5 miles). The inlier is divided on the basis of its geology into SW, Central, and NE areas. Our excursion will take us to the Central Ox Mountains. The whole inlier is represented on 1:100,000 scale map sheets 6 and 7 compiled by the Geological Survey of Ireland (MacDermot *et al.* 1996a, Max *et al.* 1992). General geological explanations of these maps appear in works by Long *et al.* (1992), Long (1992), and MacDermot *et al.* (1996b).

Rocks within the inlier as a whole are mainly crystalline schists and gneisses that were transformed (i.e. metamorphosed) from their initial sedimentary state by heat and pressure whilst buried in the earth's crust by collisional tectonic processes. Igneous rocks have been similarly transformed and occupy smaller areas of the inlier.

The age of rocks in the Ox Mountains inlier proved controversial during the 1970's and 1980's. Disagreement has since been resolved, but uncertainties remain in some areas and further work is needed.

Principal rock units

The main rock units of the entire inlier are listed here from youngest (at top) to oldest. Numbers and letter codes refer to map units in Figure 1 and Table 1. Throughout the text 'Ma' is used for 'million years'.

13. OLD RED SANDSTONE, MIDDLE and LOWER DEVONIAN, sedimentary conglomerates and sandstones in the SW Ox Mountains. Generally faulted against the Dalradian schists, but Lower Devonian rocks are unconformable on the schists. Deposition was in arid inter-montane basins of the southern hemisphere close to the tropic of Capricorn.

SLIEVE GAMPH IGNEOUS COMPLEX, intruded into a shear zone, comprising:

EA EASKY ADAMELLITE (i.e. monzogranite) and

LTA LOUGH TALT ADAMELLITE, both c. 400Ma, EARLY DEVONIAN.

OMG OX MOUNTAINS GRANODIORITE, c. 415Ma, LATE SILURIAN. A major compositionally banded and tectonically foliated granitic body.

Not on map. OX MOUNTAINS APPINITE SUITE, c. 415Ma, LATE SILURIAN.

Diverse volatile-rich hornblendic rocks ranging generally from hornblendite and diorite to granodiorite, and associated with calc-alkaline lamprophyres.

S DEER PARK COMPLEX fault-located metaigneous basic and ultramafic bodies (the latter now serpentinite) of either early ORDOVICIAN or late CAMBRIAN age, in the SW Ox Mountains. Interpreted as fragments of the Deer Park Complex (ophiolitic mélange) of the Westport and Kill (SE Clare Island) inliers.

POSSIBLY DALRADIAN, two distinct units of metasedimentary schists, each present in the SW and Central Ox Mountains and tectonically isolated from unequivocal Dalradian schists:

11b. CLOONYGOWAN FORMATION (Central Ox) & ARDVARNEY FORMATION (11a, SW Ox) are isolated portions of a proximal turbidite sequence. Probably CAMBRIAN; possibly part of SOUTHERN HIGHLAND GROUP DALRADIAN.

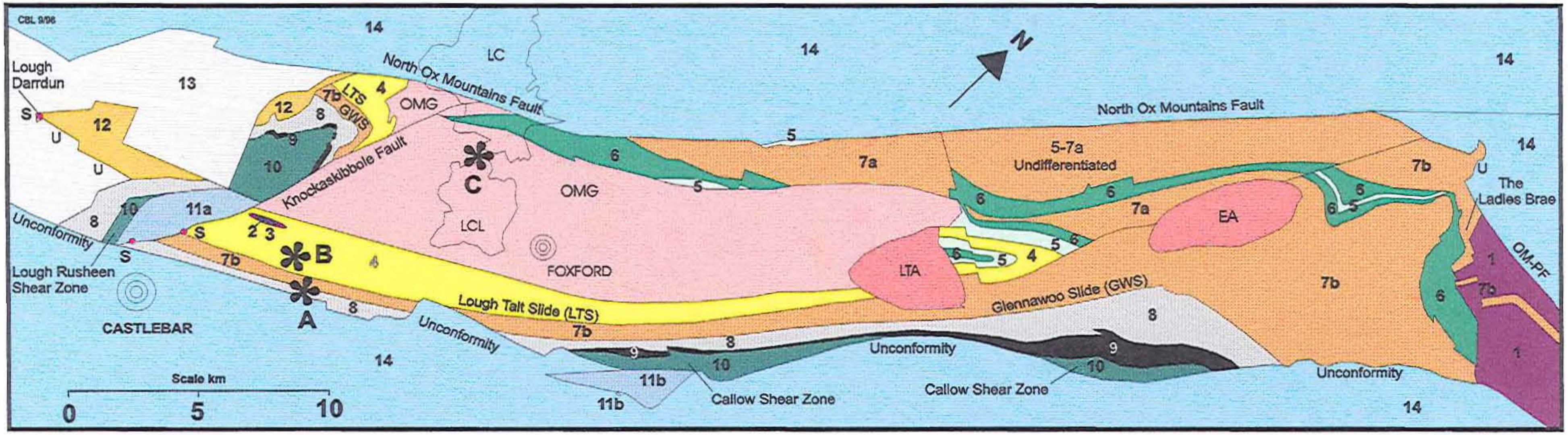

FIGURE 1
OUTLINE GEOLOGY OF THE CENTRAL AND SOUTHWEST OX MOUNTAINS INLIER

A-C Localities to be visited
LC Lough Conn, LCL Lough Cullin, OM-PF Ox Mountains-Pettigoe Fault
U Unconformity

CARBONIFEROUS
14 Lower Carboniferous (sandstone and limestone)

DEVONIAN
13 Old Red Sandstone (sandstone and conglomerate)

Possibly DALRADIAN, though probably CAMBRIAN
11b Cloonygowan Formation, and equivalent 11a Ardvarney Formation

PRECAMBRIAN, NEOPROTEROZOIC, DALRADIAN SUPERGROUP
Callow Succession (probably Dalradian)
10 Upper Lismoran Formation (possibly equivalent to 8)
9 Callow Formation (basic metavolcanics)
8 Lower Lismoran Formation

12 Raheen Barr Succession
Formations are lateral equivalents of 4 - 7 below

Ox Mountains Succession
7a Attymass Formation broadly equivalent to 7b Ummoon Formation
6 Carrick O'Hara Formation
5 Corradrishy Formation
4 Leckee Quartzitic Formation
3 Tawnyshane Tillite Formation
2 Lough Anaffrin Marble Formation

Probably Pre-DALRADIAN
1 Slishwood Division paragneisses of Northeast Ox Mountains

MAIN INTRUSIVE IGNEOUS BODIES
EA Easky Adamellite
LTA Lough Talt Adamellite
OMG Ox Mountains Granodiorite

OTHER IGNEOUS BODIES
S Serpentinite (fragments of Deer Park Complex of Westport inlier)

NOTE
Bodies of the Appinite Suite are omitted

Table 1. Tectono-lithostratigraphical sequence in se flank of central ox mountains. Numbers relate to map units on Figure 1.

(Top)

11b. CLOONYGOWAN FORMATION: POSSIBLY DALRADIAN, PROBABLY CAMBRIAN
Proximal turbidite suite of pebbly meta-quartz wackes (i.e. coarse pebbly grits), metagreywacke sandstones and phyllites: minor graphitic pelites and rare metacherts. Equivalent to Ardvarney Formation in southwest.

Callow Shear Zone (D4): major metamorphic hiatus

CALLOW SUCCESSION: PROBABLY DALRADIAN

10. UPPER LISMORAN FORMATION
Interbedded, often feldspathic, semi-pelitic and psammitic schists, everywhere mylonitic. May equate with Lower Lismoran Formation.

9. CALLOW FORMATION
Basic metavolcanics (epidote-amphibolite lithologies), probably a volcaniclastic turbidite sequence. The oceanic geochemical affinity differs from other basic metavolcanics of the inlier, except Lough Darrdun at the extreme SW end.

8. LOWER LISMORAN FORMATION
Interbedded, often feldspathic, semi-pelitic and psammitic schists: rare meta-quartz wackes (i.e. coarse pebbly grits), and graphitic pelitic schists. More psammitic than the Ummoon Formation. Psammitic beds often >1 metre thick. Garnets <5mm (commonly <2mm) in diameter. Staurolite is apparently absent, and may never have occurred. Basinal turbidite origin.

Glennawoo Slide (D4)

OX MOUNTAINS SUCCESSION: DALRADIAN

7b. UMMOON FORMATION (equivalent mainly to Attymass Formation on NW flank)
Relatively distal basinal turbidite sequence divided into 3 named members:

Meelick Member
Interbedded, often feldspathic, semi-pelitic and psammitic schists, with aluminous pelitic schists, the latter with almandine garnet (commonly c. 1cm in diameter) and staurolite. Rare graphitic pelitic schists and coarse pebbly meta-quartz wackes (i.e. pebbly quartz grits). Psammitic beds usually <1 metre thick. Less psammitic than Lower Lismoran Formation overall.

Newantrim Member
Finely banded amphibolitic basic metavolcanic tuffs, possibly with lavas: continental tholeiite (i.e. sub-alkaline basalt) affinity.

Slievenagark Member (i.e. uppermost Carrick O'Hara Fm on NW flank)
Mainly banded semi-pelitic and feldspathic semi-pelitic schists.

Lough Talt Slide (D4: excises Corradrishy Fm & most of Carrick O'Hara Fm)

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4. LECKEE QUARTZITIC FORMATION
Pale coloured quartzite and psammitic schist with rare cross-stratification. Rare metadolerite sills (or metavolcanics), and rare thin calc-silicate bands. Quartzite more abundant near base. Pink potassium feldspar clasts conspicuous near base.

3. TAWNYSHANE TILLITE FORMATION (formerly Tawnyshane Pelitic Member)
Pelitic, semi-pelitic and psammitic schists. Near the top some pelitic and semi-pelitic beds contain coarse feldspathic grains and pebbles, and cobbles of psammite. Quartzite and psammite beds generally increase in frequency and thickness upwards, forming a transition to the overlying Leckee Quartzitic Formation.

2. LOUGH ANAFFRIN MARBLE FORMATION (formerly Tawnyshane Marble Member)
Interbedded dolomitic marble and calc-silicate schist of green, grey-green, white, grey and pale brown colour. Both speckled and banded colour varieties occur. The formation is possibly a skarn (i.e. thermally altered limestone), owing to proximity of the Ox Mountains Granodiorite.

(Base)

10-8. CALLOW SUCCESSION generally semi-pelitic schists and oceanic basic metavolcanics. It may be either DALRADIAN (SOUTHERN HIGHLAND GROUP) or CAMBRIAN and has been compared with the Highland Border Complex of Scotland, and Birchy Complex, Newfoundland, (Winchester *et al.* 1992).

DALRADIAN SUPERGROUP, EARLY CAMBRIAN to NEOPROTEROZOIC, comprising metasedimentary schists, quartzite, marble and within-plate tholeiitic metavolcanics in the SW, Central and NE Ox Mountains. In the latter area such rocks occur as a small block at Manorhamilton as well as a strip tectonically interleaved with the western end of unit 1, below. Two successions are mutually correlated:

12. RAHEEN BARR SUCCESSION, in western part of SW Ox: lateral equivalent of units 7-4 in Ox Mountains Succession.

7-2. OX MOUNTAINS SUCCESSION in part of SW Ox, and in Central Ox.

1. SLISHWOOD DIVISION of the NE Ox Mountains, most probably PRE-DALRADIAN basement (or less likely Grampian Group Dalradian). Psammitic to less common pelitic rocks predominate over minor calcareous rocks. All are granoblastic paragneisses, i.e. of sedimentary origin, deposited sometime after 1700Ma, that have had an early history of extreme metamorphism (Lemon 1971, Sanders *et al.* 1987, Sanders 1991). Relatively minor orthogneisses of igneous origin include serpentinite and metabasite. Pegmatite veins are Ordovician. Slishwood Division gneisses and Dalradian schists are tectonically interleaved in the area just east of The Ladies Brae.

Regional location

The Ox Mountains inlier lies along the southern margin of the main area of Dalradian rocks in Ireland at the exposed southern margin of the ancient continent of Laurentia (i.e. the older core of North America including the Rockall Plateau and Greenland). It roughly parallels the Fair Head - Clew Bay Lineament (FCL), a conspicuous magnetic and gravity feature within the basement several kilometres below the present surface. The lineament has been traced from Achillbeg, south of Achill Island, eastward close to the north side of Clew Bay, along the faulted NW margin of the Ox Mountains inlier, obliquely across the Central Ox, and beneath the Carboniferous cover close to the southeastern flank of the NE Ox mountains. It continues northeastwards along strike and is traced into the Highland Boundary Fault (HBF) of Scotland. The surface and near surface rocks of the Central and SW Ox Mountains have been thrust in a southerly direction across the FCL and consequently there is no surface fault overlying the FCL.

Dalradian supergroup

The mainly Neoproterozoic Dalradian Supergroup is known in Ireland and Scotland (Harris *et al.* 1994). A threefold package of rocks comprising a glacio-marine sequence with diamictites ('tillites'), underlain by dolomitic carbonates (now marble), and overlain by thick white or pale coloured shallow water sands (now quartzite) lies at the heart of Dalradian lithostratigraphy. The glacio-marine sequence was thought to have been deposited at c. 660-650Ma during the first Varangerian glaciation. Recent studies (Brasier and McIlroy 1998) place this close to 600Ma (minimum age) based on new trace fossils found in the overlying formation in Scotland.

Deposition

The entire Dalradian Supergroup was deposited during the period from c. 810Ma, or possibly even from 850Ma, to c. 525Ma in the Lower Cambrian. The SE flank of the Central Ox Mountains contains just some of the younger part of the supergroup, i.e. the uppermost Appin Group (top formation of the Blair Atholl Subgroup) and lower part of the overlying Argyll Group (Islay and Easdale Subgroups), and even younger parts are ambiguously represented.

The Dalradian basin lay within or near the southern polar circle upon the stretching and thinning continental lithosphere of the Neoproterozoic supercontinent of Rodinia. This was inundated, probably from its northern or northeastern side, by a shallow sea that generally deepened and widened. Continental rifting had advanced to the stage of continental separation sometime between 600Ma and 550Ma. Oceanic lithosphere formed between the separating Rodinian successor continents of Laurentia, Gondwana and Baltica which continued to drift apart to form the Iapetus Ocean (Western and Eastern branches), as well as the Tornquist Sea. Deposition of the Dalradian sediments was close to the oceanic triple junction, in the Western Iapetus Ocean which opened between the eastern Laurentian promontory of Labrador - Rockall Plateau - Greenland, and the Gondwanan pre-Cordilleran margin at the Arica embayment between what today is southern Peru and northern Chile (Dalziel 1994).

The basal contact of the Dalradian schists of Ireland and the Central Highlands of Scotland with older basement gneisses is nearly everywhere tectonic, thus obscuring original depositional relationships. The Dalradian rocks were probably deposited upon Palaeoproterozoic basement, locally with Grenville reworking, with nearby Archaean basement as an additional source of sediment.

Dalradian lithostratigraphy

The Dalradian Supergroup throughout Ireland and Scotland is subdivided into four groups: from the oldest, Grampian, Appin, Argyll and Southern Highland, with each, excepting the upper, divided into subgroups. Further subdivisions into formations and sometimes members have been made throughout. Lithostratigraphical lateral correlation of Dalradian rocks throughout Ireland and Scotland is well established, though a few problem areas remain (Harris *et al.* 1994).

SE FLANK OF CENTRAL OX MOUNTAINS. OX MOUNTAINS SUCCESSION

General lithostratigraphical descriptions are given by Taylor (1968), Long and Max (1977), Alsop and Jones 1991, Long (1992), Long *et al.* (1992) and MacDermot *et al.* (1996b). Nomenclature still generally follows Taylor (1968) with additions and minor modifications. A summary of the tectono-lithostratigraphical sequence in the SE flank of the Central Ox Mountains appears in Table 1. The following text augments the table: it uses the same numbering, also used in Figure 1, and works up from the oldest formation.

Appin Group (upper part only)

2. The LOUGH ANAFFRIN MARBLE FORMATION is the oldest Dalradian formation in the Central Ox Mountains and is exposed on the northern shore of Lough Anaffrin (c. 3km north of Castlebar) where it was drilled by the Geological Survey of Ireland in the late 1970's to investigate its extent and qualities as an ornamental green marble. Dolomitic marble and calc-silicate schist exhibit colour banding and speckling in shades of green, white, brown and grey.

Argyll Group

3. TAWNYSHANE TILLITE FORMATION. The earliest Argyll Group deposits, immediately overlying the Lough Anaffrin Marble Formation, are distinctive over the entire Dalradian area of Ireland and Scotland. They comprise a glacio-marine sequence deposited beneath an ice shelf and contemporaneously reworked by tidal influence. Palaeomagnetic evidence on a global scale has established the continental configuration at that time, thus revealing that the formation (generally called the Port Askaig Formation in Scotland and Ireland) was deposited within or close to the southern polar circle (Dalziel 1994). At Lough Anaffrin the formation lacks the coarse cobble and boulder units that elsewhere characterize individual generally non-bedded diamictites. Only limited diamictite with tiny granular clasts is associated with mainly semi-pelitic interbeds.

4. The LECKEE QUARTZITIC FORMATION is a thick unit of well-sorted, cross-bedded shallow water, white (or pale coloured) quartzite and psammite that stratigraphically overlies the Tawnyshane Tillite Formation. Its laterally equivalent formations form much of the high ground in Connemara (e.g. Bennabeola), NW Mayo (e.g. Corslieve), Donegal (e.g. Slieve Tooey and Aghla Mountains), and also in the Central Highlands of Scotland from Islay and Jura to Schiehallion and beyond.

Deeper water conditions followed, with the incoming of turbidite deposits and rift-related tholeiitic volcanism. These were a consequence of tectonic instability that developed and increased as the supercontinent of Rodinia stretched, thinned, sagged and rifted whilst still remaining a single lithospheric plate prior to break up and ocean opening. Water depth generally increased during deposition of the Argyll Group sediments, but transient shallowing episodes also occurred.

The continuity of lithostratigraphical sequence is broken by a D4 tectonic slide, the Lough Talt Slide, marking the highest part of the Leckee Quartzitic Formation seen along the SE flank of the Ox Mountains Granodiorite. The slide has excised almost two complete formations so that the Ummoon Formation is juxtaposed on its opposite, SE side.

7b. The UMMOON FORMATION is a sequence of mica schists comprising interbedded pelites, semi-pelites and psammites, and, close to the Lough Talt Slide, a within-plate (or plate margin) continental tholeiite metavolcanic unit, the Newantrim Member, (Winchester *et al.* 1987). Many schists are conspicuously feldspathic with white or pinkish plagioclase porphyroblasts. Pelitic schists are iron-rich, aluminous and contain staurolite and 1cm diameter almandine garnet, as well as coarse kyanite in the area NE of Lough Talt. The formation was deposited in a basin from relatively distal turbidity currents.

CALLOW SUCCESSION

8. LOWER LISMORAN FORMATION. The lithostratigraphical sequence is again broken, here by the D4 Glennawoo Slide. This excises an unknown portion of the succession and of the Ummoon Formation, and juxtaposes the Lower Lismoran Formation to the SE. The formation is similar to the Ummoon Formation, being of turbiditic origin, but with more generally psammitic schists, often richly feldspathic, and lacking metavolcanics and iron-rich aluminous pelites.

9. The CALLOW FORMATION is a clastic metavolcanic unit of oceanic origin (Winchester *et al.* 1987).

10 The UPPER LISMORAN FORMATION is possibly a repetition by folding of the Lower Lismoran Formation. It lies entirely within the Callow Shear Zone.

11b. CLOONYGOWAN FORMATION The major D4 Callow Shear Zone, with its ubiquitous tectonically formed mylonites, separates the Callow Succession from the more southerly Cloonygowan Formation comprising a proximal turbidite sequence mainly of interbedded coarse pebbly meta-quartz wackes (i.e. grits), metagreywacke sandstones and phyllitic pelites.

Deformation

The structures of the Ox Mountains inlier are complex and reveal a polyphase history (Table 2, and Taylor 1969, Jones 1989, MacDermot *et al.* 1996b). All pre-Devonian rocks of the SW and Central Ox Mountains have apparently had a common history of deformation and metamorphism caused by the plate tectonic collisional processes of the Grampian and Acadian orogenies. This also applies to the NE Ox Mountains, but its geological history goes further back in time (Sanders *et al.* 1987, Sanders 1991). The Grampian orogeny has recently been redated as c. 470Ma (formerly c. 490Ma) and is therefore now known to equate temporally with the Taconic orogeny of the northern Appalachians region. The term 'Caledonian orogeny' is best applied collectively to both Grampian and Acadian orogenies.

Most of the main rock units were tectonically juxtaposed against one another in approximately their present-day configuration by major late Silurian to early Devonian sinistral horizontal shearing, and the entire Central Ox Mountains can be regarded as a major shear zone.

Phases of deformation are referred to as D1, D2, D3 etc, and the scheme of numbering has been modified over the years. The most conspicuous and abundant folds are D3, i.e. third deformation event (MacDermot *et al.* 1996b). They have a tight to close style, with subvertical to steeply dipping axial surfaces and generally show vergence towards the Ox Mountains Granodiorite. The folds have a spaced axial planar schistosity which crenulates an earlier intense penetrative schistosity that is axial planar to isoclinal D2 folds. The latter are usually only unambiguously recognized where seen to be refolded by the D3 folds. Rarely, earlier quartz segregations and locally a D1 schistosity are folded by D2. An approximately NE-SW trending stretching lineation plunges gently to the SW in the area of our visit. D2, D3 and D4 folds tend to be broadly coaxial, and their individual schistosities tend to form a composite co-planar fabric parallel with bedding. A single major D2 fold, the isoclinal Lough Anaffrin Anticline, has been traced from Lough Anaffrin to the Ladies Brae.

Table 2. Simplified sequence of events in the central ox mountains

LATER EVENTS

Uplift and erosion with intrusion of Palaeocene dolerite dykes.

VARISCAN OROGENY

D7 Weak effects in the Lower Carboniferous rocks surrounding the inlier.

ACADIAN OROGENY AND SHEAR ZONE DEVELOPMENT, SPANNING D4 TO D6.

D6 Continuing regional uplift and retrograde metamorphism. Intrusion of Lough Talt and Easky Adamellites (i.e. monzogranites). Late shearing, with localized foliation developed in Lough Talt and Easky Adamellites.

D5 Open style folding with flat lying axial surfaces. Of major significance only in general area well to NE of Lough Talt.

D4 Intrusion of Ox Mountains Granodiorite (along axis of D3 Lough Talt Antiform) and of Ox Mountains Appinite Suite during late Silurian. Development of sinistral Ox Mountains Shear Zone variably across full width of inlier, with foliation of the Ox Mountains Granodiorite, folding of contact zone granitic sheets, and development of Lough Talt and Glennawoo Slides, and of Callow Shear Zone.

Initiation of regional uplift and retrograde metamorphism.

GRAMPIAN OROGENY, SPANNING D2 TO IMMEDIATELY POST-D3.

Peak of prograde regional Barrovian metamorphism. Low amphibolite facies in Dalradian Ox Mountains Succession, and greenschist facies (garnet, to chlorite grade) elsewhere.

D3 Second phase of folding (tight to close folds, spaced axial planar schistosity, and steep axial surfaces). Formation of the major Lough Talt Antiform: minor folds verge towards the Ox Mountains Granodiorite from each limb of this fold. stage.

D2 First phase of folding (isoclinal, with penetrative axial planar schistosity), and early greenschist facies metamorphism. Formation of the major Lough Anaffrin Anticline.

GRAMPIAN OROGENY OR EARLIER

D1 Earliest quartz segregations and development of rare S1 schistosity: possibly the consequence of an extensional and not a collisional event.

DEPOSITION

D0 Deposition of Dalradian sediments spanning from 810Ma (or even 850Ma) to 525Ma (or even later) for the entire supergroup. In the Central Ox Mountains the restricted stratigraphical range spanned from not before 660Ma probably to almost 525Ma, but parts have been tectonically excised.

Regional metamorphism

The original sediments were transformed into metamorphic schists by metamorphism and accompanying deformation. Except in the NE Ox Mountains, peak metamorphic conditions during the Grampian orogeny broadly accompanied D3 and the highest temperatures were reached immediately after this, giving rise to a static mineral overgrowth.

The Central Ox Mountains has been buried in the crust at depths not exceeding 27km (8kbar) and a slightly lesser maximum depth applies to the SW Ox Mountains (Yardley *et al.* 1979, 1987). The NE Ox, (see below) has had a more extreme early history. Metasediments of the main area of the Ox Mountains Succession underwent Barrovian metamorphism in the low amphibolite facies, which in pelites produced the peak assemblage of staurolite ± kyanite + biotite + muscovite + almandine garnet + oligoclase + quartz. At the same time the Callow Succession may not have exceeded high greenschist facies with pelites containing the assemblage almandine garnet + biotite + muscovite ± chlorite + albite + quartz. The Cloonygowan Formation reached only low greenschist facies and pelites have the assemblage chlorite + muscovite + albite + quartz. The marked metamorphic contrast across the Callow Shear Zone suggests that it represents a major break.

Post-D3, post-Grampian, retrogressive metamorphism was a consequence of later events during tectonic uplift. Its effects vary, being generally minimal in the Ox Mountains Succession, except the eastern end of its main area of outcrop and its occurrence west of the Knockaskibbole Fault which, together with the entire Callow Succession, shows extensive retrogression in the low greenschist facies (chlorite grade).

In the NE Ox Mountains sediments and most igneous rocks were metamorphosed under eclogite facies conditions at >45km depth, probably during the c. 1000Ma Grenville orogeny. Later deformation and metamorphic retrogression occurred in stages, firstly under high pressure granulite facies conditions at c. 35km depth. This was followed by low amphibolite to greenschist facies conditions during the Grampian and Acadian orogenies as the rocks neared the surface.

Plutonism

Igneous rock names generally follow those of the I.U.G.S. Subcommission on Igneous Nomenclature (Le Bas and Streckeisen 1991).

The OX MOUNTAINS GRANODIORITE (McCaffrey 1992, 1994) is the major unit of the SLIEVE GAMPH IGNEOUS COMPLEX. Earlier attempts to date it proved misleading and more recent, unpublished, zircon data suggest that it is c. 415Ma old, i.e. late Silurian. Intrusion was essentially syn-D4 and occurred axially along the D3 Lough Talt Antiform as a series of mutually adjacent, compositionally distinct sheet-like bodies, during development of the major, subhorizontal, sinistral Ox Mountains Shear Zone. Consequently the granodiorite is generally lithologically banded as well as foliated. The foliation is generally apparent within the granodiorite. In the envelope rocks shearing has been localized (i.e. partitioned) into the D4 Callow Shear Zone, Glennawoo Slide and Lough Talt Slide, within which the hinges of D3 folds were tightened and their limbs sheared out.

The principal granitic lithologies were intruded in the sequence: Muscovite Syenogranite; Group 1 Equigranular Granodiorite (forming approximately two thirds of the entire body) and Biotite Syenogranite; Group 2 Megacrystic Granodiorite; Tonalite (McCaffrey 1992). Early bodies of the Ox Mountains Appinite Suite were co-magmatic with the Ox Mountains Granodiorite. Some appinite bodies enclosed within the granodiorite show evidence that both magmas crystallized together. Although the SE contact of the Ox Mountains Granodiorite is broadly concordant with bedding, it can be seen locally to cut across it. The NW contact is strongly discordant and cuts across several lithostratigraphical formations. At least two major raft trains of schists enclosed within the granodiorite mark the original boundaries of large, early sheets.

Many thin subvertical granitic sheets were intruded into the envelope schists on both flanks of the Ox Mountains Granodiorite. The greatest width of the external sheeted zone is c. 3km just north of Castlebar.

The foliation is complex: an early magmatic tiled fabric appears locally, in areas where strain remained relatively low, as an imbricated alignment of internally non-deformed plagioclase and K-feldspar megacrysts interpreted to have rotated in a viscous medium, and lies obliquely to the later main foliation (McCaffrey 1994). Early strain in the cooling body generated a partitioned series of sinistral shear offsets of internal contacts. The later component of foliation formed in the crystalline state as a crystal plastic, sinistral transpressional shear fabric. This conspicuous D4 main foliation trends northeast-southwest, sometimes slightly oblique to internal igneous contacts, and dips steeply to the NW (McCaffrey 1992, 1994). A mineral stretching lineation within the foliation plunges gently to the northeast.

Local intensification of the foliation forms a partitioned and widespread series of conjugate sinistral and dextral shear zones with mylonitic S-C fabrics. A sinistral sense predominates and the shear zones are oblique in an anticlockwise sense (plan view) to the mean orientation of the northeast - southwest Ox Mountains Shear Zone (McCaffrey 1994).

Two small granitic bodies, the EASKY ADAMELLITE and LOUGH TALT ADAMELLITE, are late bodies of the Slieve Gamph Igneous Complex. They were intruded at c. 400Ma (Long *et al.* 1984) in the early Devonian period during D6 as the shearing abated, and consequently foliation within them is generally weak.

Contact metamorphism

Heat from the Ox Mountains Granodiorite caused thermal (= contact) metamorphism of its envelope rocks. Evidence of a contact aureole mineral assemblage is minimal and largely restricted to particularly pelitic schists close to the granodiorite's contact. Both coarse prismatic, and fibrolitic sillimanite occur at rare key localities.

Both the Lough Talt and Easky Adamellites have broad thermal aureoles that are well developed in the aluminous pelites of the Ummoon Formation, and its laterally equivalent Attymass Formation of the NW flank of the Central Ox Mountains (Yardley and Long 1981). Their depth of intrusion was between 8 and 11km which indicates substantial uplift since the D3 peak of regional metamorphism when the rocks were somewhere close to 27km depth.

LOWER CARBONIFEROUS (Dinantian) sedimentary rocks surround the Ox Mountains inlier (MacDermot *et al.* 1996b, Long *et al.* 1992). By early Devonian times the older rocks of the inlier had been folded and metamorphosed during the mountain forming events of the Grampian and Acadian orogenies (in a general sense, broadly Caledonian) and had been intruded by late Silurian and early Devonian granites which furthered uplift of the eroding mountainous desert landscape. The warm tropical Carboniferous sea spread inland generally from the south and Ireland as a whole was eventually inundated. Initial shallow water clastic deposits were followed by a change to limestone with less clastic material, and abundant marine fossils.

The Carboniferous rocks lie unconformably upon the older schists of the Ox Mountains inlier's SE flank, but are in fault contact on its NW flank. Between Castlebar and Swinford the beds dip gently to the SE and younger formations appear as distance from the inlier increases.

Chadian

At the base is the MOY SANDSTONE FORMATION comprising quartz pebble conglomerates, sandstone, siltstone and mudrock, and often referred to as 'basal clastics'. This is followed by the LOUGH AKEEL FORMATION's sandy cross-bedded oolitic limestone, and the overlying CASTLEBAR RIVER FORMATION of dark grey argillaceous limestone with calcareous shale partings.

Arundian

The AILLE LIMESTONE FORMATION comprises dark fine-grained limestone with thin shale partings.

Asbian

Limestones with calcareous shales dominate the BALLINA LIMESTONE FORMATION (Lower and Upper) which appear next in the upward sequence.

Bedrock localities to be visited

Localities are quite near places chosen for their Quaternary geology or archaeology. This is a substantial constraint and time is limited.

Locality 1.5 (A) *Cloonkesh Grid Ref. M183 945, Structural age of the Ox Mountains Granodiorite*

This locality is near the northwestern margin of the Lower Lismoran Formation, within the sheeted contact zone of the Ox Mountains Granodiorite. The relationship of granitic sheets to structures in the schists will be observed and the structural age of the granodiorite assessed. Note that D3 folds can generally be seen quite easily, whereas possible D2 folds are arguable.

The interbedded generally psammitic and semi-pelitic schists of the Lower Lismoran Formation often have conspicuous plagioclase porphyroblasts. They have a strongly developed sub-vertical schistosity and a gently SW plunging stretching lineation. Upright tight to close folds are also evident. Their axial planes are parallel to the schistosity and their axes plunge gently to the SW parallel to the lineation.

Steeply dipping to sub-vertical foliated granitic sheets (pegmatite and 'microgranite') related to the Ox Mountains Granodiorite cut across the bedding and schistosity at relatively small angles and commonly display sinistral asymmetrical boudinage: they have been stretched in the direction of the lineation. Where they cut the bedding and schistosity at greater angles they have themselves been folded locally by upright D4 folds. However, these folds are much more open than those in the schists though both are not only coaxial and co-planar, but have a coincidence of their respective fold crests and troughs.

One interpretation is that the Ox Mountains Granodiorite and its marginal granitic sheets were intruded towards the end of the D3 phase of deformation, hence their similar fold geometry. The preferred alternative interpretation is that there was a significant time lapse between the c. 470Ma D2 and D3 folding of the metasediments characterized by compressional shortening, and the c. 400Ma D4 deformation (the first to deform the granodiorite and granitic sheets) characterized by extensional sinistral shear. The D3 folds in the schists were commonly tightened during D4.

Locality 1.4 (B) *Garraghill, Grid Ref. M 188 970, Leckee Quartzitic Formation*

The specific locality has not been selected at the time of writing.

Quartzites and psammites of the Leckee Quartzitic Formation will be examined. Bedding, possible cross-lamination, D3 folds with gently SW plunging axes, schistosity, granitic sheeting, and possibly appinite bodies, are anticipated.

Locality 1.2 (C) *Pontoon Bridge, Grid Ref. G 214 048, Ox Mountains Granodiorite*

The road cutting west of Pontoon Bridge near the north shore of Lough Cullin is convenient for a quick look at the OX MOUNTAINS GRANODIORITE. The nearby shore line of Lough Cullin is more instructive, but shortage of time rules this out.

Lithologically banded and tectonically foliated coarse grained equigranular granodiorite lithologies have a foliation dipping at c. 45 degrees to the NW and a gently NE plunging lineation. The principal minerals are potassium feldspar (microcline-microperthite), plagioclase feldspar and quartz, with lesser or minor amounts of white mica, biotite, epidote, hornblende, titanite, allanite, apatite and iron ores. Various granitic veins occur.

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Turlough, Co. Mayo – a landscape study

Christy Lawless

The parish of Turlough is situated in the centre of Co. Mayo, 9 km north east of the county town of Castlebar, O.S. 6'' sheets, numbers 59, 60, 69 and 70, and Mayo O.S. 1:50,000 Mayo Discovery Series Map Number 31. The parish occupies the north east corner of the Barony of Carra. It extends from Pontoon Bridge at its north to Turlough Village at its south end and from the Windy Gap on the Sheeans-Crucknaree mountains on the west to Ballyvary Railway Bridge on its east side – an area that is 8 km by 12 km. It is a landscape surrounded by strong natural boundaries such as mountains, lakes and rivers that isolate it as a distinct natural land area. On its west is the Crimlin-Largan mountain range. It is bounded by Lough Conn and Lough Cullin to the north and northeast. The Clydagh and Castlebar rivers form its east and south boundaries. The Clydagh River partly encloses the territory by looping around the south end of the Crimlin-Largan mountain range.

The south end of the parish consists of a naturally enclosed elongated strip of fertile land. It lies between the Castlebar river on its south side and the shallow flowing Clydagh river to the north. Turlough Round Tower, church ruins, Turlough village and the site of Turlough Castle, are located on this strip of land that is 7 km. E-W and from 1 km. to 2 km, wide N-S. Inside these strong natural boundaries is a unique and varied landscape of low hills, drumlins, ridges, lakes, rivers, streams, rock outcrops, bogs, stone wall field-fences and small pockets of good arable and pasture land.

The landscape is also unique because of its geographical location, geology and archaeology. It lies at the western extremity of the better arable and pasture lands which extend from the midlands of Ireland via an east-west line from Strokestown, Ballaghdereen, Charlestown, Swinford and to the Crimlin-Largan mountain range in Turlough Parish. The quality of this better land rapidly deteriorates from the parish's east boundary at the Clydagh river (Toormore river) to the west of Straide for a distance of 8 km westwards where it peters out into bog and moorland at the foot of the Crimlin-Largan mountain range. Newport on Clew Bay (the Atlantic Ocean) is 13 km west of the Crimlin-Largan Mountains. This territory is mountainous with small pockets of moory land in the areas of Burren, Glenisland, Beltra, Glenhest, and Skerdagh towards Newport.

This enclosed landscape has a varied and complex geology. Eight bands of different rock types cross the landscape from east to west (Max *et al.* 1992). The *Castlebar River Limestone* is a 1.5 km wide band of limestone that extends from south of the Castlebar river to south of the Clydagh river. The area of this band of limestone between the Clydagh and Castlebar rivers where Turlough Round Tower is located is good arable land. In the centre of this band of limestone there is a vein of dolerite 7 km long from east to west and approx. 200 m wide. This band of dolerite extends from Castlebar to Rockfield 600 m west of Turlough village. The old N5 road from Castlebar to Turlough follows the centre of this vein of dolerite.

The *Moy Sandstone Formation* north of the Castlebar River Limestone is a 400 m wide unit mainly of sandstone which straddles the Clydagh river as it flows from west to east, meandering around the Rockfield, Ballyguinn, Parke, Boyogonnell, Ballyart and Cashel drumlins.

North of the Moy Sandstone there are several units of rock totalling approximately 750 m in width laid down side by side from east to west. They extend from Newantrim north of Castlebar for a distance of 11 km through the enclosed landscape of Turlough to the Clydagh river west of Straide. These rock units exhibit numerous fascinating whale-back type rock outcrops (*i.e. roche moutonnées*) and also display good examples of metamorphic rock with complex folding.

North of these four bands is a 2.5 km wide band of schist and quartzite. It crosses the heart of the landscape from east to west. It extends from its western extremity at the Crimlin-Largan mountains eastwards into the Ox mountains and from north to south it extends from the centre of Derryhick Lough to Lack West townland. In this band of quartz rich rock lies the Lough Anaffrin marble Formation. This is a c.100 m wide unit of marble located in the area of Lough Anaffrin, a small lake at the base of the south end of the Crimlin-Largan mountain range.

The *Ox Mountain Granodiorite* extends from the centre of Derryhick Lough to the southern tip of Illannaglashy, (Glassisland) north of Pontoon Bridge on Lough Conn. It generally varies from 4.5 km to7 km wide NW-SE and overall extends eastwards from Largan-Crimlin mountain range in the west almost to Lough Talt.

Diverse rock types characterize the entire landscape. Glacial erratics have crossed their natural boundaries generally in a NE direction and can be identified in the stone walls and in cultivated land.

It is a landscape of marginal land that has produced a self-sufficient subsistence type living for its inhabitants through the ages. This is also mirrored in its earliest evidence of human habitation in the Bronze Age.

There are pockets of good arable and pasture land in the many drumlins and ridges in the landscape. These drumlins and ridges can vary in area from 20-40 hectares. Their light sandstone soil is very tolerant and workable even in wet conditions compared to the heavy limestone soils to the south of Turlough and at Straide to the east.

Levallinree and Derryhick Loughs are situated in the centre of the enclosed landscape and are orientated N-S. Levallinree Lough, the most southern of the two, is 45.56 hectares, in area and is situated in the centre of the better land inside the landscape (Figure1, Plate 1).

Derryhick Lough is 60 hectares in area and is separated from Levallinree Lough at its south end by a 300 m wide isthmus of arable land. Its northern shore is on the north boundary of the better arable land in the landscape and borders the bogs and granite rock outcrops of Pontoon and Lough Cullin areas (Figure 1).

This enclosed territory is very rich in archaeological sites and monuments, some of which date back to Bronze Age times. The earliest evidence of human habitation is in its very dense concentration of 151 *fulachta fiadh*. They are confined to an area within a 3 km radius of Levallinree Lough and are inside the boundaries of the enclosed territory (Lawless 1990). The landscape lends itself ideally to this type of monument with its many meandering surface streams and an abundance of sandstone, the most suitable stone used in this cooking process. The *fulachta fiadh* are located on low lying lands, on wet ground around the perimeter of the many drumlins and ridges; close to streams; spring wells; on the edge of boggy areas and on the shores of both Levallinree and Derryhick Loughs. They are found in groups and as single sites (Figure 1).

In 1986 a wood-lined cooking trough was discovered after drainage work in the townland of Cashel Lower (Buckley and Lawless 1988) (Plate 2). The sapling timbers in the base of the trough were radiocarbon dated and produced a date of 3310 ± 40 B.P. An axe-sharpened stake found in an unlined trough after drainage in Cashel upper produced a radiocarbon date of 2780±50 B.P. (Brindley *et al.* 1989/90, Lawless 1994) (Plate 3).

There is no evidence of Neolithic habitation in the landscape nor are there monuments that are associated with the *fulachta fiadh* era (the Bronze Age) such as ringbarrows; wedge tombs or cist burials. There is but one single megalithic structure in the entire landscape. It is situated on a plateau on the southern slopes of Derryhick hill **(Locality 1.1)** adjacent to a group of three ringforts.

It is a very interesting structure consisting of two large stones which until recently, escaped notice due to the fact that they were camouflaged in a stone wall field-fence. One is a large flagstone standing on its edge. It is 2.13 m long by 1m high and is 26 cm thick. The second stone is a large diamond shaped block standing 1.71m high, its diamond shaped top is 1.13 m N-S in diameter and 75 cm E-W. It is not embedded in the ground but rests on the ground surface and is standing 28 cm from the SW end of the flagstone. An interesting feature associated with the standing stone is its quarry site. The quarry site is to be seen in a rock outcrop which is situated 132 m north of the structure. The standing stone was wedged out of the rock outcrop, leaving a gap that corresponds to the height of the stone (Lawless 1991).

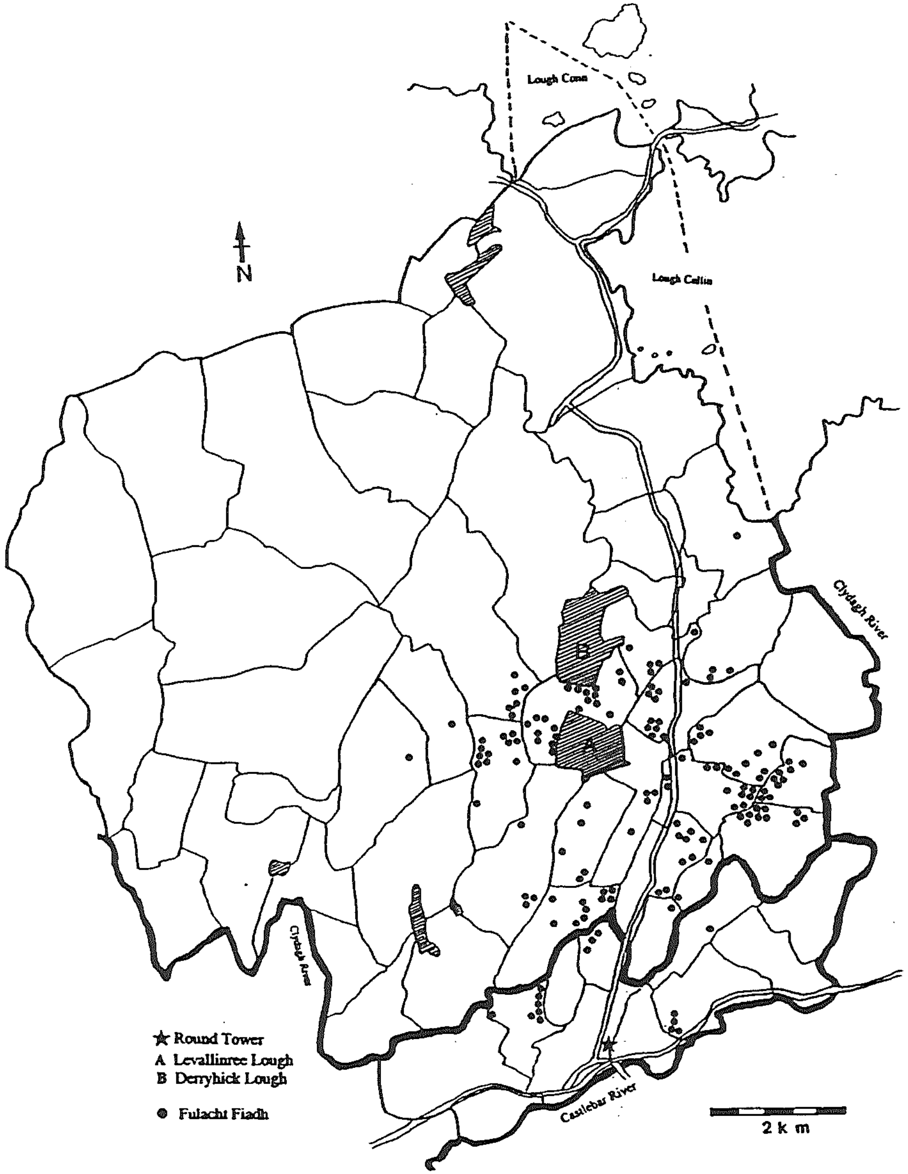


Fig.1 Distribution of Fulachta Fiadh in Turlough, Co. Mayo

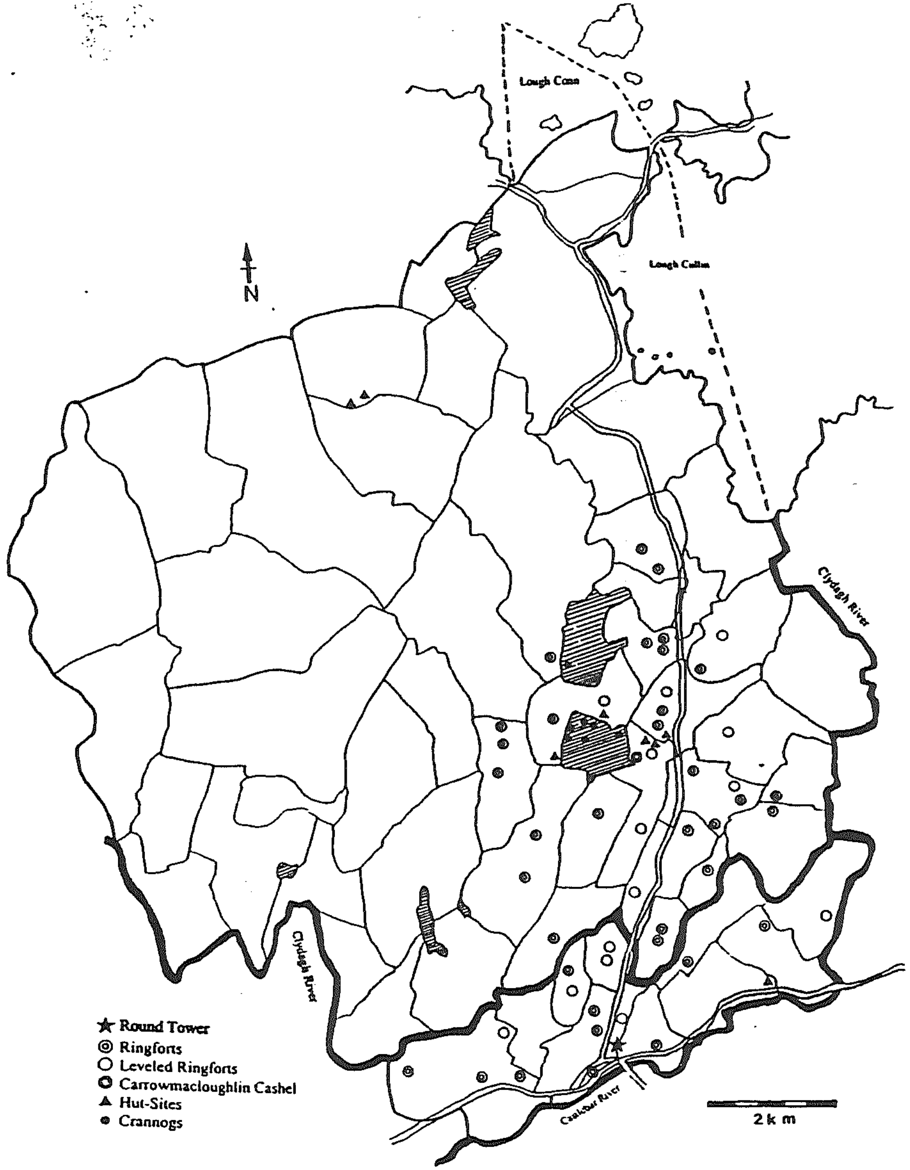


Fig.2 Distribution of Ringforts, Levelled Ringforts, Crannogs and Hutsites in Turlough, Co. Mayo.

Plate 1. Levallinree and Derryhick Loughs, from south to north, in centre of turlough landscape, with Lough Cullin in the background. (Photo C. Lawless).

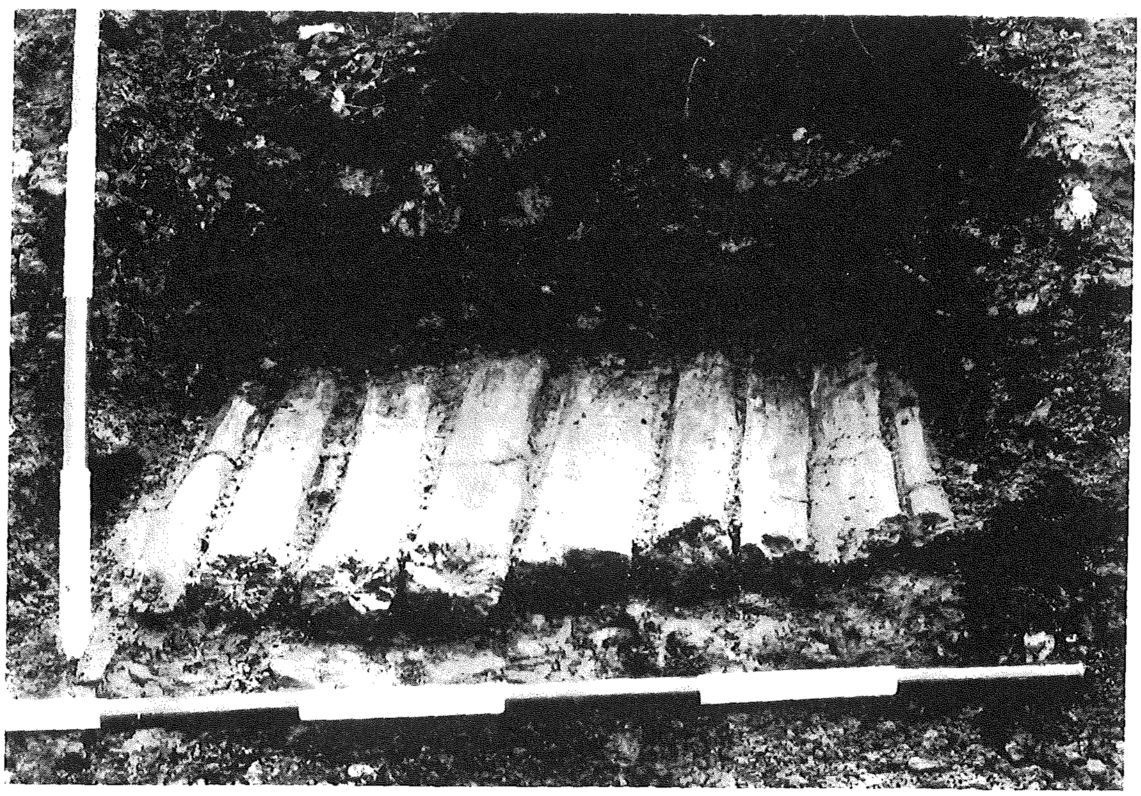


Plate 2. Base of *fulacht fiadh* trough, Cashel Lower, Turlough, radiocarbon dated to 3310±40 B.P. (Photo C. Lawless).

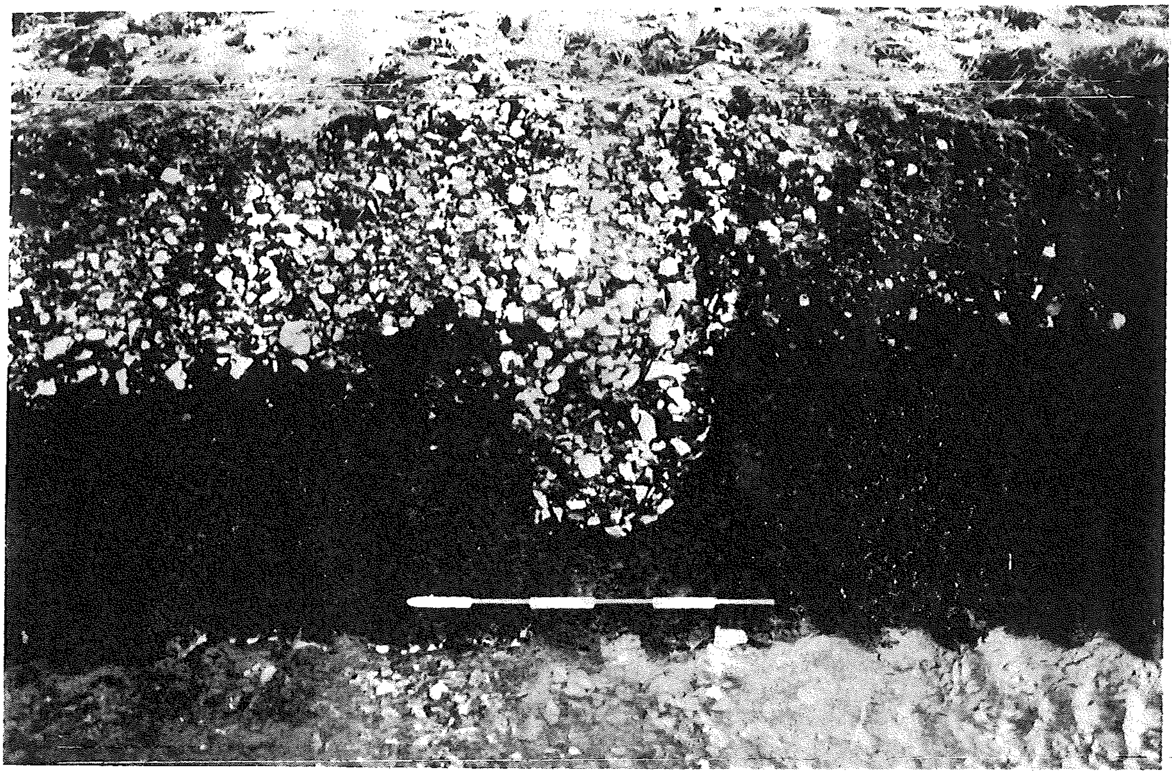


Plate 3. Section of unlined *fulacht fiadh* trough after drainage, Cashel Upper, Turlough, radiocarbon dated to 2780±50 B.P. (Photo C. Lawless).

Plate 4. *Crannóg* cairn, Levallinree Lough, Turlough, Co. Mayo. (Photo C. Lawless).

The dense concentration of *fulachta fiadh* in the landscape combined with the absence of Neolithic monuments and associated Bronze Age monuments suggests a booleying landscape. It suggests perhaps that people moved with their cattle to graze the fertile hills in the grass growing season; it might also suggest that this marginal type land was heavily wooded during the Neolithic and early Bronze Age. Its light sandstone soil has proved to be conducive to the fast growth of trees, bushes and scrub in neglected lands over a short period of time.

Levallinree Lough (Locality 1.3)

Levallinree Lough forms the nucleus inside this enclosed landscape (A, Figure 1, Plate 1). The discovery of six crannógs in the lake suggests a centre of importance. Levallinree townland name comes from the Irish language *Leath-Baile an Riogh* meaning *Half Quarter of the King* – this suggests a royal seat. Two of these *crannóg* remains are below water level. One *crannóg* is situated 182m off its nearest west shore and is constructed with 109 white soft wood birch poles. The second *crannóg* is situated 38m from the nearest north shore and it is constructed with 103 white soft wood birch poles (Lawless 1996).

Their charred tops protrude from the silty lake bottom in a circle around two mounds of charred timbers, twigs, mud and flagstones. They were constructed at a time when the water level of the lake was over 1m lower than today. Their method of construction suggests that they were pile dwellings. The charred-topped poles and charred timbers in the mounds indicate a burning down of the *crannógs*. Their construction suggests a Bronze Age date (Lawless 1996).

The two islands on the lake are *crannógs*, one of which is a *crannóg* cairn. It is situated in the northeast corner of the lake- 60m from its nearest north shore. It is a cairn of stones piled 3.75 m high in 2.25 m of water (Plate 4). It measures 19.20 m in diameter at its base on the lake bottom and is 12 m in diameter at water level. There is a layer of horizontal soft white wood logs 1m below water level in the cairn suggesting perhaps a habitation layer. A Bronze Age date has also been suggested for this *crannóg* cairn (Lawless 1996).

The second island, in the northwest corner of the lake has some very well preserved *crannóg* features. This is a very impressive structure. It is composed of stones, oak beams, peat, earth and sand (No. 29, Plate 5). It is 23.50 m in diameter and is surrounded by a treble palisade of split oak posts driven into the silty lake bottom around the perimeter of the *crannóg*. A large mortised foundation beam 44 cm wide and 18 cm thick protrudes from under the island to its east perimeter (Plate 6). There is a mortise on the end of this beam 48 cm by 15 cm, into which an upright is set. This oak beam was dated by dendrochronology to A.D. 609 (Lawless *et al.* 1989).

Iron tools were discovered on the island in 1984. They include a woodman's axe; a three pronged fish spear; and an ancient spade (Plate 7). They are dated to the 13th century (Lawless 1989).

There are four dugout canoes on the lake bottom around the *crannóg*. A large oak canoe 7 m long and 75 cm wide is positioned NW-SE on the north side of the *crannóg*. A smaller oak canoe 3.35 m long and 58 cm wide is positioned N-S on the north side of the *crannóg* (Plate 8). On the south side of the *crannóg* lies a large oak canoe positioned E-W. It is 5.80 m long and 1.15m wide. There is a very small white soft wood canoe on the lake bottom west of the *crannóg*. It is 1.50 m long and 60 cm wide and there are four large stones in the canoe as if to keep it submerged (Lawless *et al.* 1989, Lawless 1996).

Levallinree Lough is a natural sediment trap and is prone to rising waters levels over a short period.This is due to its boggy nature with both inlet and outlet located on the south boggy shore. Two drainage schemes, one in 1926 and a second carried out as part of the Moy Drainage scheme in1963 lowered the water level of the lake by 3.03 m. This drainage work exposed a wide boggy shore on the west side of the lake. Aerial photography in recent times has brought to notice a number of sites on this dry shore, namely two *crannóg* sites, two *fulachta fiadh* and two small lazy-bed gardens that were preserved under high water level. One of the *crannóg* sites is 32 m in diameter: it is a raised circular area with a degraded causeway connecting it to a *fulacht fiadh* mound on higher ground above the high water level shoreline (Lawless 1996) (No. 31 & 15, Plate 5).

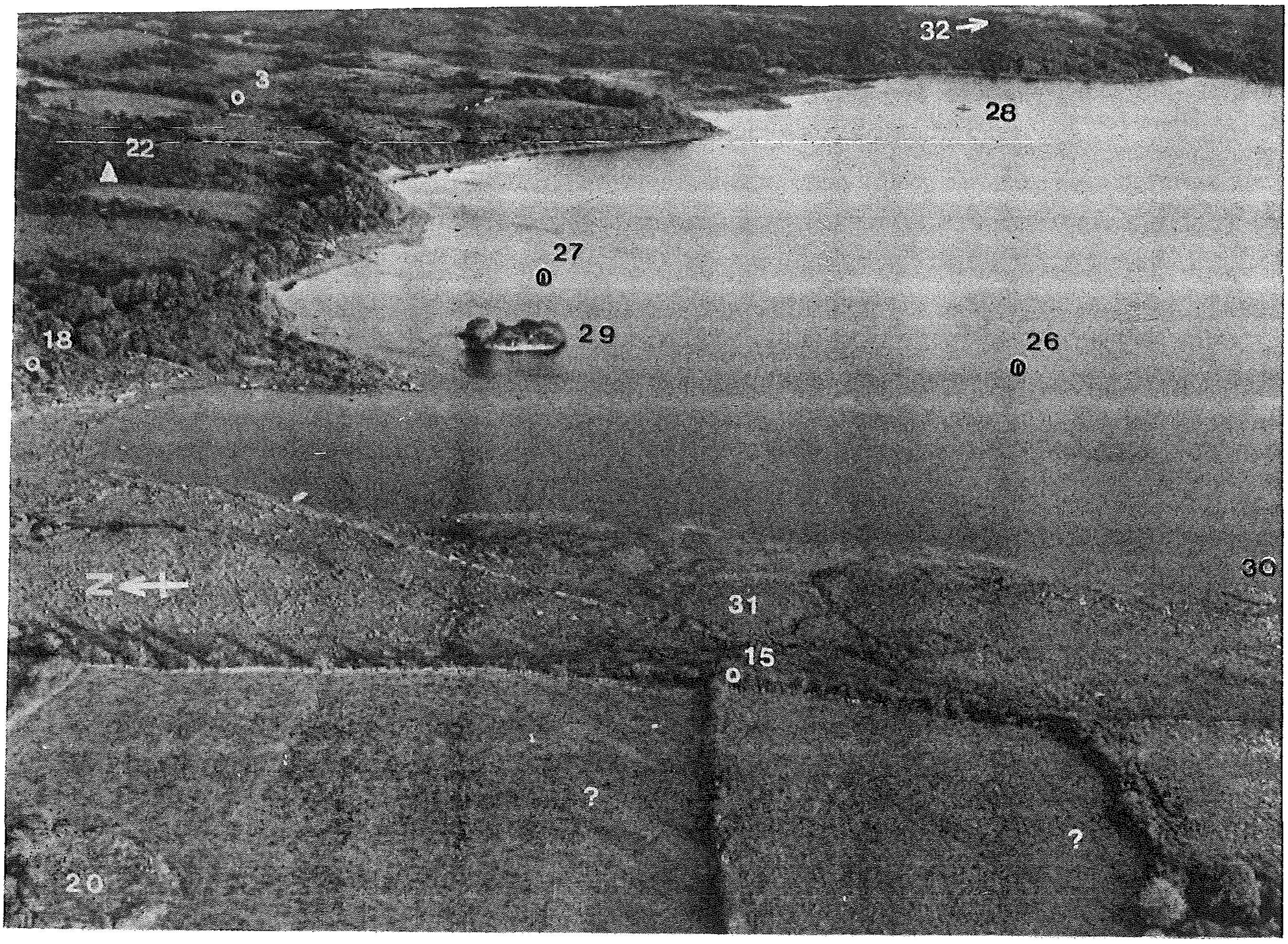


Plate 5. Aerial view of the northern half of Levallinree Lough showing the location of 6 *crannógs* (Nos. 26, 27, 28, 30, 31) and the distribution of archaeological sites. *Fulachta fiadh*: 3, 15, 18; hutsite: 22; earthen ringfort: 20; Carrowmacloughlin cashel: 32. (Photo C. Lawless).

A second *crannóg* site is at water level midway on the west shore of the lake. This is a small peat mound 12m in diameter N-S and 75cm high (No. 30, Plate 5). The mound is composed of peat, decayed softwood timbers and oak logs. The east side of the mound is continuously being eroded by the action of the water. Its most interesting feature is a *fulacht fiadh*, located on its northern perimeter. The burnt stone and charcoal from the *fulacht fiadh* is for the most part eroded from the mound by the action of the water (Lawless 1996).

Aerial photography has also revealed two small lazy-bed gardens in a cove on the west dry shore of the lake. They were preserved under high water level, but due to the long period of time submerged the structure of the lazy-beds is degraded and they are now soft and spongy. Low earthen banks surround the two gardens. To the west of the gardens on higher ground there is a small lime kiln and a hutsite.

A third *fulacht fiadh* is located on the north shore adjacent to the large *crannóg* (No. 18, Plate 5). The mound is located on the lakes highest dry shoreline. It is a well defined horseshoe-shaped mound of burnt stone and charcoal 8.50 m in diameter and 90 cm high. The hollow, which suggests the trough area, is on the NW side of the mound. Levallinree townland has nineteen *fulachta fiadh*. This is the highest number of any townland inside the territory.

A late Bronze Age date has been suggested for the two underwater *crannógs* and the *crannóg* cairn. The former suggest simple pile dwellings built in a shallow swamp or a small lake.

These *crannógs* may perhaps be contemporary with the dense concentration of *fulachta fiadh* in the area. The two underwater *crannógs* may also be evidence of the early settlers in this enclosed landscape.

The evidence for continued habitation in the landscape from the Bronze Age to the Iron Age and through to the Christian period is found in the number of ringforts. There are 50 ringforts, one cashel and an island cashel inside this enclosed landscape (Figure 2).

They occupy the tops of most drumlins, also low ridges in the better arable land areas. As with the *fulachta fiadh*, the ringforts are located inside a 3 km radius of Levallinree Lough. The most impressive of these is a cashel (stone fort) in Carrowmacloughlin townland (Figure 3) (Lawless 1993). It is located 70 m from the east shoreline of Levallinree Lough. Inside the cashel lie the 1m high walls of six houses. The cashel is part of the Levallinree Lough archaeological complex and it is contemporary with the large crannóg on the lake.

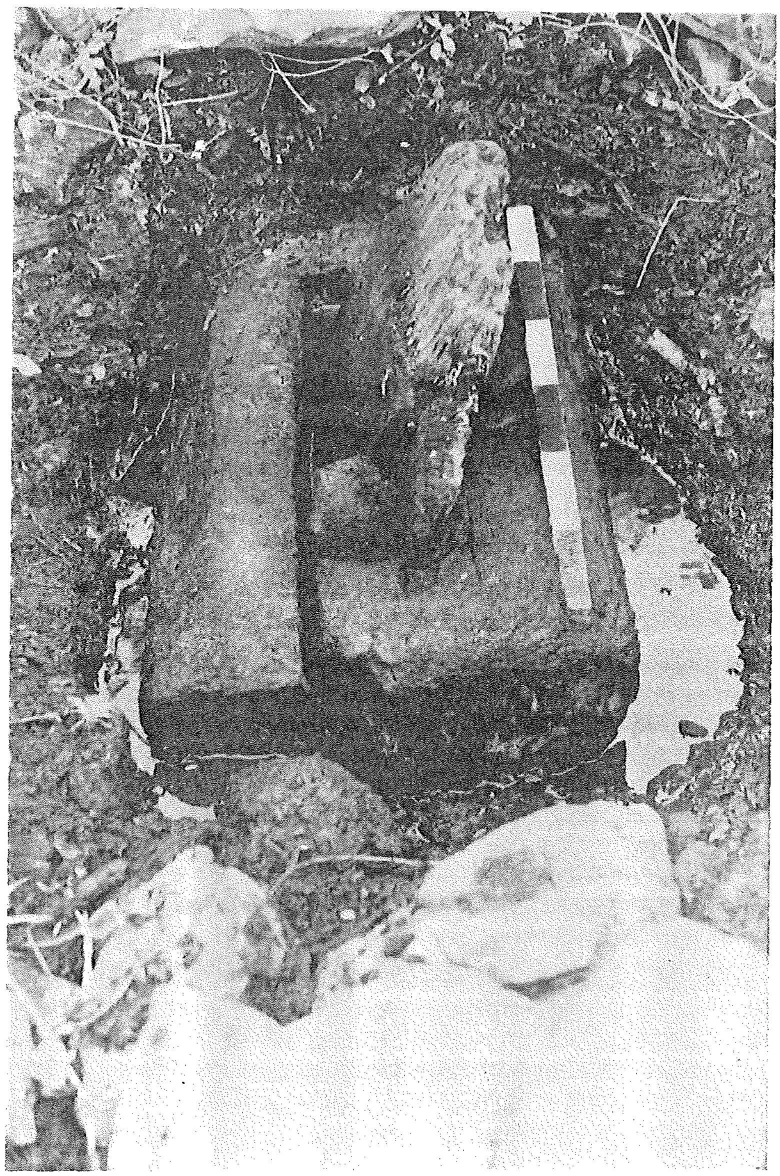


Plate 6. Morticed oak beam on the east perimeter of large *crannóg*, Levallinree Lough, Turlough, Co. Mayo (Photo C. Lawless).

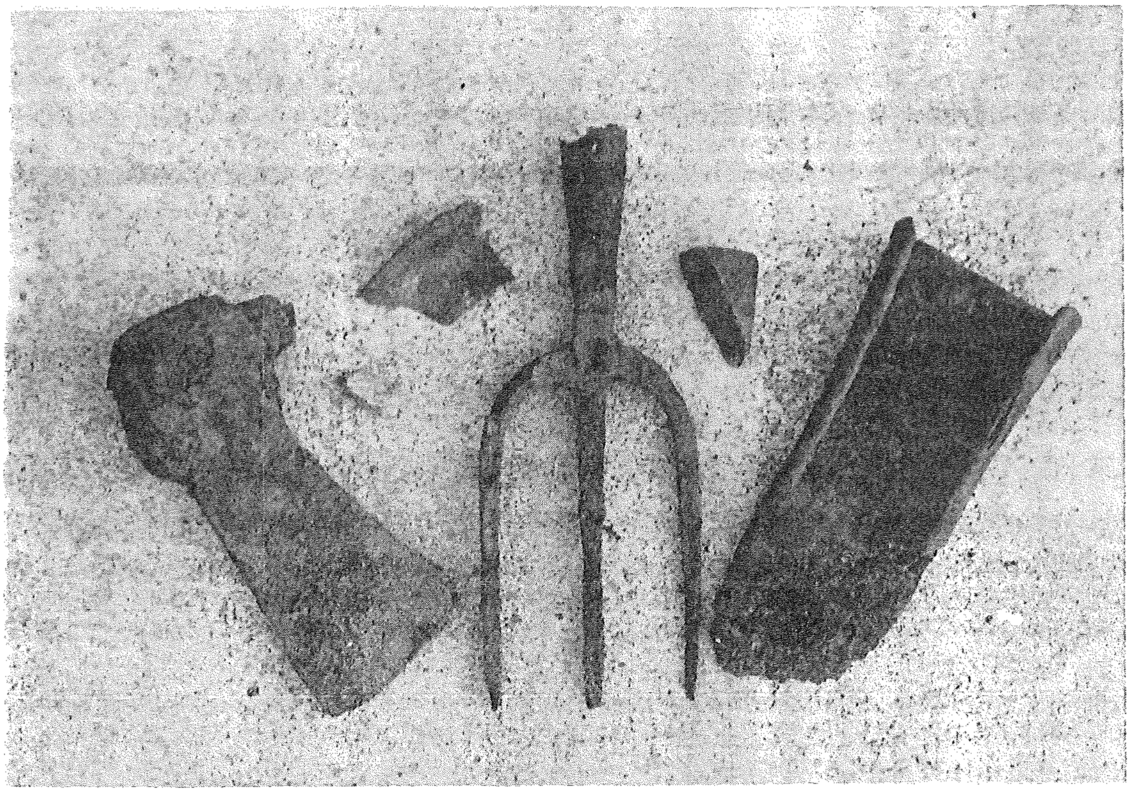
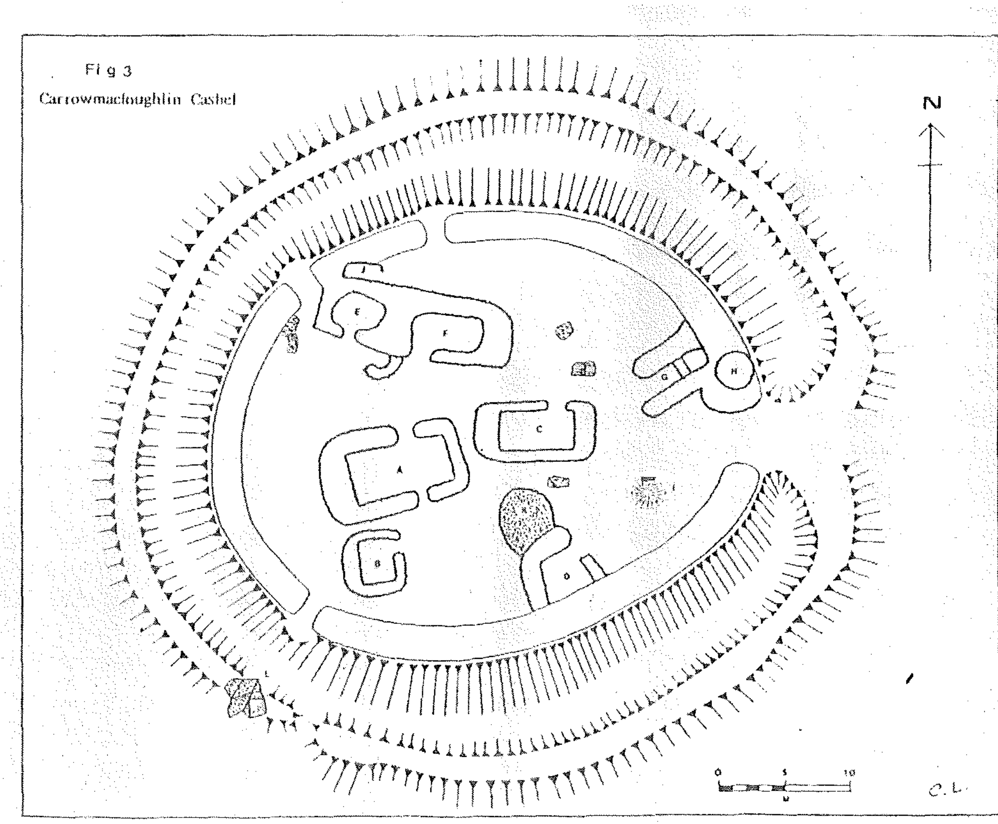


Plate 7. Iron tools from Levallinree *crannóg* – woodmans axe, three-pronged fish spear and ancient spade. (Photo C. Lawless).



Archaeological evidence suggests that Levallinree Lough was an important central location inside this enclosed landscape through the ages. The large *crannóg* on the lake exhibits a great deal of sophistication in its construction and artifacts *i.e.*, a treble palisade of split oak posts around the *crannóg*, a large mortised oak beam, evidence of wattle around its perimeter, iron tools, animal bones, four dugout canoes on the lake bottom around the *crannóg* and a dendrochronology date of A.D. 609. These artifacts combined with the townland name Levallinree, *Leath Baile an Riogh – Half Quarter of the King* strongly suggests that this may have been the seat of an ancient tuath, a small political unit or territory governed by a chieftain or king.

Monuments inside the landscape also include horizontal mill sites, hutsites, church sites, holywells, unbaptised children's burial grounds, and two castle sites. The landscape's most noted monuments are Turlough Round Tower, the adjacent church ruins and St. Patrick's Holywell. Turlough Round Tower is the best preserved of the five round towers in Co. Mayo. (Barlow 1979, Higgins 1997).

Folklore associates 12 sites with St. Patrick inside the landscape. These are located inside a 3 km radius of Levallinree Lough and consist of holywells, bullaun stone, foot prints and knee prints on rock outcrops, seats on rock outcrops in the Clydagh river and the church and a holywell adjacent to Turlough Round Tower. One of St. Patrick's knee print stones can be seen on the NW shore of Levallinree Lough in the area of the large *crannóg*.

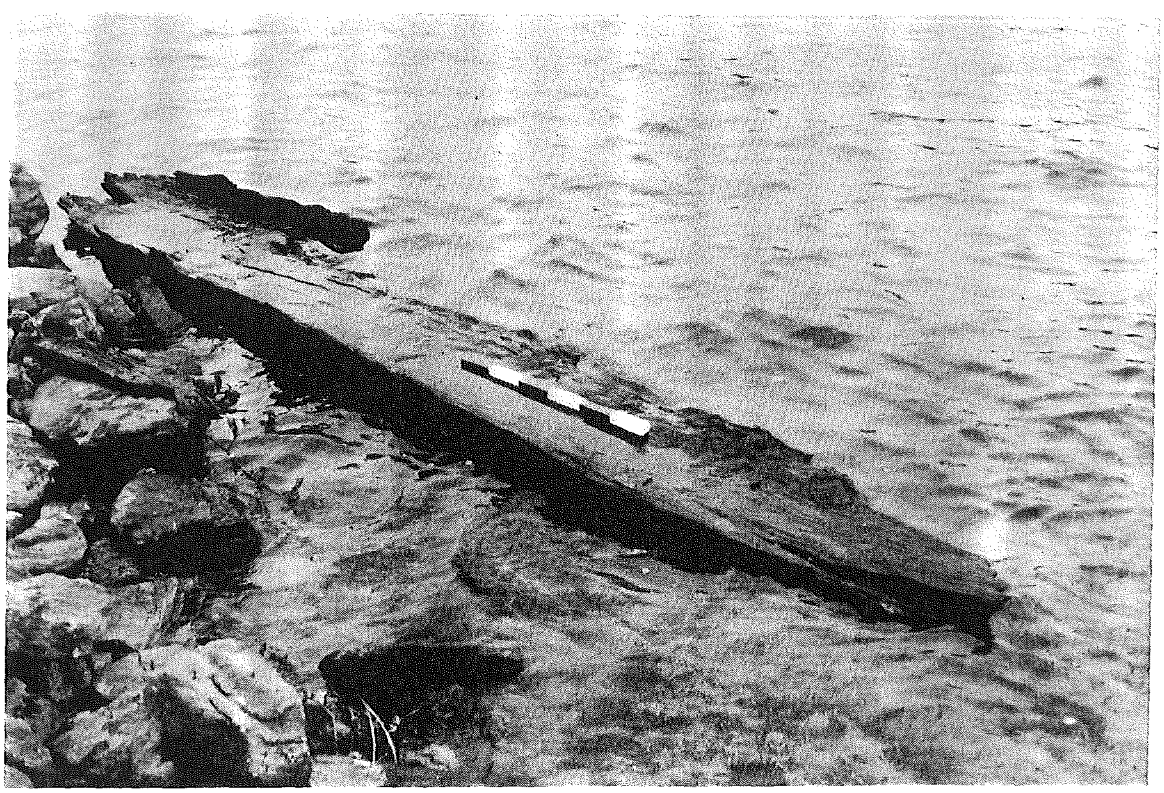


Plate 8. One of four dugout canoes from the large *crannóg* on Levallinree Lough, Turlough, Co Mayo. (Photo C. Lawless).

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Landscape heritage studies at Mayo Abbey: a local community perspective

Locality 1.6

Joe Brett

Over the past number of years Mayo Abbey has become a focus for landscape heritage studies, reclaiming in part its ancient position as a centre of learning. In early 1995 Mayo Abbey Community Council held a one day conference entitled "The Mayo of the Saxons Workshop" as part of an ongoing community development programme. This workshop helped to highlight the international significance of the Early Christian monastic settlement at Mayo Abbey. Following this workshop the local community, with the support of FÁS, initiated *The Mayo Abbey Heritage Project (MAHP).* In the first year of the project a comprehensive field survey of historical monuments was carried out throughout Mayo Abbey parish under the direction of archaeologist Leo Morahan. Monuments recorded in the 1991 SMR records were surveyed and described in detail and many previously unrecorded sites were documented. The results of this survey were compiled and published in Morahan (1996). The MAHP has continued to research all aspects of the rich heritage of the area including historical references to the ecclesiastical site, estate records and local folklore. Some results from this research work were displayed in St. Colman's Church in Mayo Abbey village this summer (1998) in an exhibition entitled 'The Spirit of Mayo Abbey'.

The studies initiated at Mayo Abbey attracted the attention of researchers from several departments at NUI, Galway. In 1996 *The Mayo Abbey Research Group (MARG)* was formed in the college to assist with aspects of the ongoing research work in the parish. Under the chairmanship of Professor Dáibhí Ó Cróinín, Department of History, this group has so far initiated two research projects at Mayo Abbey in Geophysics and Palaeobotany (Madden; Fuller and O'Connell this Field Guide). Kevin Barton, Applied Geophysics Unit, and Professor Michael O'Connell, Palaeoenvironmental Research Unit, were attracted to Mayo Abbey by the unique heritage landscape of the area.

An excellent working relationship has developed over the years between researchers, students and the people of Mayo Abbey. Local organisations help with the provision of accommodation and necessary backup services. They also negotiate access with landowners while the work of the MAHP provides a vital reference resource for the research projects. In return for this assistance the local community are kept informed of developments through periodic presentations and the sharing of information. Long term, research results will be incorporated into interpretative displays to be developed locally. The people of Mayo Abbey hope to refurbish St. Colman's Famine Church and develop it into an Interpretative and Educational Resource Centre. These plans have been greatly boosted by the involvement of NUI, Galway which has helped to raise the profile of the area locally, nationally and internationally. NUI, Galway staff and locals have successfully cooperated on funding applications to various agencies and on the production of an interpretative/promotional video.

The monastic enclosure at Mayo Abbey and the surrounding landscape provide a unique resource for research and development. Many exciting projects relating to long term environmental and cultural changes at Mayo Abbey have been identified. These projects offer researchers an opportunity to be part of coordinated multidisciplinary projects which can shed new light on the landscape and settlement history of the area.

Further information is available from *The Secretary, Research Committee, Mayo Abbey Resource Development Company Ltd., Abbey Park, Mayo Abbey, Claremorris, County Mayo; Phone/Fax: 094 65555; E-mail: mayoabby@iol.ie* or *Professor Dáibhí Ó Cróinín, Chairman, MARG, NUI, Galway; E-mail: daibhi.ocroinin@ucg.ie.*

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The geology of the Mayo Abbey area

John Madden

Mayo Abbey is situated 16 km to the south of the county town of Castlebar and 9.5 km to the northwest of Claremorris. Lower Carboniferous sedimentary strata underlie the area. To the west the Partry Mountain Series outcrop while the Ox-mountain Series outcrop 30 km to the north.

Due to the very sparse nature of the outcrops in the Mayo Abbey area and the need for micropalaeontological investigation of the outcrops, it has proved very difficult for previous workers to map stratigraphic contacts with any great degree of accuracy. This has resulted in many inferred contacts.

Subdivisions of the Carboniferous system in the area will follow those described by MacDermot (1970) who made use of microfaunal evidence, and used by Moore (1970) as subdivisions and broader grouping in his report for IBM. MacDermot's (1970) groupings and subdivisions that outcrop in the Mayo Abbey area include:

Main Limestone Group

- Lower Cherty Formation
- Light Grey Bioclastic Limestone Formation
- Dark Grey Limestones and Shaley Limestones Formation

Lower Limestone Group

- Castlebar River Limestone Formation (and associated oolites)
- Grey Bioclastic Limestone Formation
- Dolomitic Limestone Formation

The Lower Limestone Group has a total thickness in the Mayo Abbey area of approximately 120 m. The Dolomitic Limestone (20 m) has been dated to the top of the Courceyan period. It is a grey-bedded bioclastic containing up to 30% dolomite. The bioclastic nature suggests a high energy, possibly shallow water environment. The Grey Bioclastic Limestone (45 m) is not exposed in the Mayo Abbey area but is a medium grey, coarsely crystalline rock with abundant crinoidal debris and very shelly bioclastic beds. The Castlebar River Limestone (55 m) with its Chert bands, Chonetes Beds and lithostrotions was used as a recognisable marker in the field. It is a distinctive grey or crinoidal micrite with some associated shale beds leading MacDermott (1970) to favour a lagoonal type of environment for its formation. It has proved impossible to accurately map the other formations due to lack of outcrop. This has resulted in inferred contacts.

The Main Limestone Group outcrops to the southeast of the Castlebar River Limestone and to the north west of the Kiltimagh Fault. The Dark Grey and Shaley Limestones (45m) is a fine grained, dark grey and blackish limestone. It underlies much of the area to the southeast of the Castlebar River Limestone and stretches in a belt close to Mayo Abbey village. The Light Grey Bioclastic Limestone (10 m) is similar to the Castlebar River Limestone and is exposed in the southern parts of the Manulla and Meander rivers. The Lower Cherty Formation underlies the southeast corner of the Mayo Abbey area. It is medium grey, fine-grained limestone containing up to 15% chert.

The geological structure of the Mayo Abbey area is very simple. All the bedding is the right way up, indicated by the fossils in their growth positions and sedimentary structures such as ripple marks. The regional dip is to the southeast. Faulting rather than folding dominates, and on a more regional scale is seen to dominate the structure of the area. The major fault in the region, the Kiltimagh fault, trending ENE brings together the Carboniferous limestone and sandstone series and was first mapped by Moore (1970). An examination of his IBM data suggests a normal fault with the south side upthrown. The dip is unknown. Lombard (1997) obtained geophysical signatures of the fault throughout the region.

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Mayo of the Saxons – an introduction to its history and archaeology

Carmel Joyce, Jane Hawkes and Stephen Goldrick

"The site of Mayo Abbey is one of outstanding importance within the history of European monasticism, and it is indeed surprising that it had been to date, so little researched by modern scholars"(Rosemary Cramp, Emeritus Professor of Archaeology, Durham University, 1997).

Representing two Irish words, *mag* meaning an open stretch of land and *eo* meaning a yew tree, the Old Irish name *Mag nÉo* can be translated as 'the plain of yew trees' (Ó' Muraíle unpublished). Also known as the 'Plains of Mayo', the archaeological landscape in which the present village of Mayo Abbey is situated is testimony to over 1300 years of intense religious and political activity (Plate 1).

Plate 1. Aerial view of the village of Mayo Abbey and its archaeological landscape

Muigheo na Sacsan (Mayo of the Saxons) is peculiar in that it was conceived as an exclusively Anglo-Saxon monastery. Although there are other monasteries noted for their Anglo-Saxon associations in this country for example Ti Saxon, Co. Galway and Rath Melsigi, Co Carlow, none are so well illuminated as *Muigheo na Sacsan*. Unlike many monasteries from this period its story is documented from its *reason d'être*, the Synod of Whitby (AD 664) to its foundation *ca.* AD 670, by the Venerable Bede - 'the father of English history'. Completing his *Ecclesiastical History of the English People* in AD 731, Bede explains that a recurrent controversy concerning the date of Easter, the correct tonsure and other doctrinal issues identified the Celtic

Church founded by Columcille (Columba), as being administered in a manner which was contrary to the authentic Roman Church (the tonsure was the fashion of hair worn by Christian monks as a symbol of their spirituality, Celtic monks shaved their hair in front, from ear to ear, leaving it to grow longer at the back while followers of the Roman Church wore a crowning band of hair representing Christ's crown of thorns).

Doctrinal disunity had been tolerated up to a point, until Finan succeeded the much loved Aidan as Bishop of Lindisfarne (AD 651). Finan, described by Bede a s "a hot tempered man whom reproof made more obstinate" was accepted with less tolerance than his predecessor (Bede III.25, see Farmer 1990). Finan was succeeded in turn by Colman who accelerated the dispute, so much so that some followers began to fear for their souls, believing that their faith was unfounded. Such was the disunity and anxiety that it was necessary to call a council to settle the matter.

Presided over by the Abbess Hilda, the Synod of Whitby (AD 664) saw the two traditions coming face to face. The Catholic Church was represented by priests Wilfrid and Agatho and by Bishop Agilbert while the Celtic Church was represented by Bishop Colman of Lindisfarne and his laity. Vehement to disprove the teachings of the Celtic tradition, Wilfrid cast theological doubt on Colman's beliefs and those of his ancestors. He argued that Colman's forefathers worshipped God "in primitive simplicity but in devout sincerity" (Bede III.25). His followers were, however, guilty of sin if they rejected the revised interpretation of the Bible currently accepted by the universal Church: *"do you imagine that they, a few men in a corner of a remote island are to be preferred before the universal Church of Christ throughout the world?"(op. cit.)*. Forced to agree that Wilfrid's argument was convincing, Colman proved to be unwavering in his stance. In fear of discrediting the lives, customs and discipline of his forefathers Colman and his supporters refused to convert to Alexandrine system of calculating Easter. Bede continues his narrative describing how Catholic customs were introduced to England and the Irish who were unwilling to conform returned to their own land (Bede III.28). Colman with his remaining followers left their monastery on Lindisfarne, taking with them relics from the tomb of Aidan (the founder of that monastery) and travelled to Iona (Bede III.26).

It is from this turbulent background that the renowned monastery of *Muigheo na Sacsan* was born. The Lindisfarne exiles spent some time on the island of Iona before setting sail for their planned destination, Inishbofin. It has been suggested that Colman himself originates from the West of Ireland. This in part explains why he should undertake such a long journey to that remote place, it also perhaps accounts for the behaviour of the Irish monks (Chadwick 1964, 189).

A dispute developed between the Saxons and their Irish brothers, the Irish "going off on their own to wander around places they knew instead of assisting at harvest, and then as winter approached they came back and wanted to share whatever the English monks had gathered" (Bede IV.5). Some authors interpret this behaviour as the traditional Irish practice of 'booleying' or transhumance (Chadwick 1964,189). The fact that the Irish monks were visiting places which they were familiar with suggests that at least some of their number were originally from the West of Ireland.

Observing the dispute, Colman gathered his Saxon monks and left Inishbofin for the mainland. We are told that he "searched near and far"(Bede VI.5) for a site suitable for a monastery. This he found at *Mageo* were he bought a small tract of land of the local nobleman. At this site a monastery was promptly constructed for the thirty Saxon monks, with the assistance of the nobleman and his neighbours. Concluding his chapter on the foundation of the monastery at *Mageo*, Bede remarks that having "grown large from small beginnings" it is "still occupied by English monks" (*ca.* AD 730).

It is worth pointing out that, but for Bede's account of the Synod of Whitby and its results, the event might have gone relatively unnoticed. The controversy is almost ignored in the Irish Annals (Shaw 1963, 193). Bede's documentation of the foundation on Inishbofin is also significant as it is the earliest known account of an Island Monastic sanctuary in Ireland (Chadwick 1964, 191).

The Annals of Ulster, a reliable 15th century compilation, makes a reference at the date AD 668 to the "voyage of Bishop Colman with the relics of the saints, to Inis Bo Finne, where he founded a Church". If this is accepted as accurate, the date is useful when considering the foundation of the monastery at Mayo. Travelling in a light, but durable currach (such as that constructed by Kilmartin House Trust, in Mayo Abbey village in 1997) it is probable that this voyage took place in springtime, thus allowing the monks time to construct a monastery as well as to establish a food supply on the island. This must have been followed by a period during which the Irish monks developed a pattern of wandering off in summer time. The date for the foundation of the Saxon monastery at Mayo can therefore be estimated to be *ca.* AD 670. Before returning to Inis Bofin, Colman appointed the Saxon Garailt (a sadly elusive historical figure) as first Abbot of the new monastery.

It is by no means certain what the foundation at Mayo looked like or what area of ground was encompassed within is vallum (enclosure). At the moment it appears that a D-shaped area of 11.44 hectares, enclosed within a discontinuous wall, represents the extent of a monastic enclosure. Geophysical surveys are providing a tantalizing window into the apparently complex habitation of the site. In the absence of most contemporary above-ground monuments, it is necessary to infer an image of the monastic complex by using available geophysical signatures, historical documentation and archaeological parallels. Beginning as a small "promptly built" (Bede IV.5), probably wooden structure (Leask 1987), the monastic site must have been substantially enlarged in size, perhaps several times, as it began to attract new members and visitors. From present sources it may be surmised that the monastic layout followed the general pattern - a well defined focal area containing the church and other sacred structures, accompanied by domestic buildings and agricultural plots, all enclosed within a boundary or vallum (Manning 1995).

According to the Book of Ballymote there were 100 Saxon monks at the monastery by AD 700. This substantial increase in population is hardly surprising given the extent of contact which existed between Ireland and Britain in the Early Medieval period. During the time of the Bishops Colman and Finan, Bede records the many nobles and 'lesser folk' who travelled to Ireland and devoted themselves to monastic life or to study, while receiving daily food, books and instruction (Bede III.27). This pattern was to continue, as indicated by the historical records relating to *Muigheo na Sacsan.*

Apparently the Anglo-Saxon monastery in the West of Ireland became renowned as a place of great learning, throughout Christendom. The chief advisor to Emperor Charlemagne (himself a great patron of learning) Alcuin, a Saxon monk, wrote at least two letters of support and praise to Mayo of the Saxons (ca. AD 780) "To the beloved fathers in Christ of the Church of Mayo, Alcuin a humble deacon, sends his greetings. Your love has always been precious to me. I always make sure to ask for it through your brothers who visited me...believe me it would comfort me greatly before God if you would prey for me... a great light of knowledge has spread from you to various parts of our country... and the progress of many very clearly means a rich reward for you in the future".

A popular story concerning Mayo is that the site was visited by Alfred the Great while his son was alleged to have been sent here to be educated in the monastery. After his untimely death he was said to be buried in its grounds (Healy 1890, 538). It is likely that this story is a result of the corruption of the name Aldfrid, King of Northumbria. Aldfrid was a close friend of Adamnan who allegedly *'governed the monastery'* of Mayo for seven years (the source of this to reference to Adamnan is the Life of St. Gerald, a problematical work) (Ó Muraíle, unpublished).

The Irish Annals have very little mention of the Anglo-Saxon monastery, unlike English sources. The Annals of Ulster, is the first Irish record, noting the deaths of Garailt, Abbot of Mayo in AD 732 and of Bishop Aedan in AD 773. It also details the burning of the monastery during a violent thunder storm on a Saturday night in August, AD 783. Close contacts with the English church, after the death of Colman are recorded by the Annals of Ulster which states that Bishop Aduulfus of Mayo Abbey attended an English church council in AD 786 (Farmer 1990, 371). The Saxon monastery had to endure further turmoil in the early 8th and 9th century. It was burnt in AD 804, while it is believed that in AD 818 the 'Norwegian Tyrant' Turgesius destroyed it in "contempt of God and his saints".

The Early Christian sculpture of Mayo Abbey.

We know of at least two high crosses from the Early

Christian Monastery at *Muigheo na Sacsan*. The head of one was found in the old graveyard and is now in storage awaiting further archaeological study. The second represented by a base, is at present located in the grounds of the Famine Church.

The cross-head is of red-yellow sandstone and is described as a free-armed Anglican type. It was removed from the graveyard four years ago, after spending some twenty years, partly exposed to the elements. It is approximately 60 cm high by 50 cm wide and can be dated to the first quarter of the 9th century (Hawkes, unpublished). Crouched on top of the main shaft is a slender leonine creature, whose head is resting between its two, outstretched front legs. One main face and the sides of the cross-arms are decorated with carved interlace, much of which is barely recognisable as the cross has been badly weathered. On the second main face is a Christ figure, who stands with both feet turned outwards and holds both arms at right-angles to his body. The figure wears a full-length robe with a fold of drapery hanging from the left shoulder (Plate 2).

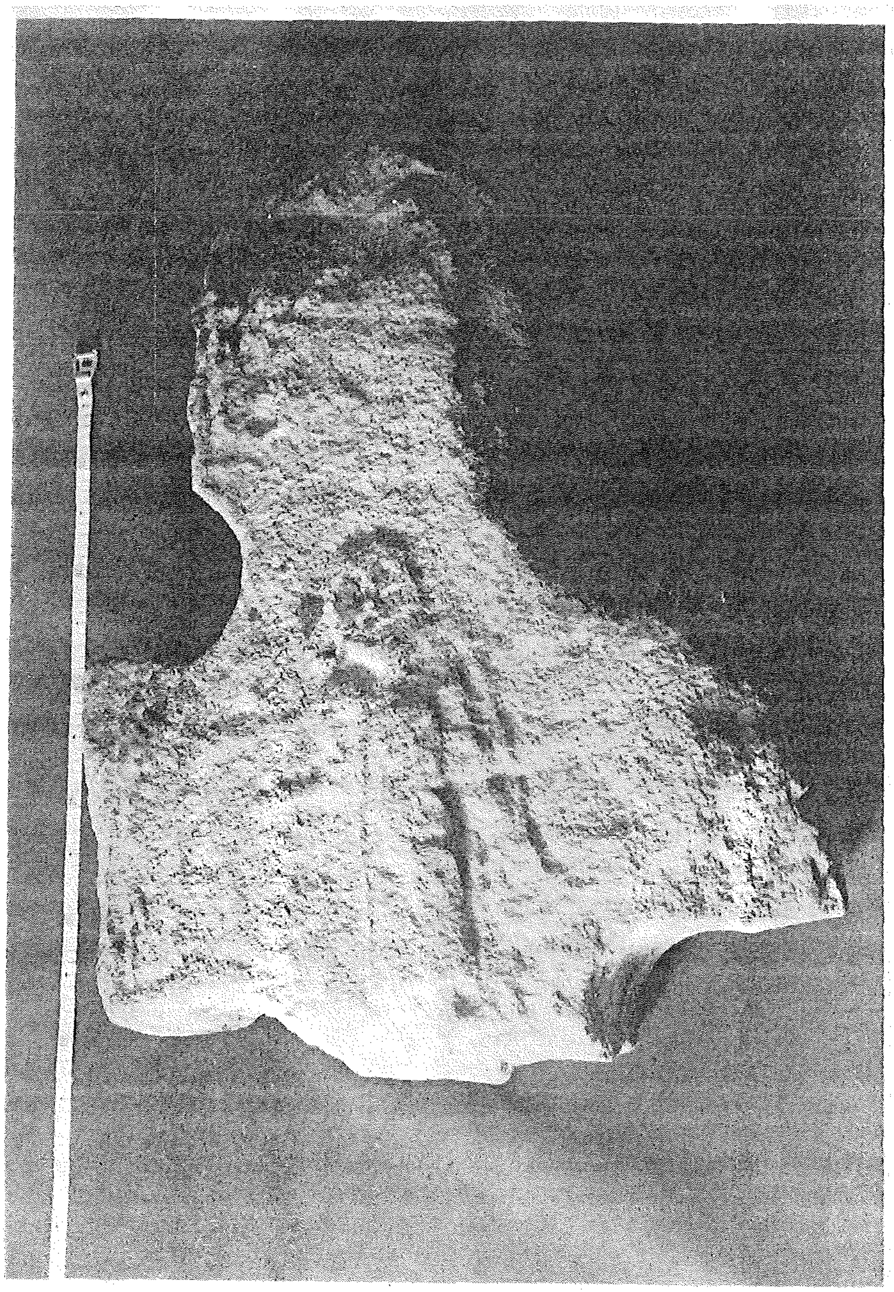

Plate 2. Early ninth century stone cross head, found in Mayo Abbey.

Many stylistic features of this cross are similar (though not identical) to Anglo-Saxon sculpture found in England. The basic shape of the cross, block-ended arms with circular armpits is a form common to Anglo-Saxon England, but rare in Ireland. Likewise, the practice of filling the main face of a cross-head with interlace designs is common to Anglo-Saxon High Crosses. Furthermore a single figure, set at the centre of a cross-head is a feature of Anglo-Saxon crosses. It is unusual, however, to find such a figure isolated at the centre of the cross-head with no apparent accompanying ornament or frame surrounding it, as seen on the Mayo Abbey Cross. The detail of the drapery hanging from the Christ's left shoulder suggests the carving has similarities with Christian art produced during the 9th century under Carolingian influence, both in Anglo-Saxon England and on the European mainland. A particularly good example of an object displaying similar decoration is the 9th century ivory cover of the *Book of Pericopes* of Henry 11, (now in Munich).

Probably the most distinctive feature of the Cross-head is the leonine creature which crouches, on the top of the cross. During, and before this time, the lion figure was used as a symbol to represent the resurrection of Christ on the third day. This was an image which was used by the early monasteries of the 'Columban federation'. It is an extremely rare decorative detail both in Britain and Ireland. Some 8th century Crosses associated with Iona are decorated with a similar animal, eg. St. John's Cross on Iona and the Kildalton Cross, on Islay (in Argyle), Scotland, but none have such a three dimensional carving on top of the main-shaft of the cross. It is believed that the figure on the Mayo Abbey High Cross is that of Christ's resurrection. All of the archaeological clues suggest that the Mayo Abbey Cross was probably produced elsewhere, at a centre which had close links with places such as Iona, Anglo - Saxon Northumbria and Carolingian Gaul. Such contacts would tie in with what is known of the early history of Mayo Abbey itself (we know that at this time Alcuin of York was in contact with the monks at *Muigheo na Sacsan*).

The cross can be seen to represent the story of *Muigheo na Sacsan* as all of the major cultural influences are depicted in its form and decoration. The result is a cross which is unique among the surviving examples of such High Crosses in Ireland. The village can also boast over a dozen early cross slabs - two in complete condition, the others fragmentary. These are thought to range in date from the early eighth century to the twelfth century. At least five fragments have been worked into the ruined abbey, one being a particularly accomplished and unique piece. These relics are symbolic not only of Christianity in Co. Mayo, but of extensive religious and political contacts throughout Europe in the Early Medieval period (Hawkes, unpublished).

Mayo Abbey and twelfth century ecclesiastical reform

Mayo Church continued to be in contact with Europe throughout the Middle ages. During the 11th and 12th century it became a part of a European wide movement which transformed contemporary ecclesiastical society. Revolutionary Papal reform influenced a small group of Irish clerics to import the resultant structural and administrative changes into the Roman Catholic Church in Ireland (Watt 1970, 2). The decentralised monastic movement did not escape the clamour for reform.

In 1111 the Synod of Rath Bresail was convened with the purpose of implementing the ideals of the reform movement throughout the country (Connellan 1950, 19). At this time Mayo Abbey was established as a parish in the territory of Ciarraighe, in the diocese of Tuam (Connellan 1950, 22). Further reform took place at the Synod of Kells in 1152 when Mayo Abbey was made a minor Bishopric within the diocese of Tuam, thus increasing the prestige and status of the parish. Mayo Abbey prelates were at the vanguard of the twelfth century reform movement, and according to the Annals of Ulster, a Mayo Bishop, Gilla Iosa Ua Mailin attended a reforming Synod at Cashel in 1172 (Gwynn 1992, 244).

This reforming movement had profound implications for the future of ecclesiastical and even political life in Ireland, the movement accepting Norman authority in the person of Henry II (1154-1189). The existing Church in Ireland was viewed by zealous reformers as a corruption of Roman ecclesiastical practice and theology. It was felt that the Irish Church had experienced several centuries of isolation from Rome therefore, the native ecclesiastical structures had become clannish and parochial.

The Abbot rather than the Bishop was the major administrator and the monastery became the centre of jurisdiction rather than the diocese (Ó 'Cróinín 1994, 132). Furthermore, the laws used in Gaelic society were the Brehon laws and were seen by reformers as pagan in origin. This resilient legacy of Celtic society has to be taken into account when considering the monastery of Mayo in the Middle Ages.

Amazingly some practices of the Celtic Church which caused controversy between Rome and some parts of North Britain in the sixth century remained to a certain extent in the thirteenth century. These included the Celtic tonsure and the dating of Easter. This tonsure was banned by the Council of Ireland in 1295 (Stokes 1910, 347). It has even been suggested that the Celtic custom of dating Easter still remained in Ireland; as late as 1444 the Annals of Dubhaltach Mac Fir Bhisigh told of a controversy between the English and Irish clergy in that year concerning Easter *(op. cit.)*.

Radical change affected traditional society in Ireland due to the advent of the Normans. The religious life, monastery and the local environment of Mayo Abbey became affected by Norman intrusion, colonisation, assimilation and settlement. Possible archaeological evidence of this colonisation is visible on the landscape in the townlands of Fahey Beg and Knockadorraghy, where moated sites are preserved. Accounts exist of the local disruption caused by the early contacts between the Anglo-Normans and the natives. During 1236 Mayo Abbey was plundered by a Hibernicised Norman, a Mac William who "..proceeded to *Maigh Eo* of the Saxons and not a stack of seed or corn of all that was in the great relig of Mayo, or in the relig of the church of Michael the Archangel, was left without being taken away together" (Hennessy 1871, 341). West Connacht became invaded by the Normans much later than the rest of the country, and in 1235 the West had been invaded by a large army headed by the magistrate Maurice Fitz Gerald. The Mayo Abbey district became colonised by the De Prendergast family (alias MacMaurice). They established a stronghold in Brize where they became known as *Clann Muiris na m-Brigh* eventually giving their name to the barony of Clanmorris (Orpen 1968, 209).

At this time vast cultural differences existed between the two peoples. Giraldus Cambrensis criticised the traditional nature of Gaelic Ireland in the twelfth century. He wrote of the Irish "who wore strange clothes and who had long beards and hair" (O' Meara 1982, 102). His major work, *The History and Topography of Ireland (ibid)* condemned the language, religion and way of life of the people of Ireland, and was written to justify the conquest of Ireland by Henry II and establish the cultural superiority of the Normans over the native peoples.

In 1242 the Annals of Loch Cé mention conflict between the Norman MacMaurices and the O' Connors when the region of Mayo Abbey became part of a power struggle between Norman magnates and Gaelic Lords. The Annals tell us "Maghnus O' Muiredhaigh was slain by Thomas Mac Murchadha. Niall, son of Domhnall Mur, Son of Ruaidhri O' Conchobhair was burned, together with three O' Sechnasaighs in a house in Magh Eo of the Saxons by Loghbhais of the people of MacMaurice" (Hennessy 1871, 359). The Anglo-Normans made a concerted effort to conquer the area when Walter Burc assembled a huge army in 1256, which was composed of over 20,000 men against Fedhlim O'Connor. This host marched to "Magh-Eo of the Saxons, and from thence to Balla" *(ibid.* 409*)*. These sources subsequently point to a resurgence in the strength of local Gaelic Lords when the Norman colony found in the locality was attacked by Aedh O' Connor, in 1262 " he collected a large army, and plundered the Foreigners of all the west of Connacht eastwards from Magh-Eo of the Saxons, and from Balla, and burned their towns and corn fields from thence to Sliabh-Lugha, and slew many persons between those places"*(ibid.,* 443*)*. This account points out a substantial Anglo-Norman infiltration into the area during the thirteenth century.

Profound changes took place during the thirteenth and fourteenth centuries when a so called 'Gaelic revival' took place affecting the Norman colony (Lydon 1972, 150). The position of Norman superiority began to change and the Gaelic Irish began both a political assertion and a cultural resurgence, in Mayo Abbey local magnates, the Stauntons and the Prendergasts would have been affected (Orpen 1968, 209). The Anglo-Norman colony was shook to the foundations by the invasion of the Scottish Edward the Bruce in 1315 (Lydon 1972, 150). This invasion though defeated marked a decisive change in the balance of power between Norman and Irish throughout Ireland. Due to these developments, by the end of the fifteenth century the area of Ireland effectively run by the English Government shrank to 'The Pale' (Lydon 1972, 151). Outside the Pale, a patchwork of shifting relationships and alliances existed comprised of both Anglo-Norman and Gaelic Lordships. The area of Mayo Abbey would have been a part of this web.

During 1380, a Parliamentary decree banned native people entering the religious life in Mayo Abbey declaring "It was this year enacted by Parliament, that no mere Irishman should be permitted to make his profession here." (Archdall 1786, 506). Both Norman and Gaelic Irish held differing religious traditions and several religious orders were divided along racial lines (Otway-Ruthven 1968, 142). In 1370 the Augustinian Order was introduced to Mayo Abbey (Gwynn and Neville 1988,186) and during the fourteenth century extensive monastic foundation was undertaken in rural areas by either Gaelic or Gaelicised local rulers (Empsey 1984, 136). This appeared to have happened in Mayo Abbey when the medieval Abbey of Mayo had been endowed by the Burkes in the late thirteenth century (Knox 1907, 90). An important event in the evolution of Mayo Abbey occurred in 1411, when Archbishop Babynge transformed the Abbey in Mayo into an organisation under the official rule and jurisdiction of the Augustinian Canons Regular. This arrangement was confirmed by the Papacy (Gwynn and Neville 1988, 186). The introduction of the Augustinians, ultimately an order from the Continent, marked a change away from the ideals of enclosed monasticism. Their ideals of preaching and evangelism were more suited to the actual situation in Ireland, where pastors rather than monks were needed to minister externally to congregations (Empsey 1984, 136).

Plate 3. Fifteenth century cloister arcade fragment from the ruined Augustinian foundation in Mayo Abbey.

The next departure in the religious life of the Abbey occurred when the Franciscans, the Friars Minor, became associated with Mayo Abbey. Franciscan model of 'poverty' and 'simplicity' were popular amongst the Gaelic Irish and with the Anglo-Normans. During the fifteenth century Nicolaus Wogmay, from a prominent Norman family was appointed Bishop of Mayo (Moody *et al.* 1984). A reconciliation had occurred to a certain extent between the two traditions; in fact both Augustinian and Franciscans ministered to both while Mayo Bishops came from both communities (Otway-Ruthven 1968, 136-138).

Mayo Abbey faced huge social, religious and political upheaval during the sixteenth century. Tudor monarchs extended their sovereignty over the whole of the island, gradually re-conquering the country so that by Elizabethan times Mayo Abbey came under the renewed jurisdiction of a powerful centralised English state. Tudor rule saw the introduction of Protestantism and the destruction of the old monastic way of life. The Reformation did not take hold in Ireland, but many monasteries were dissolved and the prestige and reputation of Mayo Abbey Church suffered as a result. A description of the once great monastery, dating from 1578, refers to the structure as a ruined cloister, insignificant cemetery and a couple of rooms (Archdall 1786) (Plate 3 above).

Despite the decline, the new shire of Mayo was named, during the 1570's, after the village of Mayo and its Abbey is recorded in Browne's sixteenth century map of the county. The story of Mayo Abbey as a significant religious centre finally comes to a close in 1631 when a final union of the Mayo diocese with Tuam diocese took place.

Mayo Abbey today is a tiny, vibrant village, quietly preserving this legacy of its remarkable place in local and European history. As it was in the past, Mayo has become a focus of learning, through geophysical, palaoenvironmental, archaeological and historical research. This work is sponsored by the local community, FÁS and NUI, Galway.

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Long-term vegetation dynamics and human activity at Mayo Abbey, central Mayo

Janice L. Fuller and Michael O'Connell

Introduction

Mayo Abbey lies 10 km north-west of Claremorris in a region rich in field monuments and artefacts representative of all the major archaeological and historical periods from the Neolithic to the present day (Morahan 1996). This paper presents initial results of palaeoecological investigations that aim at reconstructing long-term vegetation dynamics and the environmental context of human activity during the post-glacial in the Mayo Abbey area. The main tool employed, i.e. pollen analysis, has the potential to provide continuous records of vegetational and environmental change that span millennia and with a temporal resolution of decades or less. It is the most powerful means to reconstruct farming activity and human impact on natural ecosystems through time (cf. Behre 1988, Molloy and O'Connell 1987). The results presented here provide an outline vegetation history for a part of Mayo which, until now, has been largely neglected from the point of Holocene vegetation and land-use dynamics.

Palaeoecological studies, already carried out, provide Holocene records of land-use history and vegetation change for various parts of Co. Mayo, including western Mayo and Clare Island (Coxon 1987, 1994, Foss and Doyle 1990), north-east Mayo (O'Connell 1986, 1990, O'Connell et al. 1987, Molloy and O'Connell 1995, Jennings 1997), and mainly upland parts of central Mayo (Browne 1986, Bradshaw and Browne 1987). As well as providing evidence of climatic change during the course of the Holocene, these studies suggest considerable variation in vegetation history related possibly to the underlying bedrock and land-use history.

Palaeoecological investigations on Inishbofin (Ní Ghráinne 1993, O'Connell and Ní Ghráinne 1994) should also be mentioned in that, firstly, Inishbofin was an administrative part of Mayo until the end of the last century and, secondly, Church Lough, Inishbofin, was the site of the first monastery founded by St Colman (AD 665). Colman subsequently withdrew the Saxon monks from Inishbofin and proceeded to central Mayo where he founded the monastery of 'Mayo Abbey of the Saxons' at the place that is since known by that name (in Irish, *Maigh Eó na Sacsan*). The pollen analytical record from Church Lough clearly demonstrates the intensive nature of the farming associated with the early Christian/medieval settlements on Inishbofin. It is obviously of interest to establish the nature of early farming activity, and especially early medieval farming, and its impact in the quite different geographical, geological and edaphic setting of central Mayo.

The current palaeoecological project is undertaken in the context of multi-disciplinary investigations centred on Mayo Abbey. The focus is on Mayo Abbey mainly because of the monastic settlement founded by St. Colman in AD 668 and which subsequently attained considerable importance in the Early Christian church of the Hiberno-Saxon world. The Mayo Abbey Resource Development Company Ltd. (Morahan 1996) has led local community efforts to develop the monastic site at Mayo Abbey from a heritage perspective, while much of the research is being undertaken by the Mayo Abbey Research Group (MARG) based at the National University of Ireland, Galway. A variety of disciplines and data sources is being brought to bear on this task, including archaeology, geophysics, palaeoecology and historical data. While the last 1300 years are the main focus of the research, the palaeoecological investigations aim to provide a palaeoenvironmental record for the Holocene as a whole, but with emphasis on the later Holocene.

Study area

Mayo Abbey lies in undulating countryside where the bedrock consists of Lower Carboniferous limestone. At Mayo Abbey and its immediate environs, there are substantial tracts of fertile, undulating farming land that now support almost exclusively pastoral farming. Extensive tracts of bog lie some kilometres to the south

Figure 1.

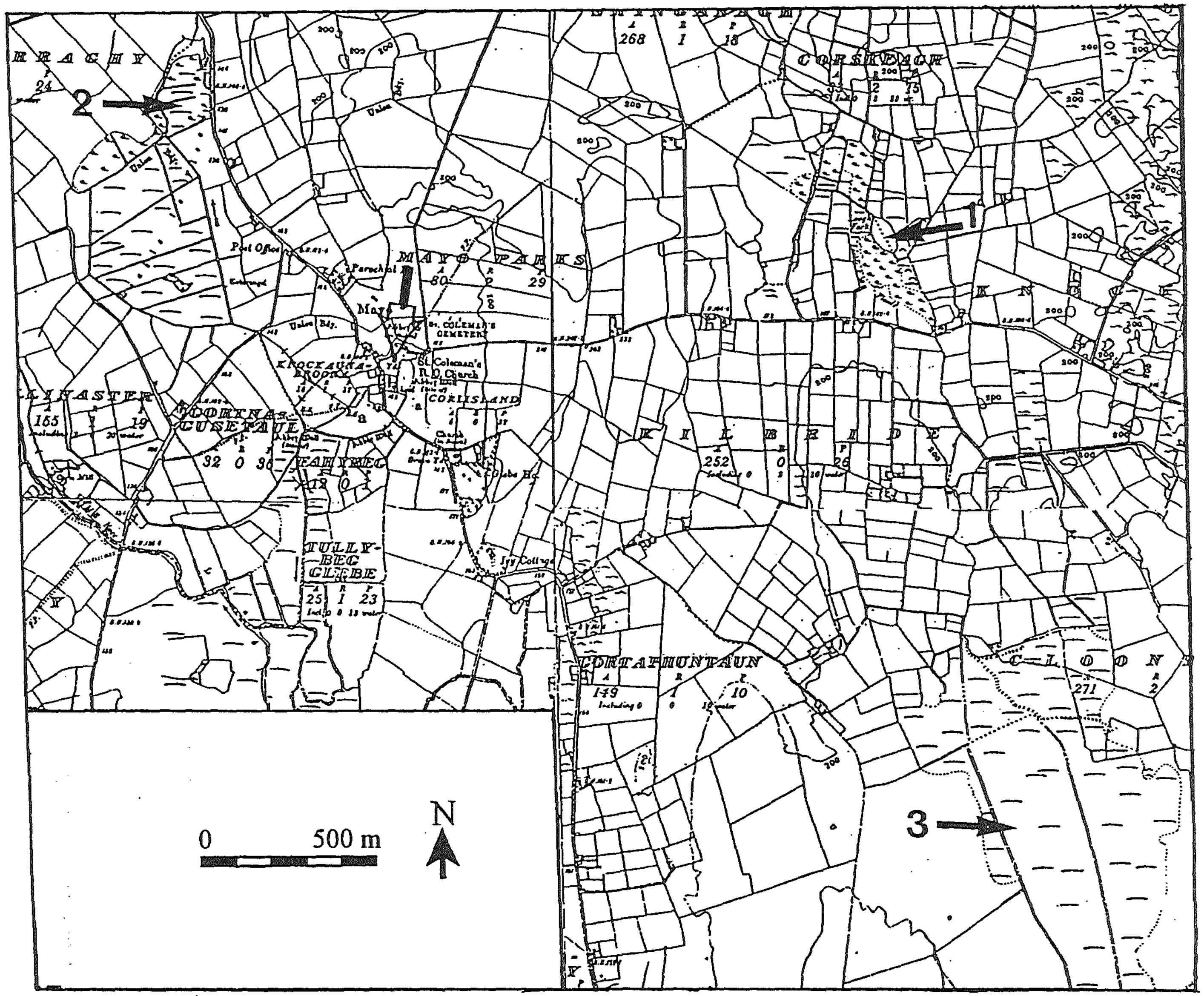
Site map of Mayo Abbey and its environs (based on OS 6" maps).

Coring sites indicated by solid arrows; arrow with non-filled head indicates location of medieval monastic site.

1: Lough Fark

2: Freeheen (MAB1)

3:Cloonbaul



and west while nearer the monastic settlement there are several less extensive wetlands, including bog, reedswamp and fen, and also some small lakes and palaeolakes.

There are numerous field monuments in the parish of Mayo Abbey (at least 122 recorded by archaeological survey, Morahan 1996). Ringforts are the most numerous but there are also megalithic tombs (3), *fulachta fiadh* (9) including a large *fulacht fiadh* in Lough Fark basin (see below), early ecclesiastical enclosures, and moated sites with a possible Norman influence, including a moated farm and an 'industrial' area possibly associated with the medieval abbey (E. Fitzpatrick pers. comm., Madden 1997). The monastic site at Mayo Abbey had two major periods of occupation, namely in the early Christian period and an Augustinian abbey in the later medieval period (Morahan 1996).

Site selection and coring

To date, trial corings have been carried out at three sites (Figure 1) with a view to assessing their relative potential for palaeoecological investigations and, where sediments appeared to be promising, cores have been collected for detailed investigations.

Cloonbaul Td.

Two trial coring were made using a gouge corer in a small (c. 200 m wide) but more or less intact peat bog that lies *c.* 2.3 km south-east of Mayo Abbey in Cloonbaul Td. (the bog straddles Cloonbaul and Knockroe Tds) (grid ref. M 283 782; 9° 05.3'W, 53° 45'N; 65 m asl; Fig. 2). Peat deposits up to 6.7 m thick were recorded near the centre of the basin. The peat appears to be predominantly formed from raised bog plants (*Eriophorum vaginatum* remains are common; *Vaccinium oxycoccos*, a diagnostic raised bog species, is common in the present-day bog vegetation). Near the base, *Betula* wood is frequent and the basal peat is charcoal-rich. Late-glacial sediments were not recorded. It is likely that a complete Holocene record is represented. However, since the peat contains considerable amounts of *E. vaginatum* remains which can create difficulties for dating by radiocarbon, it was decided not to carry out further investigations here.

Freeheen Td.

Several trial corings using a gouge corer were made in the small basin (<150 m wide) that lies *c.* 0.8 km to the north of Mayo Abbey and immediately to the west of the main Mayo Abbey/Balla road in Freeheen Td. (grid ref. M 259 803; 9° 7.4'W, 53° 46.05'N; 40 m asl). This basin may be flooded to a metre or more during winter floods but in the summer the water normally lies below the surface which can be quite firm under foot.

The trial corings showed that the sediments (maximum thickness recorded: 5 m) consist predominantly of highly decomposed peat – presumably largely fen peat – with intercalated marl layers and with silt/clay sediments at the base (cf. Table 1). In some of the trial cores, the typical tripartite stratigraphy (silt/clay, marl, silt/clay) of Late-glacial sediments was noted but, in general, the Late-glacial appears to be poorly represented.

In the deeper part of the basin, at *c.* 10 m to the south of a east/west-running deep drainage channel, a 10-cm-diameter core was taken (MAB I). This consisted mainly of peat and with intercalated marl layers. The basal sediments (409-445 cm), consisted of a grey-blue silt/clay sediment with occasional grey, marl-rich, spherical bodies (Table 1).

Lough Fark

Lough Fark (9°06' W, 53°46' N; grid ref. M 278 798; *c.* 45 m asl) is a small lake (longest axis *c.* 100 m), located 1.3 km to the east of Mayo Abbey. L. Fark and its basin straddles the townlands of Corskeagh and Kilbride (south part). Maximum water depth is 4 m. The lake had a much greater extent in the past (maximum length of lake and basin: *c.* 350 m) but the basin is now largely infilled especially to the south of the lake where sedge (including *Carex rostrata, C. lasiocarpa* and *C. diandra)* and rush-dominated communities prevail. Reedswamp, consisting mainly of *Scirpus lacustris* and some *Phragmites australis*, fringes the open water of the lake. The undulating landscape around the lake is mainly in pasture, with a stand of mature ash trees to the north, and an outcrop with gorse (*Ulex europaeus*) to the east. There is a substantial *fulacht fiadh* near the south-western margin of the lake which is surrounded now by wetland vegetation. The nearest megalithic tomb (court tomb type) lies c. 1.2 km to the north (Morahan 1996).

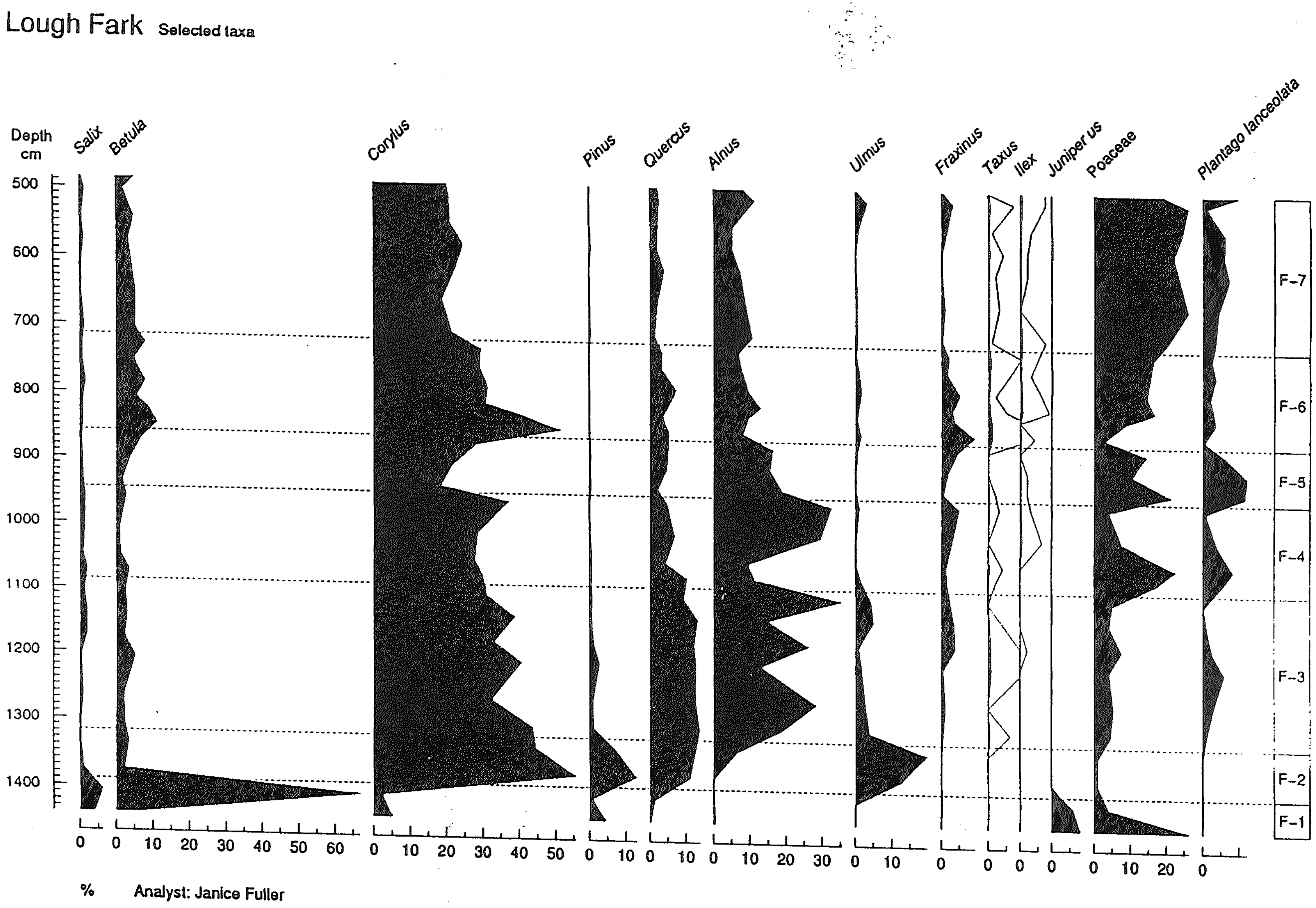
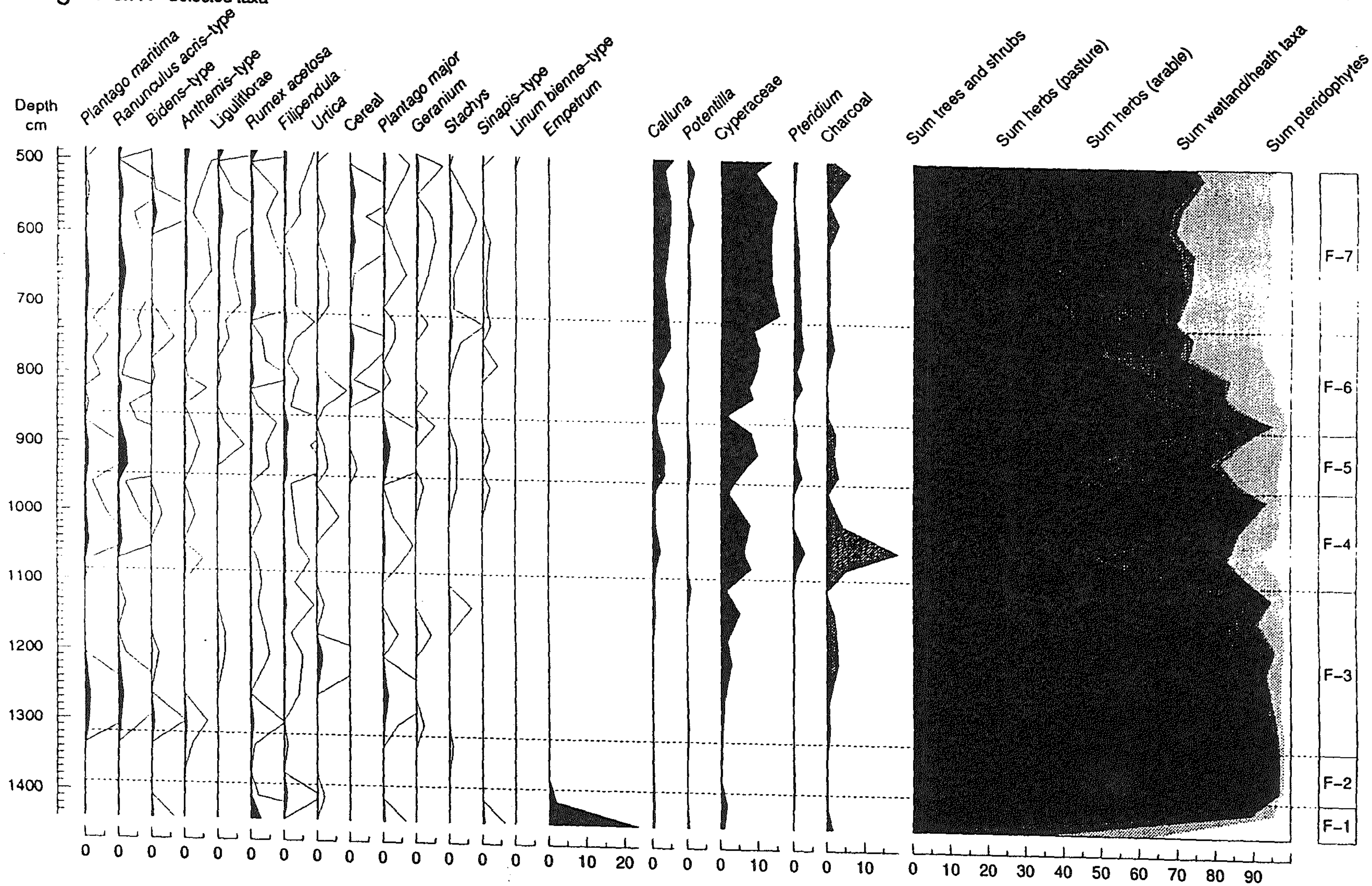


Figure 2 Percentages of pollen and spores for selected taxa from Lough Fark, Mayo Abbey. Depths are measured from the water surface.

Lough Fark Selected taxa



Analyst: Janice Fuller

Trial coring, using a gouge corer, revealed *c.* 7 m depth of sediment in the infilled basin near the southern and south-western margins of the lake. The sediment consists mainly of shell-rich marl overlain by a thin layer of gyttja and above this reedswamp/fen peat deposits (ca. 3.5 m thick at ≤10 m from the lake margin). At the base of some of the cores, a short, weakly developed tripartite stratigraphy typical of Late-glacial sediments was recorded.

Duplicate cores were collected using a Livingstone corer from within 10 m of the southern lake margin.

The thickest sediments (approx. 12 m) have been recorded near the centre of the present-day lake. From here, triplicate cores were extracted using a Livingstone piston corer. The uppermost, poorly consolidated sediments (~1 m) were collected with a mini-Mackereth corer.

Table 1. Stratigraphical details of core MAB I, Freeheen.

Depth (cm)	Stratigraphy
70-104	Peat
104-121	'Dirty', grey marl. Gradual and poorly defined upper and lower boundaries
121-189	Highly decomposed peat
189-230	'Dirty', grey marl of uneven consistency. Vertically running dark streaks (roots?). Distinctly greyer between 223-230 cm. Gradual and poorly defined upper and lower boundaries
230-251	Dark, peat/marl mixture. Diffuse and gradual lower boundary
251-284	Highly decomposed peat; 251-260: peat with a white tinge due to marl
284-292	Grey marl; sharp upper boundary; lower boundary well defined but gradual
292-294	Light brown peat with marl. Lower boundary v. gradual
294-361	Peat
361-406	Grey marl; a brownish layer between 401-401.5 and 405-406; latter layer more pronounced
406-409	Dark grey silt/clay with some marl
409-412	Uniformly dark fine silt/clay
412-445	Dark grey silt/clay with spherical bodies (largest c. 4 cm ⌀; this near base) or flecks consisting of pale grey marl

Laboratory work

Cores collected from Freeheen Td (MAB I) and Lough Fark (LF-B) were sub-sampled and the samples prepared for pollen analysis using standard methods, including addition of *Lycopodium* spores to enable estimation of pollen concentrations. Sievings from the pollen preparations were kept for macrofossil analysis. Pollen and spores were identified using a light microscope at x500 magnification and phase contrast (x1250) where necessary. A pollen sum of ≥700 terrestrial pollen grains and spores was aimed for. Poaceae pollen grains with a maximum length ≥41μm, pore ≥3μm, and pore plus annulus ≥8μm are classified at cereal-type. Microscopic charcoal fragments were also counted.

The pollen data from L. Fark were zoned numerically using psimpoll version 3.0 (Bennett 1994) to aid description of the pollen and charcoal record. Only terrestrial pollen taxa that were present at ≥3% at some point in the sequence were used for zonation. Seven pollen assemblage zones were obtained objectively using the optimal splitting method (Bennett 1996). Future analyses will include radiocarbon dating, scanning for tephra, examination of the physical properties of the sediments, and further macrofossil analyses.

Results of preliminary palaeoecological analyses

Freeheen Td.

An outline pollen diagram (MAB I) was constructed with a view to establishing the potential of the core for detailed palynological investigations. Low pollen concentrations made pollen counting difficult and slow and hence it was decided not to proceed with detailed investigations. The pollen data (not presented) show that the basal marl was laid down in the early Holocene at a time when *Betula* and *Salix* were the main woody taxa. As peat began to form (361 cm), hazel spread and pine assumed importance, at least locally. A feature that may be the Elm Decline (5100 BP; all BP dates in ^{14}C years unless otherwise stated) is recorded at *c.* 3 m which suggests very low peat accumulation rates in the earlier Holocene. Unfortunately, there are few diagnostic features in the upper part of the outline diagram that might enable a chronology to be fitted. The marl layers at 284-292 cm and 189-230(-251) cm lie immediately after the Elm Decline and at the point where the *Pinus* curve more or less ceases, respectively. If, as seems probable, initiation of marl deposition signifies a rise in water table, then the water table appears to have been raised shortly after the Elm Decline and again at *c.* 3000 BP. The uppermost marl layer (104-121) probably falls in the earlier part of the first millennium AD.

Marl from 395-399 cm was dated by the mass-spectrometric U-Th method. It yielded an age of 11 450±500 calendar years BP (M. Roberts and F. McDermott, pers. comm.). The marl had a relatively low ($^{230}Th/^{232}Th$) (parentheses denote activity rather than atomic ratios) ratio of 16.6, reflecting contamination by non-carbonate detritus. In the absence of Th-isotope data for this detritus (work in progress), a correction based on the 'global'($^{230}Th/^{232}Th$) value of 1.7±0.7 was applied (Kaufman, 1993) and this gives rise to the relatively large age uncertainty of 500 years. The pollen spectra at 377, 352 and 345 cm are dominated by *Betula*, Poaceae and, to a lesser extent, by *Salix* and *Juniperus* (in basal spectrum). *Corylus* is represented mainly by single grains (it first achieves substantial representation in the sample immediately above 345 cm, i.e. 337 cm). On a palynological basis (also on the basis of stratigraphy; silt/clay gives way to marl at 406 cm; cf. Table 1), it is clear that the U-Th-dated sample can be assigned with confidence to the earliest centuries of the Holocene. The best available age estimate for the beginning of the Holocene, based on Greenland ice core records and also stable isotope patterns in dendrochronologically dated pine timbers from central Europe, is 11 450 to 11 390±80 calendar years BP (Björck et al. 1996). The date cited above therefore agrees excellently with this estimate.

Lough Fark

The sediments from the lake are predominately brown gyttja with some shelly material (mostly molluscs), and clay-rich material at the base of the sequence. Initial results of pollen analysis (core FK-B; Figure2, Table 2) suggest that there is a full Holocene sequence (the uppermost (400-486 cm) and lowermost (1440-1575 cm) sediments have yet to be sampled). Seven pollen assemblage zones have been identified and are described briefly in Table 2. An interpretation of the Holocene pollen data from Lough Fark follows.

It is important to note that the pollen data are limited and that many more analyses are needed to obtain the necessary resolution to adequately describe vegetation history and human impact at this site. In addition, no independent dates have been obtained for the sequence, so that there is considerable uncertainty about the chronology, especially for the more recent sediments. Macrofossils and bulk sediment samples will be submitted for AMS and conventional radiocarbon dating, respectively. An approximate chronology of events, based on radiocarbon-dated pollen data from other sites in western Ireland, is tentatively proposed (Table 2). This chronology obviously needs to be substantiated using independent dating methods.

Table 2. Brief description of pollen assemblages zones with a tentative chronology based mainly on correlations with ^{14}C-dated pollen diagrams from the wider region, and, in the upper part, on correlations with known historical events. The latter are especially tentative.

Note: depths are with respect to the water surface.

Depth (cm)	Zone	Zone descriptions	Depth (cm): Age	Basis for the chronology
714-486	7	Poaceae representation continued to increase (to >20%) as tree pollen taxa reached their lowest levels. Several other herbaceous pollen taxa increased in abundance including *Ranunculus*, *Bidens*-type, *Geranium*, *Anthemis*-type, Liguliflorae, *Rumex acetosa* and *Potentilla*.	710: 350 BP	Plantation of Connacht
858-714	6	Tree representation increased at the beginning of this zone but declined towards the end of the zone as herbaceous pollen types increased again. Cereal-type pollen were recorded in several levels.		
946-858	5	Representation of tree taxa declined sharply again at the beginning of this zone as herbaceous taxa increased markedly including *Plantago lanceolata* (to almost 10%). Cereal-type pollen recorded for the first time. Tree pollen increased in frequency towards the end of the zone as herbaceous pollen declined.		
1086-946	4	Several tree pollen taxa decreased in abundance at beginning of this zone while herbaceous taxa, including Poaceae (15%) and *P. lanceolata* (>5%) increased markedly. Charcoal and *Pteridium* fern spores reached their highest values. Representation of several tree taxa, *Corylus*, *Alnus* and *Fraxinus* increased again towards the end of the zone as NAP representation declined. *Pinus*, *Ulmus* and *Quercus* pollen remained at lower frequencies.	960: 1800 BP 1085: 3000 BP	End of Late Iron Age lull Late Bronze Age upsurge
1318-1086	3	*Alnus* representation continued to increase (to >25%) as *Pinus* pollen decreased in frequency. *Ulmus* pollen percentages declined sharply as *P. lanceolata* increased, for the first time, Poaceae and other herbaceous pollen types increased in abundance. *Fraxinus* and *Taxus* representation also started to increase.	1320: 5100 BP	cf. Elm Decline
1390-1318	2	*Betula* representation declined (to <5%) as *Corylus* pollen increased in frequency (>50%) along with other tree taxa, *Pinus*, *Quercus* and *Ulmus*. *Corylus* and *Pinus* representation later declined as *Alnus* representation increased.	1360: 6700 BP 1390: 8600 BP	*Alnus* rise Invasion of tall canopy trees
1434-1390	1	High herbaceous representation dominated by Poaceae at 25% with some *Filipendula* and *Rumex*. Also high values for shrub and tree taxa, such as, *Empetrum* (>20%), *Salix* (5%) and *Juniperus* (5%). Representation of *Empetrum* and herbaceous taxa declined as *Betula* increased sharply >60%.	1435: 9800 BP	Late glacial/early Holocene

A typical early Holocene vegetation succession is recorded in zone F-1 (the lowermost sediments have yet to be analysed). The base of the sequence probably dates to *c.* 9800 BP (dates quoted in non-calibrated radiocarbon years). Initially the landscape appears to have been grass-dominated with woody taxa, such as *Empetrum*, *Salix* and *Juniperus*, abundant. *Pinus* pollen is recorded (4%) but this may be a long-distance component. *Betula* invaded converting the landscape to one dominated by trees as herbaceous taxa and *Empetrum* declined. *Juniperus* and *Salix* remained important elements of the vegetation.

Vegetation cover changed markedly again as *Corylus* populations expanded dramatically in zone F-2 along with other tree taxa such as *Pinus*, *Quercus*, and *Ulmus* to form mixed, tall-canopy woodland (possibly dating to *c.* 8600 BP). *Ulmus* reached relatively high values (>15% of the terrestrial pollen rain) when compared with other sites in western Ireland (e.g. O'Connell et al. 1987, Molloy and O'Connell 1995). The relatively fertile soils in central Mayo may have been an important factor. There was a corresponding contraction of *Betula*, *Juniperus* and *Salix* populations. *Pinus* and *Corylus* declined in abundance as *Alnus* later expanded although *Corylus* still dominated the pollen rain. Data from other sites in western Ireland indicate that *Alnus* expanded between 7000-6000 ^{14}C yr BP (e.g. O'Connell et al. 1987, O'Connell et al. 1988). Woodland composition at this time appears to have been dominated by *Alnus*, *Corylus* and *Quercus*.

Pinus declined further in zone F-3 and remained at low levels (<4% of the pollen rain). *Pinus* also declined relatively early at Lough Doo, although not to such low levels, and was a relatively insignificant component of the forest flora at this site and at Carrownaglogh, both in north-eastern Mayo (O'Connell 1986, O'Connell et al. 1987). This contrasts with the records from Connemara where, at least in some parts, *Pinus* remained relatively abundant until *c.* 3500 BP, possibly due to a competitive advantage on the poorer soils (O'Connell et al. 1988).

Ulmus declined sharply in zone F-3 followed by the first increase in abundance of the tree taxa, *Fraxinus* and *Taxus*. This decline probably reflects the classic Elm Decline, a feature well-recorded in many other studies dated to around 5100 BP. If the assumption that the Elm Decline is recorded at the base of zone F-3 is correct then the increase of herbaceous taxa, such as *Plantago lanceolata*, *P. maritima*, *P. major*, grass pollen and *Ranunculus* acris-type, can be regarded as indicative of Neolithic farming. Though the number of samples analysed to date is limited, the available evidence suggests that this was mainly a pastoral-based economy and so similar to that at Céide Fields (Molloy and O'Connell 1995).

Several tree taxa declined in abundance at the beginning of the subsequent zone, F-4, including the dominant taxa, *Corylus*, *Quercus*, *Alnus* and *Fraxinus*, indicating further woodland clearance. This decline corresponds with another increase of herbaceous taxa, including *P. lanceolata* and grass pollen, reflecting another phase of pastoral farming. There was a sharp increase in charcoal values possibly reflecting fire in the catchment that may have been associated with land clearance or land use. *Pteridium* spores were also more common and the presence of this fern species may have been associated with the post-fire succession. This period of intensive agriculture may correspond with the late Bronze Age upsurge in agricultural activity dating to around 3000 yr BP (Molloy and O'Connell 1991, 1993, O'Connell *et al.* 1988, O'Connell 1990).

Woodland taxa, *Corylus*, *Alnus* and *Fraxinus*, increased in abundance again towards the end of zone F-4 following an apparent decline in agricultural activity marked by the decline of herbaceous taxa. This period of woodland recovery may correspond to the Late Iron Age lull (ca. 1800 yr BP) a distinctive feature in most Irish pollen diagrams, first highlighted by Mitchell (1965) and especially notable in the west (e.g. Molloy and O'Connell 1991, 1993, 1995, Jeličić and O'Connell 1992). The significant decline in pastoral activity reflected by the decline of several herbaceous taxa including *Plantago* spp. and Poaceae, probably facilitated the woodland expansion. However, it is highly uncertain whether this event is, in fact, the Late Iron Age lull.

In zone F-5, a third phase of agricultural activity resulted in a sharp decline of woodland taxa and a marked increase in *P. lanceolata*, Poaceae, *Ranunculus acris* and *Filipendula*. Cereal-type pollen were recorded for the first time (mainly *Triticum*), along with *Sinapis*-type and *Stachys* indicating the development of arable, as well as, pastoral farming. Could this reflect the start of the early Christian period and agricultural intensification? The end of zone F-5 is characterized by another phase of woodland recovery driven mainly by *Betula, Corylus* and *Fraxinus*.

Another period of woodland regeneration appears to have occurred at the beginning of zone F-6 as *Betula, Corylus, Ulmus, Taxus* and *Fraxinus* increased in abundance. Herbaceous taxa declined in abundance again. The timing of this phase of woodland recovery is uncertain and it is impossible, without independent dating, to be sure it isn't a reflection of the Late Iron Age lull. Cereal-type pollen grain were also recorded suggesting that farming activity included an arable component.

Marked woodland decline occurred in zone F-7 and most tree taxa reached their lowest levels for the sequence. Grass pollen continued to increase, dominating the pollen rain. The diversity and abundance of other herbaceous taxa increased. This apparent increase in farming activity may be connected with historical developments such as the plantation of Connacht that took place in (350 BP/ AD 1650) resulting in increased pressure on the land. The uppermost sediments have yet to be analysed to complete the record to recent times.

Future work

This project is still in the early stages. Future work includes obtaining a detailed pollen record from L. Fark with a view to elucidating local vegetation history at a fine temporal resolution and correlating this with the prehistoric and historic record of human activity. The length of the core (approx. 12 m) will allow for high temporal resolution in the final record. It is also essential to obtain independent dating of the sequence for chronological control. This is obviously important from point of view of matching the archaeological and especially the historical records from the area and also reconstructing rates of change and deciphering the main factors that underlie the changes that are recorded.

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Using geophysics to detect archaeological sub-surface features at the Monastic Enclosure at Mayo Abbey – preliminary results

John Madden and Kevin Barton

Some of the most sophisticated survey and geophysical equipment, much of which was specifically designed for archaeological purposes, was employed during the course of an extensive survey carried out over a 2.5 acre part of the Monastic Enclosure at Mayo Abbey, Co. Mayo. The techniques employed were used to measure the geophysical properties of archaeological features now buried beneath the ground surface. The first geophysical work undertaken on the site was by O'Rourke (1997) who carried out magnetic susceptibility, gradiometry and resistance surveys as part of a feasibility, or test survey, of a small area of the enclosure.

The fieldwork was dependent on an accurately plotted survey grid extending across the area to be surveyed. This is particularly true in relation to archaeo-geophysics which involves defining small sub-surface features in fine detail. This survey grid was laid out using a Sokkia Set 5E Total Station, which is an electronic survey instrument which combines the functions of a theodolite and Electronic Distance Measurement (EDM).

A resistance survey was used to measure the electrical resistance of the soil. If the soil contains water or has a high clay content the values are low whilst if the sub-surface contains sand, gravel or stones the values will be high. Generally speaking, a ditch will have a low resistance whilst a wall will have a high resistance. The survey used a Campus Instruments square array with 0.5 m side and resistance meter to acquire data on a 0.5 m X 0.5 m grid. The depth of the investigation of this array is c. 0.25 m.

A magnetic gradiometry survey tells us something about the magnetic properties of the soil and what it contains. Archaeological features may possess magnetic characteristics either by being composed of naturally magnetic materials or by acquiring an artificial magnetic signature having been heated intensely and then cooled (eg. kiln, hearth). This is known as remnant magnetisation which can produce localised anomalies in the Earth's magnetic field by either adding or subtracting to it. The survey used a GeoScan fluxgate gradiometer with 0.5 m separation between the sensors. Surveys were carried out on a 0.25 m X o.25 m where detail was required. The technique samples down to a depth of 1.5 m depending on the physical properties of the buried features.

Once the field work was completed, the data were processed using various software packages to produce an image of the sub-surface which is then interpreted to indicate features which may be related to past human activity. The anomalies at Mayo Abbey have been identified as archaeologically important from comparative studies of other monastic sites.

This recognition of archaeological anomalies through the use of non-invasive, non-destructive methods of survey minimises the serendipitous element of excavation and therefore allows the archaeologist to plan the work so the minimum of damage is caused to the site. There are however, some circumstances which obscure certain sub-surface features from being detected by the equipment. It now generally accepted that geophysical surveys have an important role to play in archaeology. The work at the Mayo Abbey Monastic Enclosure demonstrates this well.

The preliminary results presented in Figures 1 and 2 clearly indicate that there has been intensive human activity within this portion of the enclosure. The resistance image (Figure 1) shows linear features which could relate to trackways, walls or causeways. Arcuate features may delimit small enclosures or walled subdivisions of the main enclosure whilst circular features may relate to hut sites

The gradiometer image (Figure 2) shows much fine detail re-enforcing some of the features seen in the resistance data. There is an overprint of the response from cultivation ridges, which have no surface expression, in parts of the surveyed area. Again the data show feature-shapes, such as linears and circles, which can be explained when comparative analysis is done of excavated monastic enclosures which span a similar time period. The latter work is in progress and once complete will further add to the reconstruction of the life and lifestyle of the settlement of Mayo of the Saxons.

Acknowledgement

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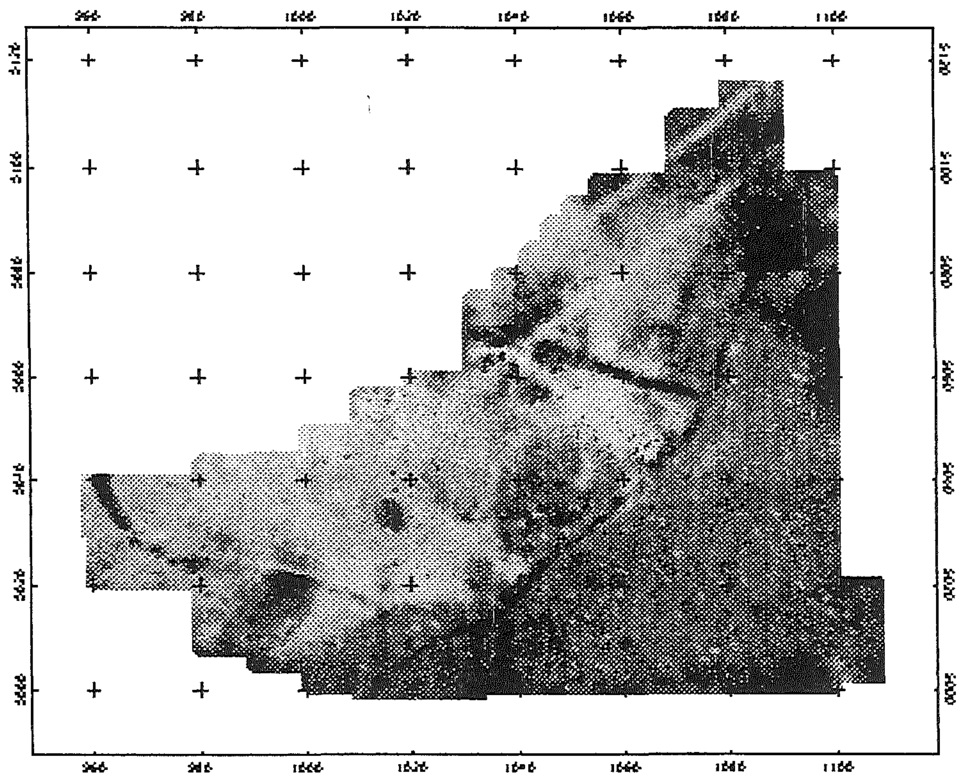
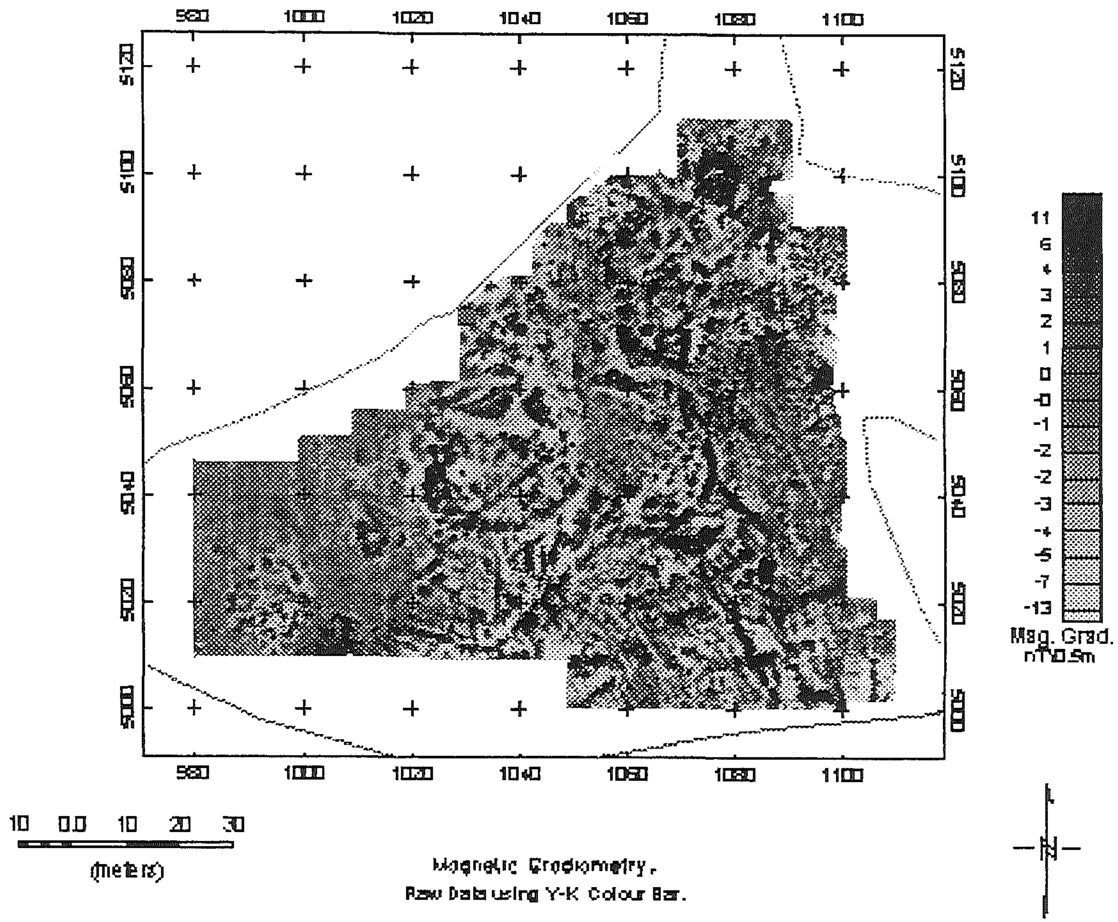
Ledgends for figures presented overleaf

Figure 1. Results of resistance survey undertaken at the Monastic Enclosure, Mayo Abbey.

Figure 2. Results of gradiometry survey undertaken at the Monastic Enclosure, Mayo Abbey.



Monastic Enclosure.
Square Array electrical resistivity.
John Madden.



Magnetic Gradiometry.
Raw Data using Y-K Colour Bar.

— Outer wall of monastic enclosure.

Fulachta fiadh - a brief review

Kevin Barton and Christy Lawless

Introduction

The classic description of a *fulacht fiadh* describes it as a small, grass covered mound; a burnt mound, which is characterised by a bank, horseshoe-shaped in plan, lying close to a watersource. The mound is a result of accumulated debris from the repeated burning of stones to heat water. The debris comprising burnt and firecracked stone, often intermingled with ash and charcoal, can often be seen in eroded or disturbed mounds. The hot stones, heated in a nearby hearth, were put into a water-filled trough, often timber-lined, and allowed the water to boil.

Function of *fulachta fiadh*

Conventionally *fulachta fiadh* have been described as cooking places (O'Kelly 1954) whereby food, wrapped in straw, was cooked in the boiling water. Some workers have speculated that their primary function was as bathing places (Barfield and Hodder 1987). The debate on the function of *fulachta fiadh* continues with Ó Drisceoil (1988) and papers in Buckley (1990) generally referring to them as cooking places.

Dating evidence

There is mention of usage of *fulachta fiadh* in early Irish literature but evidence from those that have been both excavated and radiocarbon dated indicates a date range in the second millennium BC (Brindley *et al.* 1989/90 and Brindley 1995) and therefore they are largely categorised as Bronze Age monuments.

Geographic distribution

Since Buckley (1990) there has been no substantive work published on the distribution of fulachta fiadh in Ireland and at that time it was speculated that they were likely to become the most common prehistoric monument in Ireland if a systematic survey were carried out. If we take the work of the Cork Archaeological Survey (Ó Drisceoil 1988 and Doody 1993) as an example of a systematic survey, we find that there are almost 2500 *fulachta fiadh* reported from this county alone. Condit (1990) reports 250 found in Kilkenny as part of a preliminary review of the distribution of *fulachta fiadh* in the county. At a local parish level, in Mayo, Lawless *et al.* (1995) records 151 *fulachta fiadh*. Further systematic survey work is likely to confirm that *fulachta fiadh* are indeed Ireland's most common monument type.

Settlement context

In the field *fulachta fiadh* can be found as single monuments or in clusters and invariably do not lie close to any visible settlement evidence. Excavation evidence, when available, has tended to be limited to the immediate area of the mound of the *fulacht fiadh* and hence may not have revealed any associated settlement if it existed. The isolated nature of some *fulachta fiadh*, lack of artifacts and associated settlement has given rise to the theory that they were part of a temporary, possibly seasonal, hunting camp. Where there is a high density of *fulachta fiadh* (e.g. Cork) then the argument for them representing permanent settlement as part of a larger regional settlement distribution seems plausible. Doody (1993) points out that the date range in the Bronze Age in which they occur is rather restricted and that this might indicate a high population density and therefore it could be argued that their very numbers indicate transitory settlement perhaps associated with transhumance or 'booleying'.

Concluding remarks

Few artifacts likely to be in context have been found associated with *fulachta fiadh* despite the fact that they have been recognised in increasing numbers in Ireland and have been recorded in other European countries (Buckley 1990). The lack of finds has made it difficult to place *fulachta fiadh* in a social and landscape context. *Fulachta fiadh* are being recorded in the field in larger numbers as workers become more adept at recognising them.

In recent times *fulachta fiadh* in Ireland have generally been only excavated in a rescue situation in advance of say an industrial or retail development. The latter results in the focus being on the mound and generally not the area surrounding it which itself may contain material and artifacts which could provide further insights into these enigmatic monuments.

Aside from major industrial and retail developments, the intensification of farming and forestry activities in drainage and planting has both revealed new sites to the experienced eye and also, in doing so, is likely to have destroyed significant numbers in areas of marginal land.

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An experimental *fulacht fiadh* at Lack East, Turlough, Co Mayo

Locality 1.7

Christy Lawless

The discovery of a dense concentration of *fulachta fiadh* inside a 3 km radius of Levallinree Lough prompted a trial of this ancient cooking method. The first experimental cooking was successfully carried out on the 24th September 1988, ' National Archaeology Day'. On this first occasion it was conducted on a wet peatland site using the natural bog seepage as a water source (Lawless 1990).

In 1989 a more permanent and authentic modern working *fulacht fiadh* was constructed in the townland of Lack East, Turlough which is in the heartland of the ancient *fulachta fiadh* sites. With the permission and help of landowner Mr. James O'Hora, it was constructed in a most authentic setting on the edge of a small marshy valley where within 100 m there are five ancient *fulachta fiadh* (Lawless *et al.* 1995).

A small natural stream that flows into the southeast corner of the marsh was chosen for the construction of this modern working fulacht fiadh. A wooden trough with a capacity of 514 litres (113 gallons) of water was placed in the ground 3 m from the stream. The top of the 90 cm deep wooden trough was placed flush with the ground. As the bottom of the trough was only 55 cm below the water level of the stream, it was necessary to construct a small dam 35 cm high across the stream using a flagstone.

This increased the water table to the required 90 cm water level in the trough. The small dam illustrates the fact that shallow meandering surface streams could quickly and simply be dammed with earth. This would raise the water table and facilitate the sidetracking of water to higher ground. The water seeps through an underground channel of 12 mm stone chippings from the dam to the trough. Once the water has filled the trough to the level of the top of the dam, there is no circulation of water in or out of the trough except when displaced by the immersion of red-hot stones in the trough. This element of stagnant water in the trough was a major factor in boiling and maintaining the water at boiling point while cooking.

A large hearth of flagstones was laid down on one side of the trough. For the cooking method a large fire of timber and turf mixed with 60 stones, 20-30 cm in diameter, is lit on this hearth. After 90 minutes the fire is well established and there are plenty of red hot stones. It takes 22 red-hot stones to boil the 514 litres of water in the trough. The red hot stones have been rolled into the trough in quick succession and it has taken from 25 to 17 minutes on different occasions to bring the 514 litres (113 gallons) of water to boiling point. Three 2.75kg (6 lbs) joints of lamb wrapped in straw have been cooked on each of the eight occasions. The wrapped joints are placed in the trough of boiling water with a stone attached to keep them submerged. The water is then brought back to boiling point and thereafter kept boiling by adding one red hot stone every 10 -15 minutes until the meat is cooked. The cooking time for lamb in a *fulacht fiadh* has been calculated at 30 minutes to the lb plus 30 minutes over for well-cooked lamb.

After eight cookings at the site the mound of burnt stones mixed with ash and charcoal has emerged. This small mound is now the ideal hearth for the next fire. After each cooking a barrowful of shattered stones is cleaned out of the trough and thrown onto the mound. Each fire of timber and turf mixed with stones to be heated for the next cooking will be lit on the shattered stone mound. This creates the mixture of charcoal in the mound which is characteristic of the material found in the ancient *fulachta fiadh* mounds.

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A geophysical survey of an ancient and a modern *fulacht fiadh* at Lack East, Turlough, Co. Mayo

Kevin Barton and Christy Lawless and Dominic Monaghan

Introduction

As part of ongoing work in characterising geophysical signatures of Irish archaeological monuments the opportunity was taken to compare the field magnetic susceptibility responses of *fulachta fiadh* at Lack East (Lawless *et al.*, 1995). A longer term objective is to monitor the geophysical response of the modern *fulacht fiadh* through time as it gets burnt and develops the characteristic mound of burnt stone, charcoal and ash. The geophysical method obviates the need to excavate and hence disturb the integrity of *fulacht* mounds.

Some work has been done in Ireland on the field magnetic susceptibility response of ancient *fulachta fiadh* (Barton and Kulessa 1994, Monaghan 1995 and Slater *et al.* 1996). The latter work, when using magnetic susceptibility method, found it to be the best in providing a rapid indication of burnt debris which seems to correlate well with higher susceptibility values.

The magnetic susceptibility survey

The survey was carried out using a Bartington MS2 instrument with a 20 cm diameter fieldloop (Clark 1990). The method indicates how easily rock or soil can be magnetised; the higher the susceptibility, the more easily a material can be magnetised. Rocks and soils containing a higher percentage of iron minerals will generally have a higher susceptibility. Another key factor which influences the degree of susceptibility a material may have is burning. If burning occurs, then generally there will be a higher susceptibility due to chemical alteration of certain iron minerals which can be present in rocks and soils. Sedimentary rocks, such as limestones and sandstones, can have small percentages of iron minerals whilst igneous and metamorphic rocks such as granites, schists and gneisses often have an appreciable iron content. Rocks such as dolerites, which often form dykes and sills in igneous and metamorphic terrains, have a high content of iron minerals.

The depth of investigation of the technique is a function of the fieldloop diameter with this depth being approximately half the loop diameter i.e. not greater than 10 cm. There is some debate amongst archaeological geophysicists about the depth of investigation of the technique with some arguing that it 'sees' even deeper than say 10 cm if one accepts that worm activity (Yates 1988) from depth may bring debris, such as ash, charcoal etc., up to within 10 cm of the surface. The surveys were carried out on a 0.5m x 0.5m grid laid over the *fulachta fiadh* with the grid origins being recorded so they can be re-laid at future dates.

Results from the ancient *fulacht fiadh*

The results are shown in Figure 1 with a photograph of the monument shown below. It should be noted that the geophysical map and photograph do not have the same orientation. The monument exhibits the characteristic horseshoe-shape with raised portions, of possibly more substantial burnt debris, lying either side of a low lying area presumed to contain the trough. The latter feature can be seen to the right and above the waterlogged area in the photograph.

The contoured geophysical map shows areas of highest susceptibility in white, grading to the lowest, or background, areas in the darkest grey tone. The highest value recorded was 40 SI units, the anomalous areas lie in the range 5 to 15 SI units against a background of about 0 to 3 SI units. The previously mentioned raised portions of the *fulacht fiadh* correspond well with the twin anomalous areas lying at approximately 7E,7N and 11E, 11N. The area of the trough can be roughly defined by an arbitrary 2.5 contour. The area of the monument is not fully isolated by this 2.5 contour but grades into additional anomalous areas to the NW and NE of the map. These areas could relate to spoil material dredged up from the nearby drain which runs along the northern perimeter of the survey area. Another possibility could be that these anomalous areas are related to nearby buried *fulachta fiadh* which have been partially destroyed, here probing or excavation would be needed to resolve the source of the anomalies.

Results from the modern *fulacht fiadh*

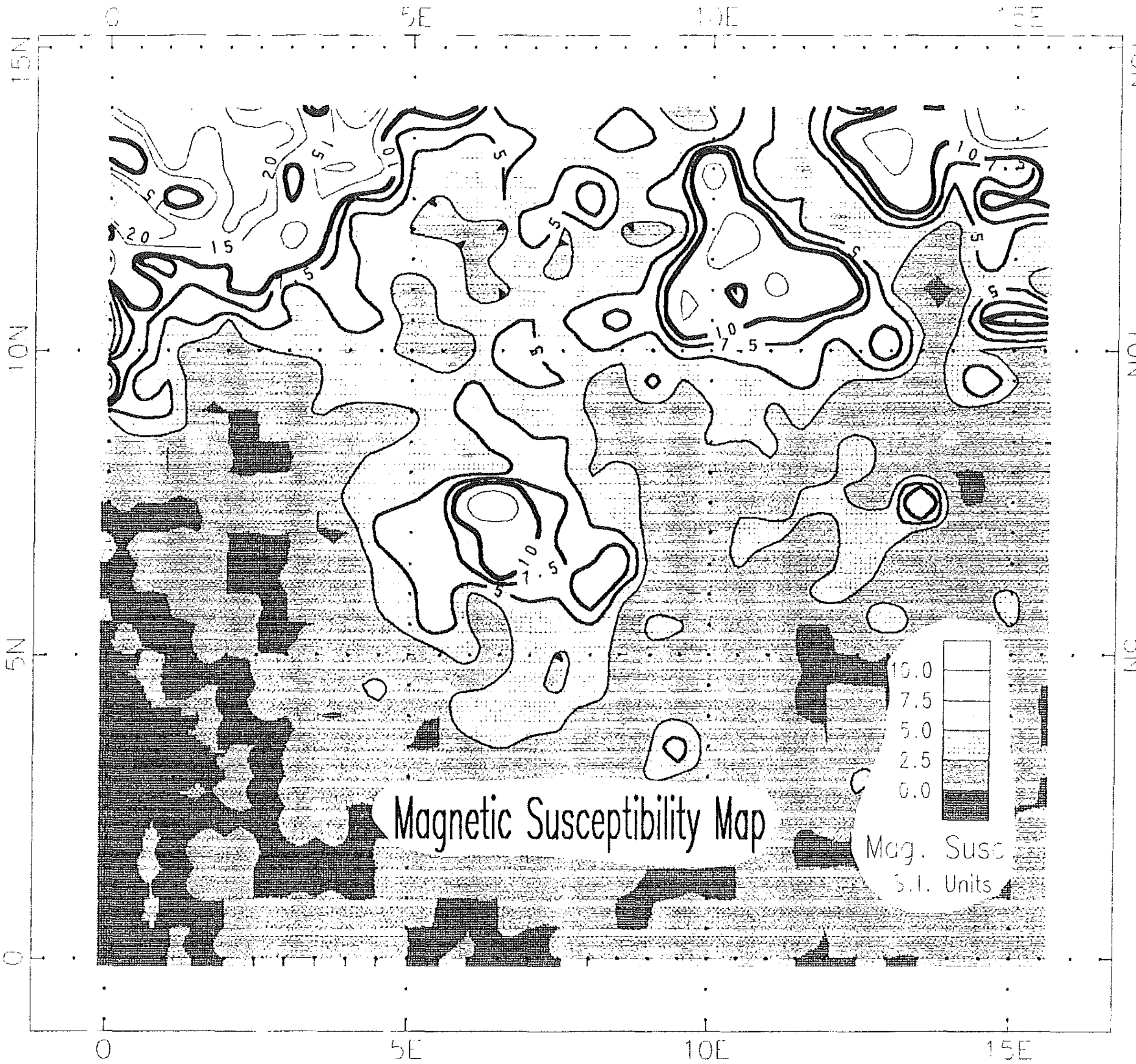
The results are shown in Figure 2 with the general site layout depicted in the accompanying photograph. Again the geophysical map and the photograph do not have the same orientation. A common reference point in the diagrams is the canalised stream which runs to the bottom right of the photograph and which is represented by a broken linear susceptibility low running from 11E, 1.5N to 8E, 13.5N in the map.

The size of the susceptibility values recorded in this survey were very different from those from the ancient *fulacht fiadh* in that they were up to an order of magnitude higher and also displayed a great degree of variability. White spots on the diagram reflect isolated anomalies of hundreds of SI units which possibly relate to the iron content of individual rocks or small boulders of the schists, gneisses or dolerites which compose the bedrock of the area (see Long in this Field Guide). There is an appreciable high zone (> 40 SI units) to the west of the line running from approximately 4E, 0N to 7E, 13.5N, this is thought to relate to ground cleared during the construction of the fulacht fiadh. The higher 'background' here must relate to iron-rich, disturbed soils and debris derived from the bedrock of the area.

The next most noticeable feature in the data is the medium high zone of anomalies in the range 10 to 40 SI units which largely comprise the eastern portion of the map. These data may reflect the more natural background for the area which may have been less disturbed than the higher area to the west of the 40 SI unit contour. Further work outside the geographic area of the present survey would be needed to confirm this. Within this medium zone lie the previously mentioned isolated highs and the mound of burnt stone and debris of the modern *fulacht fiadh*. The *fulacht* mound is represented by a distinctive, closed 40 SI unit contour surrounded by a 'halo' of relative lows which generally are defined by closed 10 SI unit contours. There are two other susceptibility features to note in the vicinity of the *fulacht* mound. The first is the gap in the surrounding 'halo' which corresponds with the area of the trough and the second is the break in the linear low defining the line of the canalised stream. It is likely that these two medium susceptibility areas just reflect the susceptibility of the flagstones which surround the trough and which also have been used to form a bridge across the stream.

Conclusions

The magnetic susceptibility method has a role to play in the non-destructive evaluation of potential *fulacht fiadh* sites. Further work is necessary to investigate the depth of investigation of the method in a variety of soil types with different underlying bedrock. This could be achieved by repeated surveys during the excavation of *fulachta fiadh* combined with laboratory magnetic susceptibility measurements on the spoil from the excavation. Work will continue measuring susceptibility signature of the modern *fulacht fiadh* after subsequent burnings.



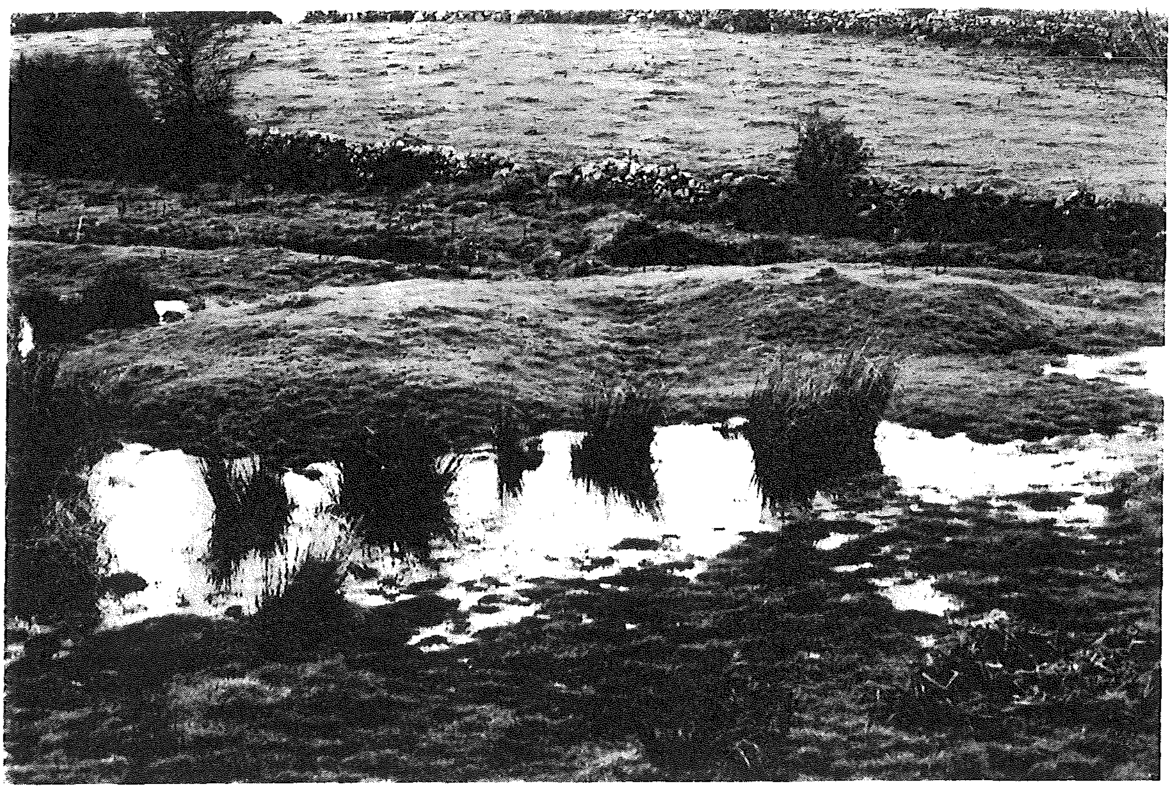
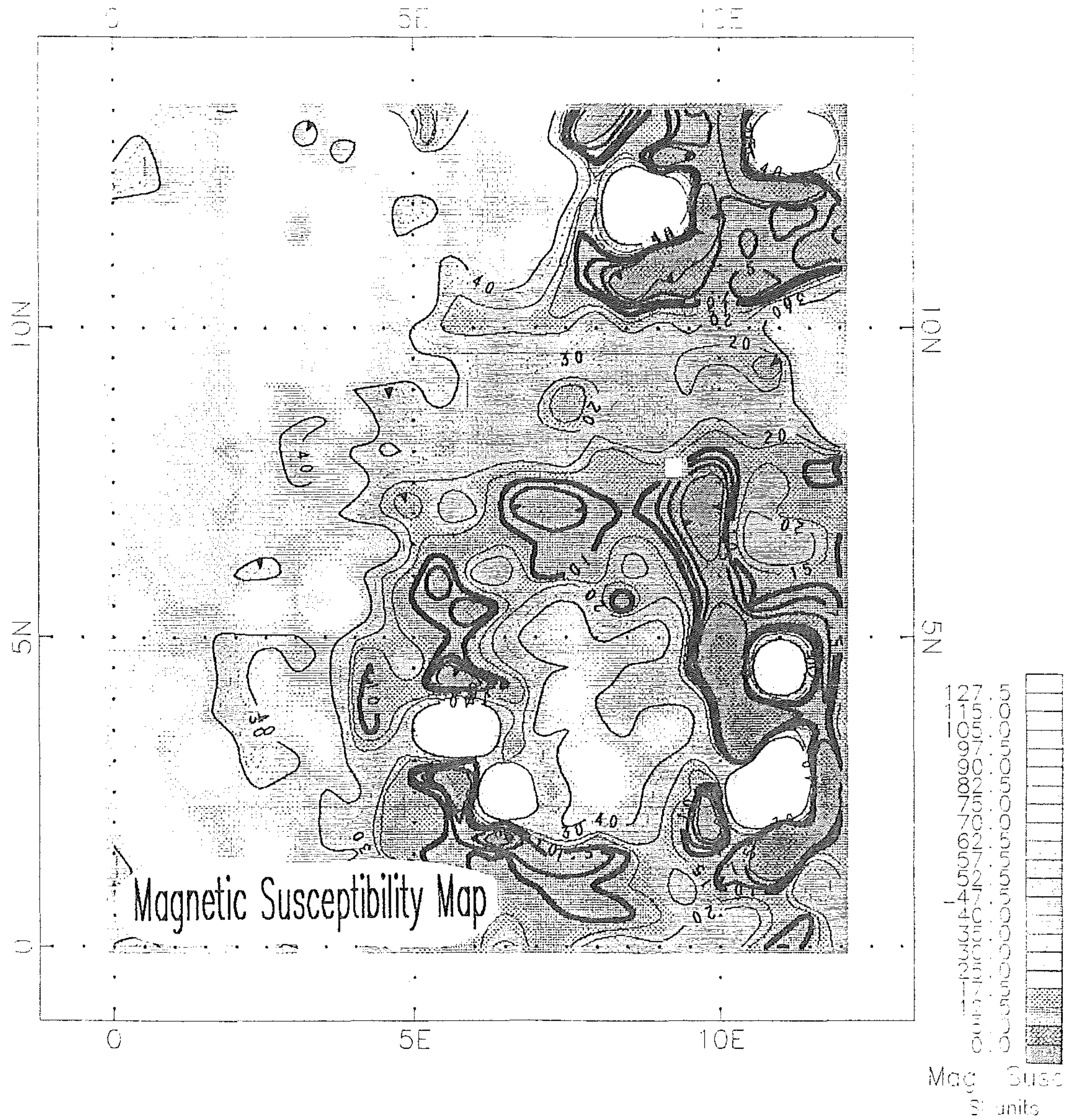


Fig 1 Lack East - Ancient Fulacht Fiadh



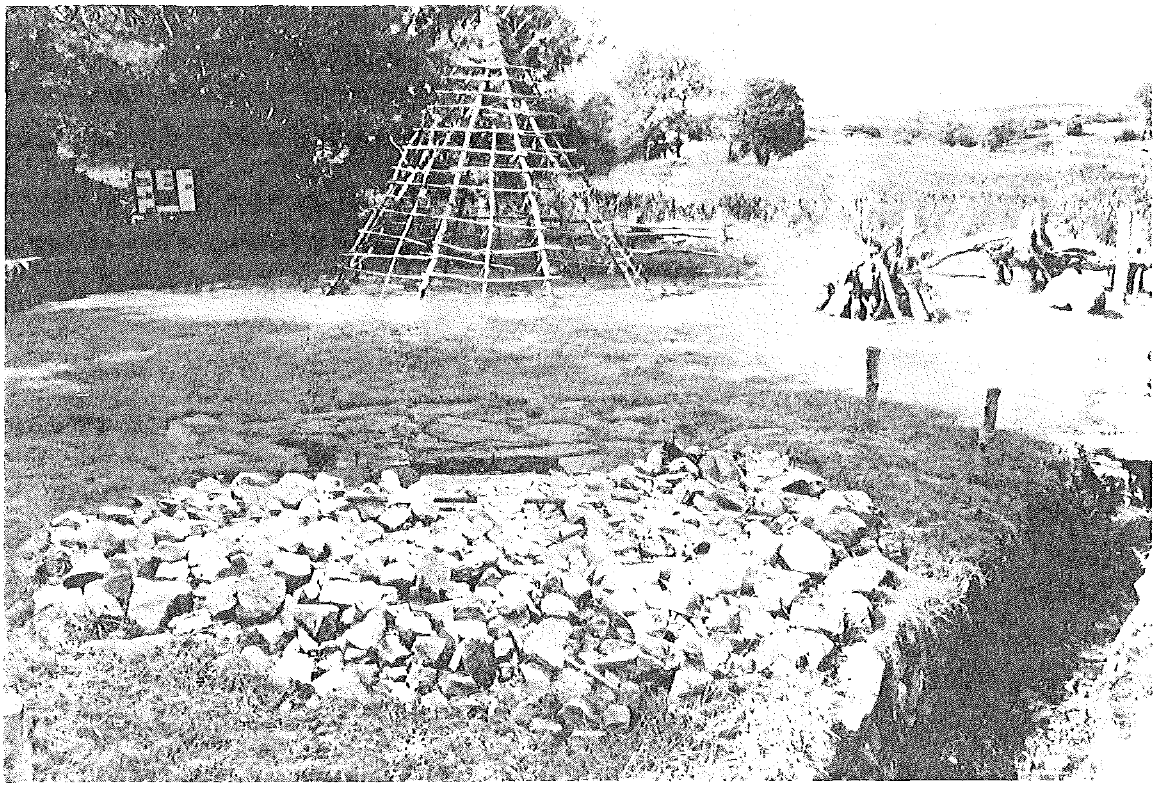


Fig 2 Lack East - Modern Fulacht Fiadh

Acknowledgement

The authors would like to thank the landowner, Mr James O'Hora for his help and co-operation during this work.

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Introduction to the limestone lowlands of Galway and southeast Mayo

David Drew, Catherine Coxon and Peter Coxon

Introduction

The Carboniferous limestones west of the River Shannon, and extending from Ennis in the south to the plains of Mayo in the north are karstified to a greater or lesser extent and form one of Europe's most extensive lowland karst regions.

In general the degree of effective karstification appears to diminish to the east, partly as a result of the presence of less-karstifiable limestones but also perhaps to the increased thickness of glacial deposits which may clog fissures in the limestone and so inhibit groundwater movement.

A distinction may be drawn between the area lying to the south of Galway Bay which is almost wholly lacking in integrated surface drainage and the area to the north which has a network of at least seasonal streams, though in both areas groundwater is of great importance. Much of the surface drainage of the more northerly area is, in part at least, artificial resulting from nineteenth century arterial drainage schemes which linked series of turloughs with channels (see Figure 1 A and B). The River Clare is an example of such a semi-artificial hydrological system. Many of these rivers exhibit very low flows or become dry altogether in summer (Coxon and Drew 1986).

The Visean limestones are overlain by a thin, patchy cover of glacial deposits. The discontinuous cover of glacigenic sediments includes areas of lodgement till (up to 2 or 3 m thick), glacially transported rafts of the local bedrock and patches of sand and gravel, the latter forming localised kame topography. While the influence of glaciation means that the area does not have the appearance of a classic karst landscape, features such as caves and swallow holes are found and the hydrologic system is karstic in nature.

Water from swallow holes and influent reaches of rivers generally drains westwards along lines of high permeability with underground flow velocities of the order of 100-150 m/hr determined by water tracing experiments (Drew and Daly 1993). The karstic nature of the aquifer is also indicated by the high proportion of failed wells (comparable to adjacent areas of poor or non-aquifer) combined with a high proportion of wells with excellent yields and a large number of major springs (Daly 1985). East of Lough Corrib groundwater flows south-westwards to a line of springs situated 1-3 km east of the shore of Lough Corrib (Drew and Daly 1993).

River Robe Area

The River Robe marks the northern limit of the area visited on the field excursion. To the north of the river the density of stream channels is much greater than to the south, typical in fact of the central and eastern part of the central plain of Ireland where thick deposits of glacial materials overlie the limestone bedrock. This increase in stream channel abundance approximately coincides with the outcrop of impure limestones north of the River Robe. South of the river and to the east of Lough Mask is an area of some 200 km^2 with no integrated surface drainage other than that imposed by arterial drainage. Turloughs are common in the area and in most instances they have not been drained. Almost all of this area is underlain by pure, Burren limestones. As over all the area considered in this report glacially deposited materials are thickest in the east, thinning to a patchy cover with much bare rock or rendzina soil close to Lough Mask.

The River Robe is the only natural surface stream of any magnitude and there is considerable interchange between river flow and groundwater. For example for c.40% of the year flows in the river increase downstream roughly in accordance with the increase in area drained. However, from mid-winter until late spring, flows downstream of Kilrush, where drift cover becomes markedly thinner, (Figure 3) are disproportionately high, up to 3m^3 higher than upstream - thus there are large inflows from groundwater to the river (effluent conditions) associated with high water table levels. In the summer and early autumn the reverse applies and upstream discharges are up to 300% of those prevailing further downstream, a maximum difference of almost 1 cumec has been measured. Water is being lost via the stream bed to the body of groundwater beneath as watertable levels are below the level of the river.

All of the drainage in this area reaches Lough Mask either via the River Robe or from springs close to the lake e.g.

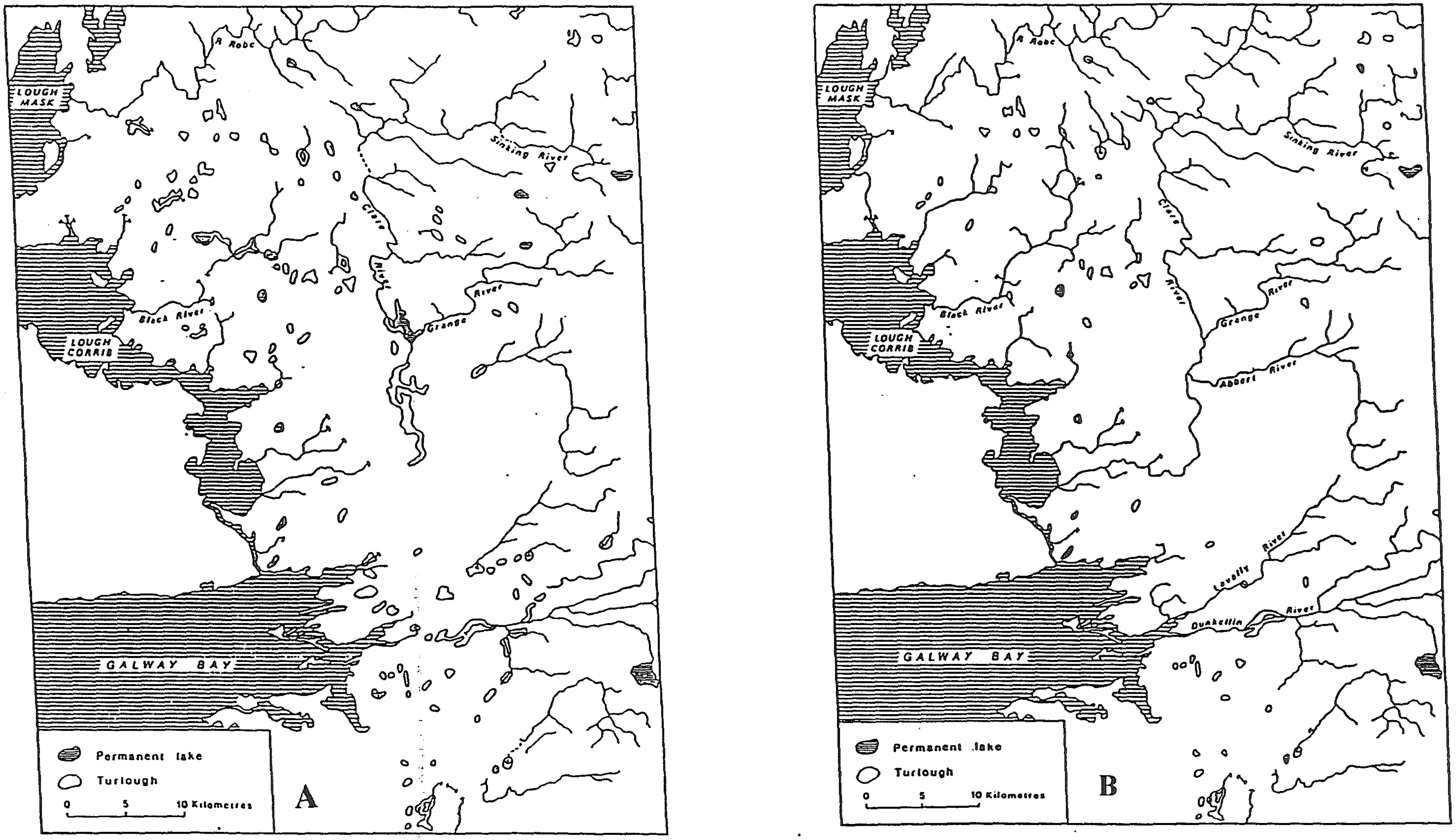

Figure 1. Natural drainage conditions (A) and the present day system of modified drainage (B) in the lowland limestone of south Mayo and east Galway.

Bunatober [mean discharge 5000 m^3/d], Fountainhill [1500m3/d], Cross [12,000 m^3/d]. In addition there are 'internal' springs such as that at Kilrush [1500 m^3/d] - the water from which sinks again a short distance below the spring, the Loop Spring on the bank of the Robe [750 m^3/d] and the set of springs at Cregduff [7500 m^3/d] which formerly drained into a turlough but whose waters are now conduited to the River Robe at Ballinrobe.

Lough Corrib Catchment

The eastern shore of Lough Corrib between Galway city and Headford receives drainage from an area of limestone lowland more than 900 km^2 in extent and reaching eastwards as far as the River Suck catchment boundary. Two short rivers the Black and the Cregg and one major stream- the Clare River collect the great majority of the drainage. The Clare River with a catchment area of c.780 km^2 originates at the confluence of the Sinking and Dalgan Rivers near Dunmore and pursues a southerly course as far as Claregalway before flowing west into Lough Corrib. The westward flowing streams of the Abbert and Grange Rivers are tributary to the Clare south of Tuam.

The Burren limestone underlies all of the area under discussion with the exception of the region in the extreme southeast where Calp limestone outcrops and the Slieve Dart upland to the north of Dunmore formed of Devonian sandstones. Groundwater yields from the Calp are commonly much less than those obtained from the Burren limestones, presumably due to a lesser degree of karstification.

At least as important in determining the hydrological characteristics of the area are the nature and thickness of the superficial deposits. With the exception of the peat over marl deposits that mark the former southeastern extension of Lough Corrib north of Galway city, superficial deposits are mainly thin and patchy for some 20 km to the east of the lake thus allowing rapid unconcentrated recharge of the limestone aquifer. However, east of a line linking Athenry - Tuam - Dunmore drift cover becomes thicker and although coarse textured in parts extensive areas of raised bog overlie regions of less permeable drift. Many of the bogs are bounded by fluvioglacial landforms such as eskers or kames. Infiltration of rainfall is inhibited over much of this terrain and the relatively dense network of surface streams implies that a much greater proportion of rainfall is converted to quickflow rather than to groundwater and hence baseflow. By contrast in the western part of the area where drift cover is thinner, tributaries to the main rivers are rare and such increments to flow as there are come from springs or from seepages into the river bed from groundwater.

As indicated above, recharge to the limestone aquifer is greatly affected by the presence and nature of superficial deposits. Recharge is assumed to be inhibited in areas of clayey drift or peat and to be facilitated in areas of coarse textured or thin deposits. In the latter instance recharge occurs in three ways.

(i) Diffuse recharge in which there is little or no concentration of rainwater prior to its percolating into bedrock. Total recharge is dependent on evapotranspirative losses of water.

(ii) Point recharge where surface streams sink underground. Prior to arterial drainage many of the rivers of the area disappeared underground in this manner but now maintain surface courses in partly artificial channels. However, there remain in excess of one hundred small streams (mean discharge 10-50 l/s) *e.g.* the Fairy Mills sink north of Tuam, the sink of the Glenamaddy turlough in the northeast of the area and the sink at the overflow from Lough Hackett near Headford. Sinking streams with a large discharge are uncommon but include the engulfment of a part of the flow of the River Abbert at Ballyglunin (c. 250 l/s) and the Terryland River (c.500 l/s) a distributary of the River Corrib in Galway City. The contribution of sinking streams to total recharge is small, probably less than 10%, but because concentrated inputs of water such as these may pursue underground flow routes in zones of high permeability their significance in the hydrology of the area is much greater than their volume implies.

(iii) Line/strip recharge of the limestone aquifer is of considerable importance in the River Clare catchment. Some reaches of most of the major rivers are influent (water flows from the river channel into the underlying limestone aquifer) for at least a part of the year (as does the River Robe described earlier). For example the River Abbert at Ballyglunin, in addition to losing water to a sinkhole, is influent all year round over a distance of 1.5 km. One third of the mean summer discharge of 1.5 m^3/s is lost over this reach whilst in winter losses exceed one cumec.

The Sinking River upstream of Dunmore looses 80-85% of its flow over a 400 m long reach in summer low flow conditions. The River Clare is influent over at least five reaches of its course for 7-9 months of the year, 30% of summer flow sinking in the vicinity of Liskeevy Bridge south of Milltown. It is presumed that influent zones in a river channel correspond to zones of very high permeability in the aquifer which may be due to a localised high degree of fracturing and/or a zone in which Pleistocene infillings have been excavated from earlier karst conduit systems thus rendering them accessible once more to groundwater.

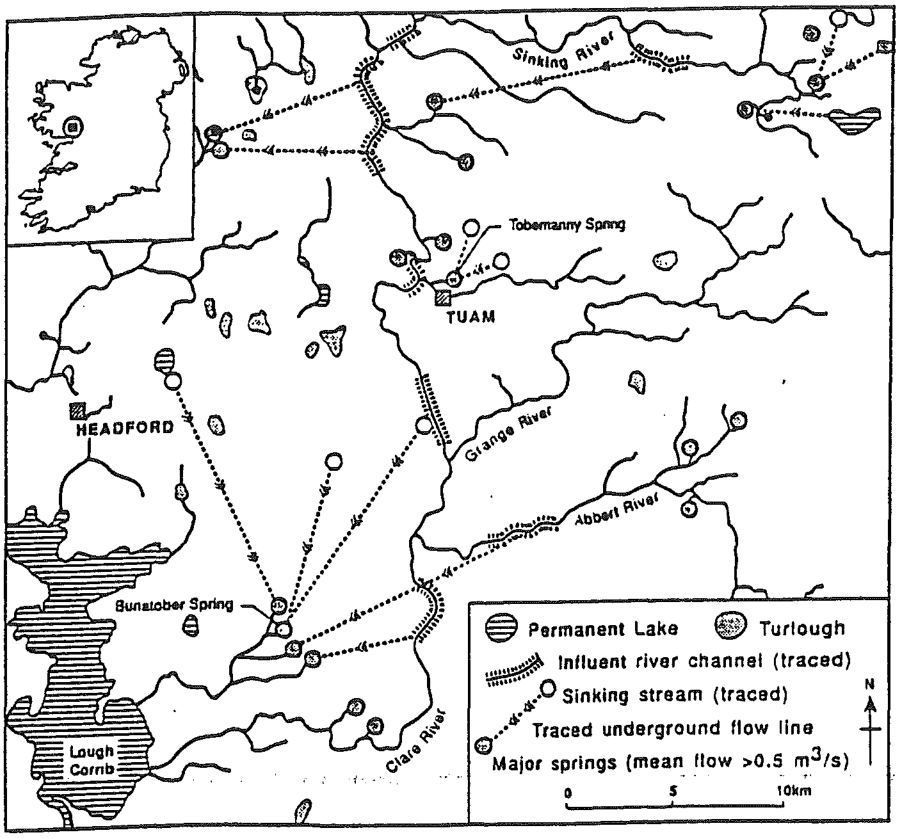

Figure 2. Surface and underground drainage east of Loughs Mask and Corrib.

Discharge of groundwater is apparently from springs and no examples of effluent reaches of river channels have been located (line discharge of groundwater). The major springs are shown on Figure 2 but numerous other small springs and seepages exist also, many of them seasonal or operative only during high water conditions. One group of springs supply the headwaters or augment the downstream discharge of some of the rivers of the area. The Lettera and Gortgarrow springs southwest of Glenammady form the headwaters of the Sinking River. The Black River originates from springs at Millburn whilst flow in the River Clare is augmented by large inflows of spring water near Tuam. There is no obvious single explanation for the location of all of these springs though in some instances, Lettera for example, the waters emerge at the foot of a low scarp where the topography intersects the shallow flow of groundwater.

A second set of springs is located some 1-3 km east of the shore of Lough Corrib at an altitude of 12-15 m O.D. The springs (Kilcoona, Doegheoona, Bunatober, Aucloggeen, Cloghaun and Laghtgeorge) issue from the foot of a limestone scarp 3-15 m in height that may represent a former shoreline of Lough Corrib. Between the springs and the present-day shore of the lake is an area of peat underlain by calcareous lacustrine marl (Figure 3) shows the approximate catchments for three of the springs: Kilcoona, Bunatober-Doegheoona and Aucloggeen, which have been defined by water tracing experiments.

The subterranean catchments have no correspondence with the surface drainage system of the area.

The Bunatober and Doegheoona springs 600 m to the north are linked, the latter functioning as an overflow for Bunatober. Discharge from the Bunatober spring appears to be constrained to a maximum value of c. 1.5 m^3/s (mean flow c. 0.5 m^3/s, low flow 0.05 m^3/s) with excess water being discharged over an extended period from Bunatober and/or via Doegheoona. This set of springs may have developed graded to the edge of an earlier more extensive Lough Corrib and it is possible that they are overflow springs with deeper groundwater flow occurring to outlets beneath the waters of Lough Corrib. To the east of the springs the gradient of the watertable is c. 1:500 but in the vicinity of the scarp it steepens to c. 1:100.

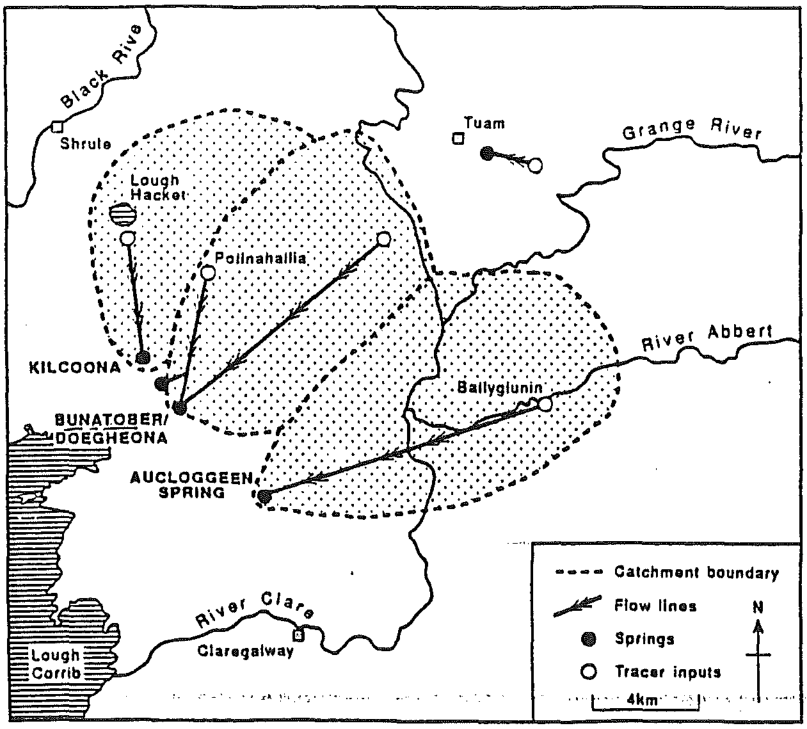

Figure 3. The catchments of three springs draining to the northeastern part of Lough Corrib.

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Turloughs near Ballinrobe and their Quaternary deposits

Catherine Coxon and Peter Coxon

Introduction to turloughs

Turloughs are a characteristic feature of the Carboniferous limestone lowland of Ireland west of the river Shannon. These are seasonal lakes which lack a natural surface outlet and generally contain swallow holes. Flooding generally occurs due to groundwater entering the turlough by springs or estavelles (*i.e.* openings which act as both springs and swallow holes), or in some instances also from surface water inputs. This occurs in a matter of hours or days in September or October, and the turloughs are filled to a depth of a few metres through the winter and early spring. They empty *via* swallow holes or estavelles, usually over several weeks in April to June, and in summer they are pasture land, used for grazing.

Most Irish turloughs are located on well-bedded, pure grey calcarenite similar to the limestone of the Burren plateau; indeed the turlough cluster to the east of Ballinrobe lies in limestone which is both stratigraphically and lithologically equivalent to the Burren limestone. Although turloughs have been found to occupy bedrock hollows anywhere that it has been possible to determine this, nonetheless their shape appears to be controlled in many instances by the surrounding glacial depositional landforms, and their orientation appears to reflect the direction of ice movements during the last glaciation (Coxon 1987a). The origin of turloughs is discussed in the section of this guide dealing with Pollnahallia, under the heading "The age of the limestone landscape". A detailed discussion of turlough hydrology and geomorphology can be found in Coxon (1986).

The seasonal flooding and emptying of turloughs gives rise to distinctive flood-tolerant grassland communities. The freshwater invertebrates are also distinctive and many turloughs are important winter feeding areas for ducks, geese and waders. The ecological value of these sites can only be maintained by retaining their natural hydrological regime. The greatest threat to turloughs is posed by drainage schemes. A survey of turlough sites throughout Ireland (Coxon 1987b) identified 90 sites with areas greater than ten hectares, however, a third of these no longer flood to any significant degree due to drainage schemes carried out from the mid-nineteenth century to the present day. Turloughs have been identified as priority habitats under the European Habitats Directive (92/43/EEC) and 43 turloughs have been proposed as Special Areas of Conservation under this directive, including the two sites in the Ballinrobe area discussed below (Greaghans and Kilglassan).

Present day carbonate depositional processes

On emptying, the turlough floor vegetation is seen to have a whitish coating; microscopic examination shows this to consist of calcite crystals. In some turloughs, tufaceous crusts coat stone walls and bedrock outcrops, and more rarely, a striking white paper-like deposit known as "algal paper" is found covering the floor and suspended from vegetation, fences etc.

An investigation of the water chemistry of four turloughs in the Ballinrobe area (Coxon 1994) suggested that present-day calcite deposition is due predominantly to supersaturation caused by the loss of excess carbon dioxide from the water to the atmosphere. This process occurs throughout the winter. Biological influences are thought to play a minor role in causing supersaturation, although further studies are required to investigate the turlough phytoplankton, and to determine the role of plants in calcite precipitation associated with tufaceous crusts and algal paper.

Turlough marls

The springs, swallow holes and estavelles through which the turloughs fill and empty are usually located near the perimeter of the flooded area, while the floor of the turlough contains deposits of low permeability, often several metres deep. A survey of ninety turloughs found that the majority (69) contained either peat or marl or a deposit transitional between the two. Marl was found at 46 out of 90 sites. These ninety locations, and the forty-six sites containing marl, are shown in Figure T1.

The term marl is discussed in Coxon and Coxon (1994).

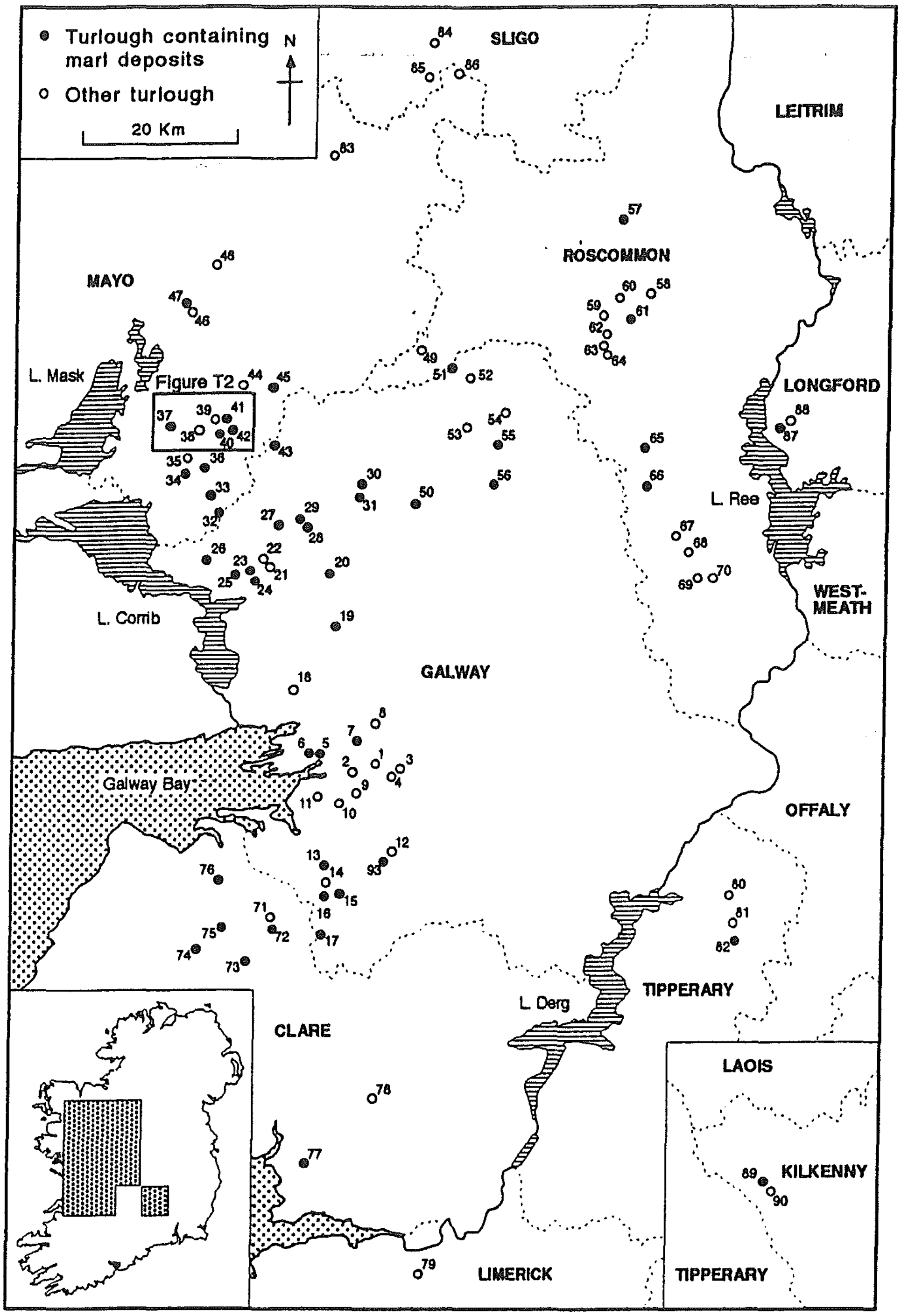


Figure T1 : Location of the ninety turloughs surveyed, and the forty-six containing marl deposits

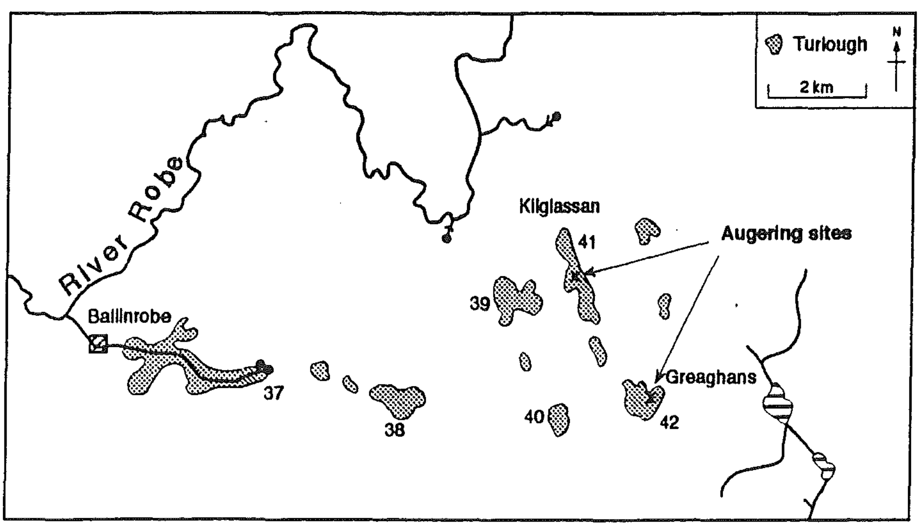


Figure T2 : Location of the two turloughs in the Ballinrobe area in the present context it indicates white or cream coloured deposits found in many turloughs which consist largely of calcium carbonate. Similar deposits are found at other locations in Ireland, notably below fens and raised bogs (see Coxon 1987c).

The pure white turlough marls consist largely of inorganic calcite crystals, although they frequently contain shells and shell fragments. The freshwater shell species found indicate that the marls were laid down when these turloughs were permanent water bodies (Coxon and Coxon 1994).

The depositional record from two turloughs in the Ballinrobe area

The stratigraphy and pollen record of two turloughs in located 9 km to the east of the town of Ballinrobe, County Mayo has been examined in detail. The sites (Greaghans, no. 42, grid reference M 2963, and Kilglassan, no. 41, grid reference M 2864) are shown in Figure T2. The following is a summary of the findings discussed in Coxon and Coxon (1994).

Greaghans **(Locality 2.1)**

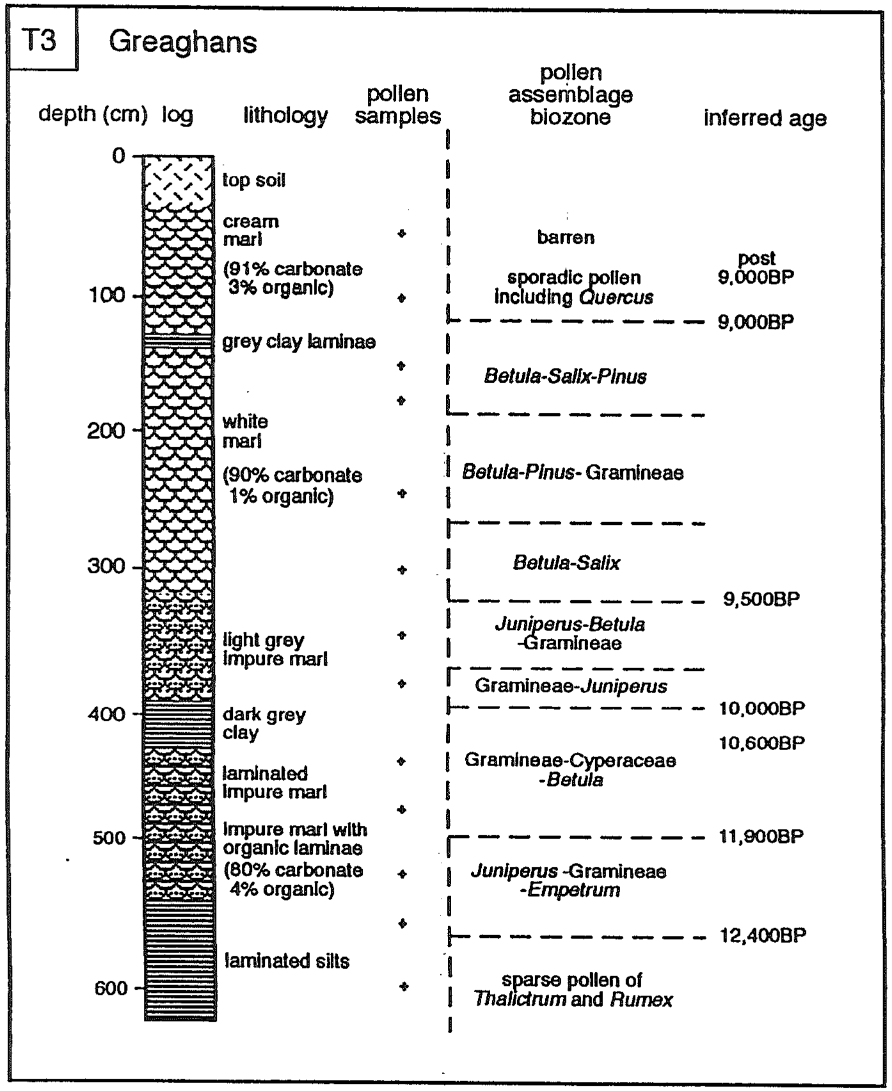
At Greaghans turlough (area 37 ha), the marl fills a bedrock hollow, deepening to six metres towards the centre of the turlough. The detailed stratigraphy from the deepest part, investigated with a Dutch Edelman auger with a gouge attachment, is shown in Figure T3, together with the content of carbonate and organic matter.

[From Coxon and Coxon 1994]:"Broad pollen assemblage biozones (p.a.b.) can be recognised, and biostratigraphically correlated with radiocarbon-dated pollen zones from elsewhere, enabling the turlough deposits to be tentatively dated. The dating is possible because a well-established chronology exists of Late-glacial (13,000-10,000 years BP) and Early Holocene (10,000-8,000 years BP) litho- and biostratigraphy (Craig 1978, Watts 1977, 1985 and Cwynar and Watts 1989). The p.a.b. and the inferred dates for the Greaghans core are shown in Figure T3. The inorganic laminated silts with sparse pollen at the base of the core are overlain by the first peak of *Juniperus* which is a characteristic Late-glacial pollen assemblage indicating that deposition in the basin started more than 12,400 years BP (Cwynar and Watts 1989). The onset of impure marl deposition coincides with the period between 12,400 and 11,900 years BP (the *Juniperus-Empetrum* p.a.b.) which is thought to have been the warmest phase of the Late-glacial (Watts 1977, Cwynar and Watts 1989 and Atkinson *et al.* 1987). This warm phase is known in Ireland as the Woodgrange Interstadial (Mitchell *et al.* 1973). The subsequent change to grassland (Gramineae-Cyperaceae-*Betula* p.a.b.) indicates climatic deterioration during the latter part of the Late-glacial (Woodgrange) Interstadial (from 11,900 years BP) which culminated in the Nahanagan Stadial (Colhoun and Synge 1980) between 10,600 and 10,000 years BP (Cwynar and Watts 1989). The latter stadial is represented in the Greaghans core by a horizon of dark grey clay, a common lithological unit recognised at the termination of Late-glacial sequences throughout Ireland.

The deposition of purer marl, starting at *c.* 4 m depth, probably commenced at approximately 10,000 - 9,500 B.P. onwards and can be dated by the second peak of *Juniperus* pollen. The pollen assemblages containing *Betula-Pinus-Salix* and Gramineae at 1.3-3.2 m are thought, on biostratigraphical grounds, to date from *c.* 9,000-9,500 years B.P. Such a date is supported by the absence of *Corylus, Quercus* and other thermophilous taxa. The top samples are virtually barren of pollen, due to oxidation of the sediment, but given that the sediment from 6 m to 1.3 m was probably deposited between 12,500 and *c.* 9,000 B.P. (a sedimentation rate of the order of 1.3 mm/annum), it seems unlikely that the uppermost 1.5 m of marl was deposited much after 8,000 B.P. The presence of the pollen of *Quercus* but the absence of diverse thermophilous taxa supports this. Therefore it is suggested that the site was a marl depositing permanent lake in Late-glacial and early Holocene times, but that marl deposition ceased several thousand years ago, at which time the lake may have become a turlough as at the present day."

Kilglassan **(Locality 2.2)**

Kilglassan turlough (area 29 ha) contains extensive deposits of peat, which have been cut for fuel in places. The peat is underlain by marl in the deepest central parts of the depression. The deepest part of the turlough, where the augering was carried out, contains 2.5m of marl overlain by *c.* 85cm of peat, but may originally have had a greater depth of peat.



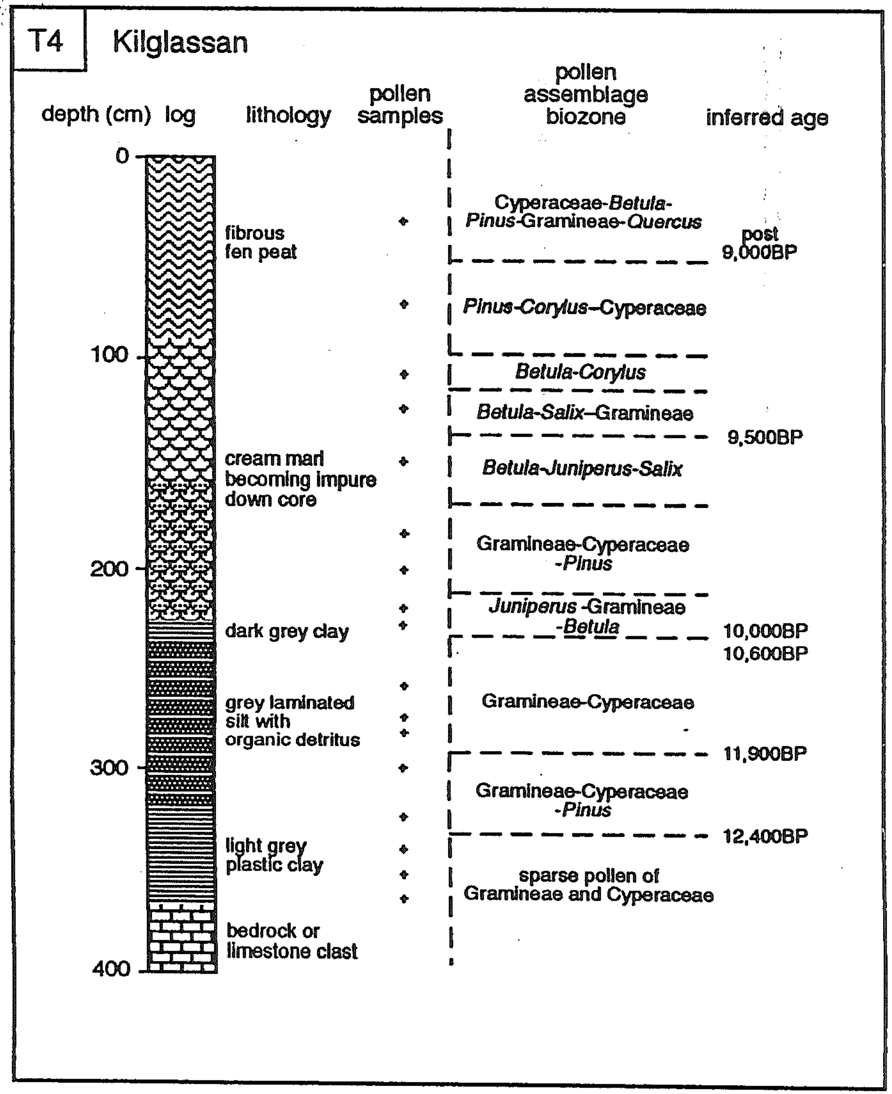


Figure T3 : Stratigraphy and pollen assemblage biozones from Greaghans turlough

Figure T4 : Stratigraphy and pollen assemblage biozones from Kilglassan turlough

[From Coxon and Coxon 1994]: "The detailed stratigraphy and pollen assemblage biozones at the central point are shown in Figure T4. It can be seen that the initial deposition, of inorganic sediment, is similar to that at Greaghans and was probably deposited prior to 12,400 years B.P. The litho- and biostratigraphy corresponds closely to that at Greaghans, e.g. the dark grey clay band at 2.3 m (Nahanagan Stadial), with grey laminated marl with organic matter below (Woodgrange Interstadial), and purer non-laminated marl above (Early Holocene), correlates with the band at 4 m depth in Greaghans, and the pollen assemblages at these levels also correspond. Thus, as in Greaghans, the deposition of purer marl appears to have commenced at *c.* 9,500 B.P. Interestingly the appearance of *Corylus* is recorded above 1.2 m at Kilglassan, indicating an age of later than 9,500 years BP.

The cessation of marl deposition at Kilglassan is followed by a period of accumulation of fibrous fen peat. So, unlike in Greaghans turlough, it is possible to assign a date to the cessation of marl deposition, of approximately 9,000 B.P. The pollen in the uppermost peat sample (with its pollen assemblage including *Betula, Pinus* and *Quercus* following on from one containing *Corylus*) indicates an age of post 9,000 years B.P. (see Craig 1978). In addition the absence of *Alnus* suggests that this same material probably pre-dates 7,500 B.P. However, as mentioned above, part of the peat record may be missing due to cutting, so it cannot be determined whether peat accumulation continued until recently."

Conclusion

The pollen record from the deposits in these two turloughs indicates clearly that these seasonal water bodies were permanent lakes in Late-glacial and early Holocene times. The deposition of pure marl started at approximately 9,500 B.P., and marl deposition ceased 8,000-9,000 years ago, at which time seasonal flooding may have commenced. The change from permanent to seasonal flooding may have been due partly to silting up of the depression. Also, it is proposed that increasing karstification in postglacial times resulted in better connections between the lake and groundwater, and in the development of the zone of higher permeability in the aquifer associated with the turloughs. Similar investigations of the deposits in other turloughs elsewhere on the western limestone lowlands could help to determine why this change occurred, and whether it occurred simultaneously throughout the region.

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Pollnahallia: a Tertiary palaeosurface and a glimpse of Ireland's pre-Pleistocene landscape

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Introduction

The distinctive white sands and associated lignite exposed in the area of Pollnahallia (M340 470) and Kilwullaun Townlands, County Galway (Figure P1), have been used locally for well over 50 years and a they have also gained a wider reputation both for their potential as a mineral resource and as a fragment of Ireland's landscape history.

Aubrey Flegg and co-workers (GSI) carried out the first extensive field survey of the deposits in the late 1970s and early 1980s and Aubrey's work included an assortment of sampling and borehole work and prompted a geophysical survey by D. Mullen of UCG (Mullen 1981) of the surrounding area. Frank Mitchell referred to Aubrey's work in his "Search for Tertiary Ireland" paper of 1980 and he cites a palynological analysis by Bill Watts as showing the lignite to be Tertiary in age (Mitchell 1980, page 23). PC and CC visited the sand pit at Pollnahallia in February 1984 (after considerable pressure was exerted three days earlier at Botany coffee time by Frank Mitchell) and subsequently obtained samples of the lignite taken by Aubrey Flegg during the GSI's work at the site. A visit to the Pollnahallia exposures in October 1985 by Aubrey and PC culminated in a first attempt to describe the area and its importance to landscape history in some detail (Coxon and Flegg 1987). A subsequent paper (Coxon and Coxon 1997) attempts to put the palaeosurface around Pollnahallia into context.

This visit by **IQUA** to the Pollnahallia site will allow the presentation of new material collected during a week long drilling operation carried out during September 1987 using a grant from The Royal Society of London. Two boreholes were made in 1987 and continuous U4 samples taken from the site. The preliminary results of the most recent work (carried out over the last two years) are presented here including a new pollen diagram from the thickest part of the biogenic sediments recovered.

Geomorphology of the area around Kilwullaun and Pollnahallia (Locality 2.3)

(from Coxon and Coxon, 1997)

Figure P2 is a detailed geomorphological map of the region compiled by Corcoran and Flegg (in Coxon and Flegg 1987) and from a field survey by Coxon (1986). It shows the distribution of surface depressions, small scarps, bare limestone and superficial deposits in a 200km^2 area centred on Pollnahallia. Some of the closed depressions marked on Figure P2 may be irregularities in the glacial drift, but many are of karstic origin. Some of these latter depressions are shallow features but there are also deeper collapse features e.g. at Pollaturk and near Knockmaa (Po and D1 on Figure P2). Several turloughs exist in the vicinity of Pollnahallia, both active turloughs and drained turloughs (whose flooding regime has been seriously affected by drainage schemes) are shown in Figure P2.

Extensive surveys in this local area (Figures P1 and P2) confirmed in detail the karstic nature of the limestone bedrock in the region as a whole. A resistivity survey (Mullen 1981) and a comprehensive drilling programme was carried out in the early 1980s in and around Kilwullaun and Pollnahallia. The location of these boreholes and the results of the resistivity survey are summarised on Figure P1 and the details are discussed in Coxon and Flegg (1987). The geomorphology of this small area of 3.3 km^2 is very complex and includes large shallow depressions (up to 5 m deep), deeper depressions and fractured limestone (up to 15 m deep), deep gorges (up to 20 m deep) and cave passages (identified in borehole A, Figure P1) within the limestone. One such gorge, associated with deep depressions and caves in the bedrock, occurs at Pollnahallia and it was recognised from sand quarrying operations, from a resistivity survey and from borehole data. The form of the sediments lying in this gorge can be seen in Figure P3. The latter Figure shows the local geology of the sand pit area depicting the resistivity lows, the distribution of the important geological units, the location of boreholes and the

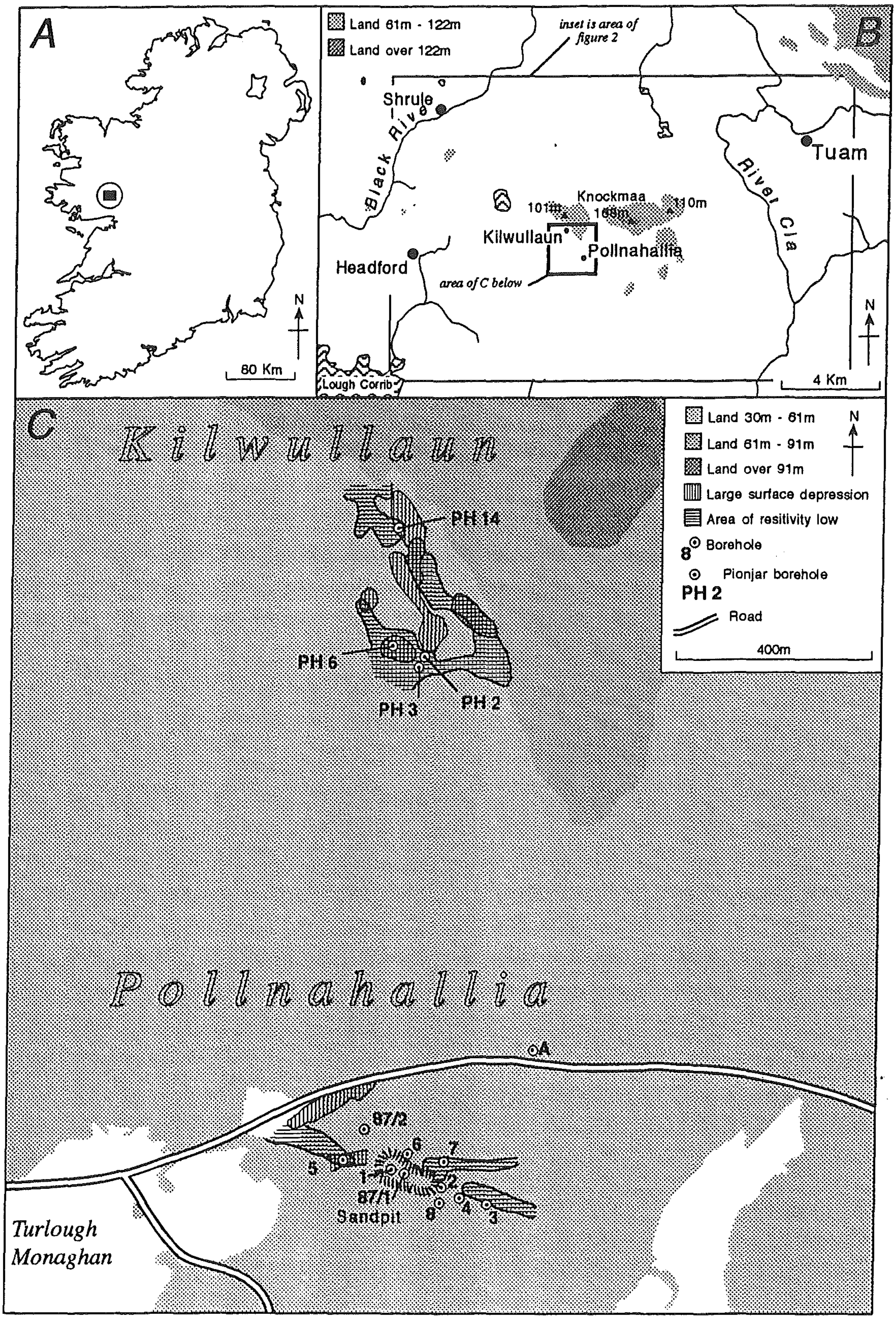


Figure P1 The location of the Kilwullaun and Pollnahallia areas and the borehole locations and results of the resisitivity survey carried out in the area. A and 1-8 are Geological Survey of Ireland boreholes referred to in Coxon and Flegg, 1987. The Pionjar holes in Kilwullaun are also referred to in that publication. Boreholes 87/1 and 87/2 were drilled with funding from the Royal Society in 1987 and are referred to here. (from Coxon and Coxon, 1997) reconstructed nature of the surface of the limestone bedrock.

- Several distinct lithological units lying on the limestone were identified and described by Coxon and Flegg (1987) and were classified within an informal lithostratigraphy:

1. *Pollnahallia organic silt and clay* Directly overlying the limestone in both the Kilwullaun and Pollnahallia areas are organic silts and clays containing compressed biogenic material. The extent and nature of these organic materials are variable and ranges from thin black silty clays in shallow depressions in the Kilwullaun area to thicker accumulations exposed at (or near) the surface as at borehole 87/2 to thick lignite accumulations as recorded in boreholes 1 and 87/1 (Figure P3). In the shallow depressions and in surface exposures the sediments are primarily yellow, white, or dark grey and black silty clays containing organic debris. Much of the organic material from these shallow sites is heavily oxidised. These sediments appear to represent organic sedimentation in wet conditions, in shallow depressions on the limestone surface, possibly as soils, blanket peats or in shallow pools.

2. *Pollnahallia sand* The Pollnahallia organic silt and clay unit can be seen to coarsen upwards within the gorge sequence where increasingly thick horizons of sand occur. Eventually, pure white sand overlies the organic sediments. This sand is very-well sorted (Inclusive graphic mean =0.2 mm) and silica-rich (99%). Sections in the quarry showed large-scale cross-bedding of the white sands and it has been inferred that these sediments represent wind-blown material infilling the gorge. The source of the silica sand is unknown but it is possibly the product of a weathered residue of any of a number of rock types that lie to the west. The most likely source (Coxon and Flegg 1987) are the quartzites of Connemara, found 30 km to the west of Headford. Deeply weathered quartzites can be found in a number of localities in Connemara and such weathering could have occurred throughout the Tertiary (Mitchell 1980 and 1985).

   Subsequent reworking of the sands by glacifluvial meltwater is apparent in the sections as are shear planes, large injections of the overlying till and rafts of glacially transported bedrock. Some of the sections showed evidence of post-depositional subsidence (faulting) indicating that limestone solution and subsequent collapse was also occurring after the sands had been deposited.

(iii) *Headford till* The till capping the sequence at Pollnahallia is a lodgement till containing a strong preferred orientation of clasts and numerous shear structures suggesting ice movement from the north west. The till has incorporated large limestone rafts (one is 16 x 4 x 20(+) metres in dimension), and it has been injected down into the underlying sand and has extensively sheared and disturbed the underlying deposits in parts of the pit. The ice movement that produced the Headford till appears to have come from the north but a large number of erratics in the till have a provenance from the west and south and may have been reworked from earlier ice advances. Till of this type is found smeared in patches across the whole of the area and its age is unknown although the lack of decalcification suggests that it probably dates from the Midlandian (Last) Glaciation.

The Royal Society boreholes of 1987. Borehole 87/1. Lithology

Funding from the Royal Society allowed the drilling of further boreholes in the Pollnahallia area. The first, borehole 87/1, was drilled from the floor of the sand pit and the detailed sediment log, pollen sampling points and loss on ignition data are shown on figure P4. The borehole was sited close to the original GSI borehole 1 (figure P1) and individual samples and "cutting shoe" samples (prefixed S on figure P4) and whole U4 cores (prefixed U4-) were taken with almost continuous coring of the organic sequence possible.

Borehole 87/1 confirmed the earlier outline findings about the nature of the organic sediments below the Pollnahallia sand but allowed a far more detailed description and sampling exercise to be undertaken. Borehole 87/1 was 20.26m long and bottomed in limestone. From the base upwards the sediment succession is one of laminated clays, silts, organic detritus and lignites alternating with numerous sandy horizons and with a varying sandy matrix. Lignite predominates portions of the core (between 17.23-15.48 m and 13.85-12.55 m) whilst the upper part of the core (from 12.50-10.67 m) shows an upward transition from silt and clay into laminated silts and clays into laminated silts and finally into laminated yellow clays with sand horizons (the latter between 11.08-10.67 m). The loss on ignition data, shown on figure P4, displays the variable nature of the organic content and shows a marked variability associated with sandier horizons. The sandy matrix associated with the organic detritus shows up as a low % carbon content whilst the compressed organic material (lignite) is far richer in carbon. The uppermost laminated yellow clays with sand horizons grade into well-sorted white sands (10.67-0.0 m).

The sedimentological interpretation (allied to the geomorphological information) is that the sediments were laid down in an open gorge cut into limestone bedrock under conditions with long periods of quiet (or still) water deposition interspersed by occasional flows capable of transporting sand. A considerable volume of organic debris accumulated in the narrow gorge from rotting vegetation.

Presumably the latter sediments were derived both allocthonously and autochthonously.

Borehole 87/1. Palynology

To date (August 1998) 30 samples have been analysed from borehole 87/1 and it is possible to present a preliminary pollen diagram of this new information (figures P5 and P6). Unfortunately space precludes including the full list of taxa and many important, but infrequent, types are not shown. The methodology has been outlined in Coxon and Coxon 1997. The 87/1 pollen diagram is broadly comparable to that obtained from the eight samples that were recovered from the GSI's borehole 1 (Coxon and Flegg 1987) but the longer sequence recovered, the certainty of stratigraphic position of the samples and the increased number of samples taken has allowed a more detailed synthesis to be made. The preliminary pollen diagram can be subdivided into 5 pollen assemblage biozones (pab).

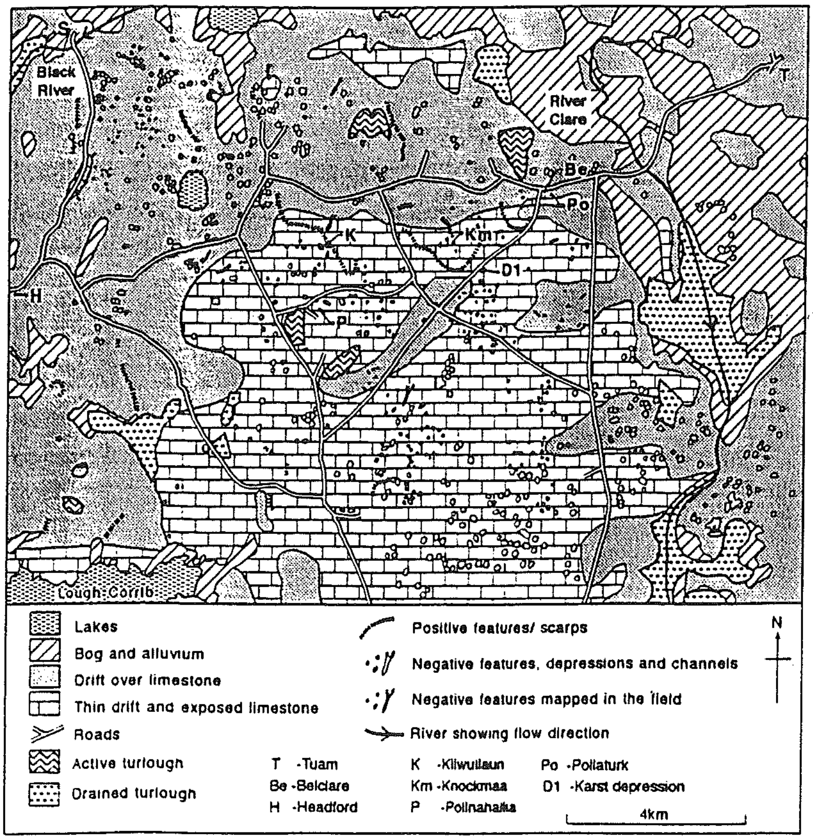


Figure P2. Geomorphological map of the area between Tuam and Headford (after Corcoran and Flegg in Coxon and Flegg, 1987 with some alterations)

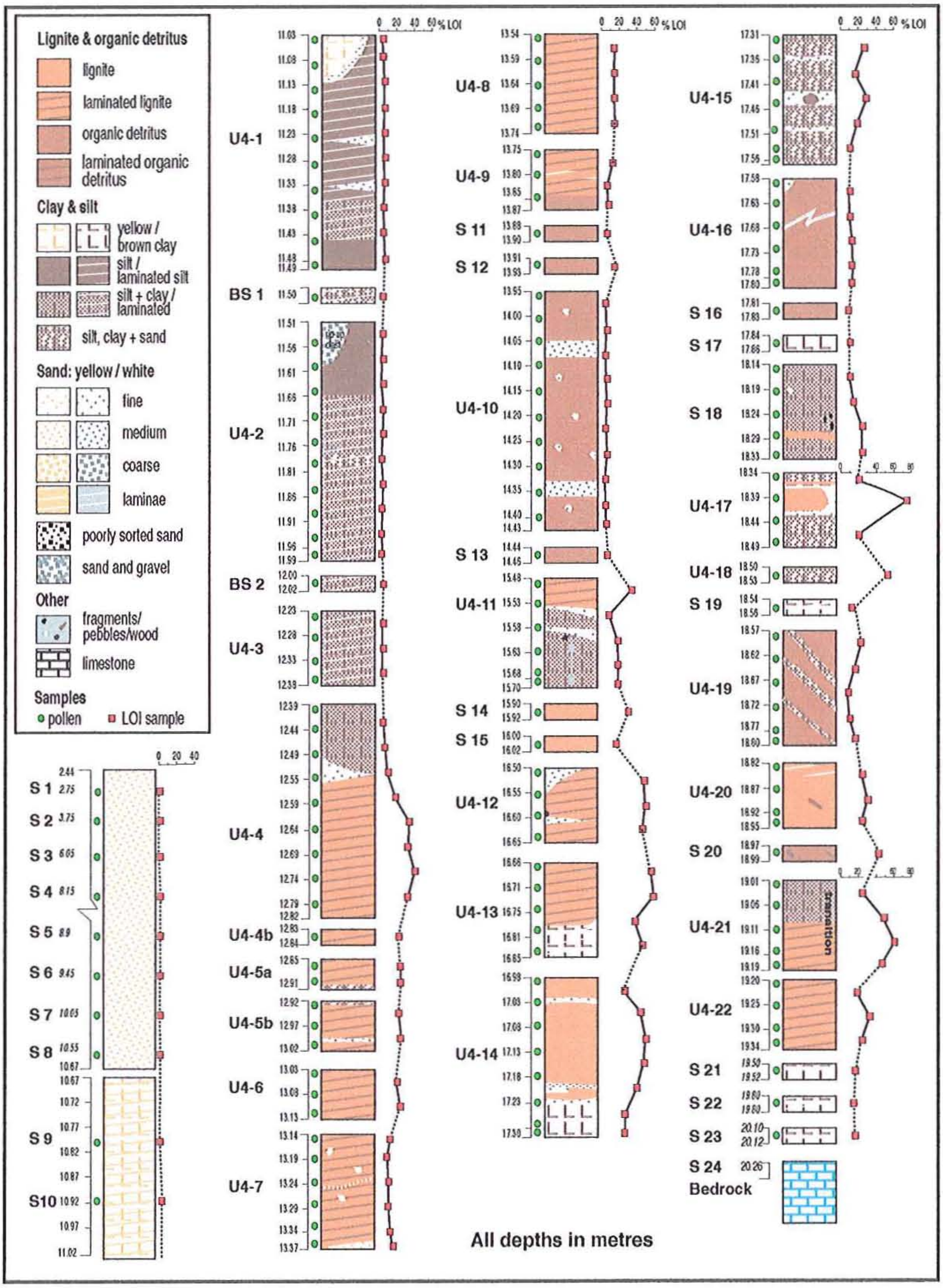


Figure P4. The lithology and loss on ignition data from Pollnahallia borehole 87/1

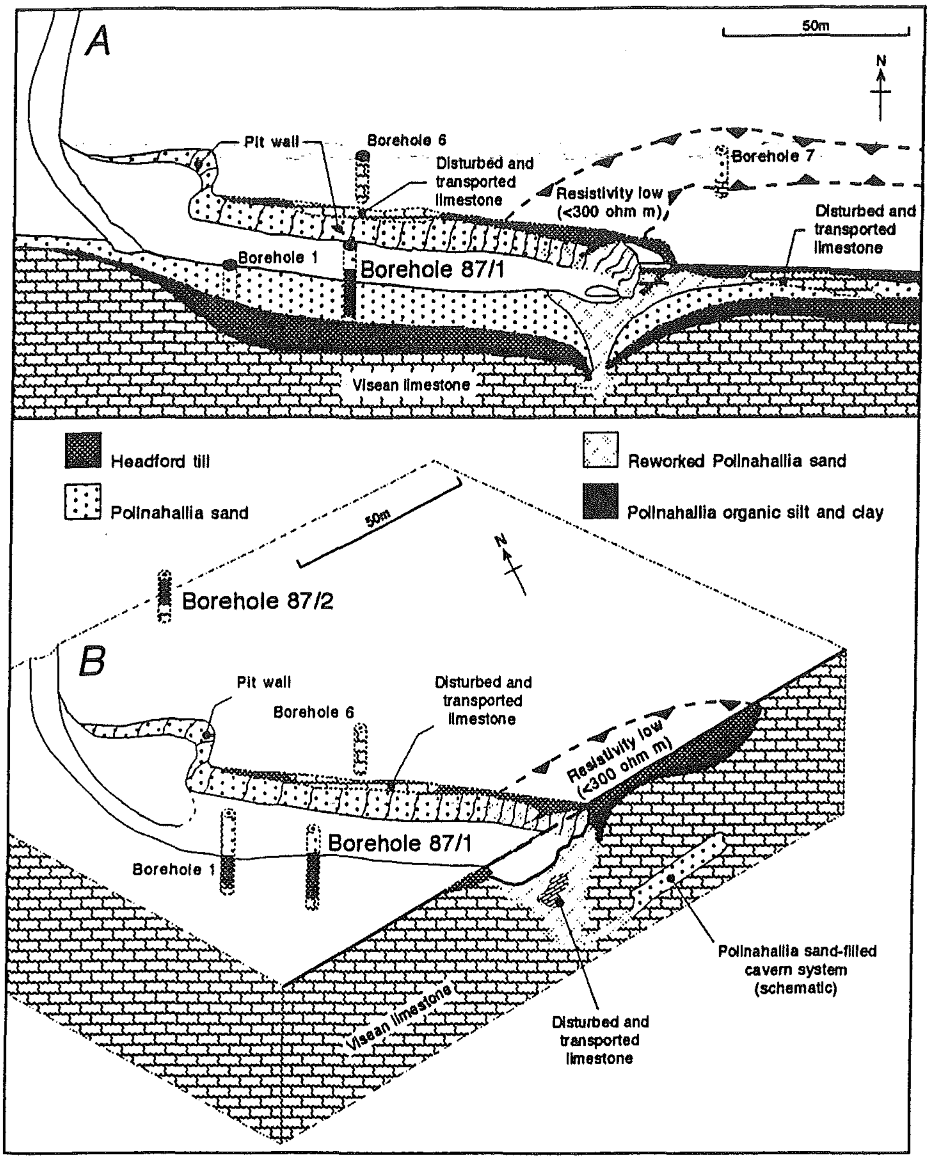
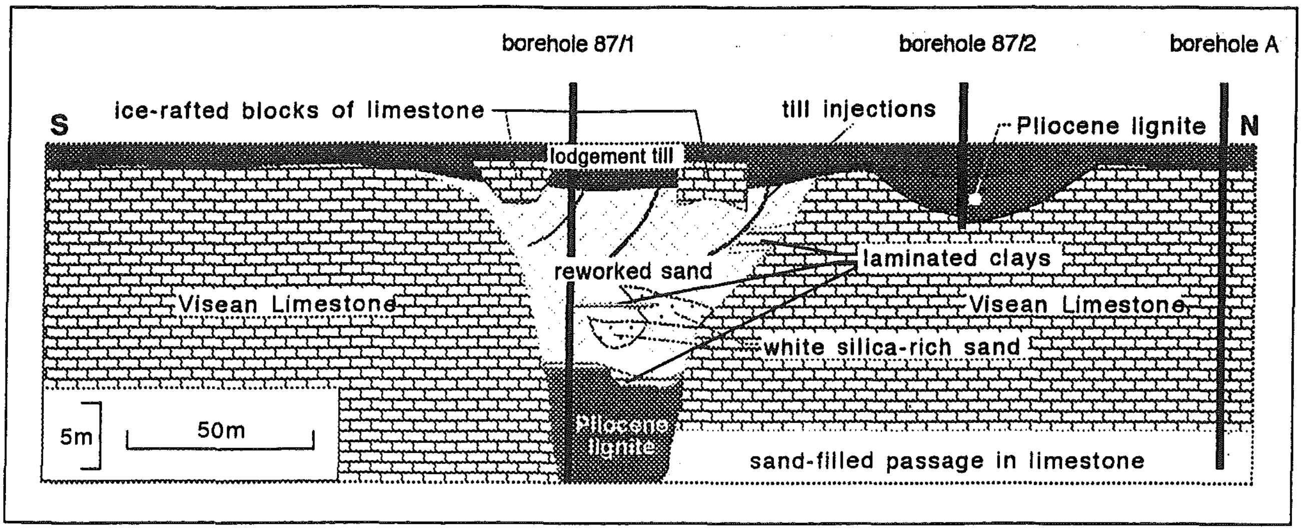


Figure P3. Schematic cross-sections of the deposit at Pollnahallia based on the original surveys (Coxon and Flegg, 1987) and on boreholes carried out late in 1987 with funding from the Royal Society (Boreholes 87/1 and 87/2). From Coxon and Coxon, 1997.



pab	depth (cm)	assemblage
87/1 -5	1050-1100	*Pinus* - *Betula* - *Larix* - Gramineae
87/1 -4	1100-1275	*Pinus* - *Corylus* - Ericaceae-*Carya*
87/1 -3	1275-1575	*Pinus* - *Taxus* - *Taxodium* - Ericaceae
87/1 -2	1575-1875	*Pinus* - *Corylus* - Ericaceae
87/1 -1	1875-2012	*Pinus* - *Taxodium* - Ericaceae - *Sequoia*

Below is a checklist of taxa (mostly trees and shrubs) selected for the preliminary Pollnahallia pollen diagram in this guide.

n.b. some of the families and genera have many members (e.g. Within the Fagaceae family the genus *Quercus* (oak) contains 600 species) making the identification to species level using palynology difficult/impossible. A further problem is that with deposits of Tertiary age some of the individual species are probably extinct, indeed some authors refer to Tertiary taxa as form genera only (i.e. they describe the pollen morphology rather than attempt an identification to any living taxa e.g. *Tricolpollenites* -type) whilst others might refer to a genus but avoid a direct classification to a living member of that genus i.e. *Quercoidites*)

botanical name (Family or *Genus* / *species*)	common name	botanical name (Family or *Genus* / *species*)	common name
Abies	fir	*Nyssa*	sourgum
Acer	maple	*Osmunda regalis*	royal fern*
Aesculus	horse chestnut	*Osmunda cf. claytoniana*	north American/east Asian fern
Alnus	alder*		
Azolla	water fern	*Ostrya*	hop-hornbeam
Betula	birch*	*Picea*	spruce
Calluna	heather (ling)*	*Pinus* (subgenus Diploxylon)	pine*
Carya	hickory	*Pinus* (Haploxylon)	pine
Castanea	sweet chestnut	(Haploxylon pines have a different pollen morphology and represent a subgenus of different species to Diploxylon pines)	
Corylus	hazel*	Polypodiaceae	ferns*
Coryloid indet.	possibly hazel? (or another of numerous triporate pollen taxa)	*Pterocarya*	wingnut
Cupressaceae	cypress family	*Quercus*	oak*
Cyperaceae	sedge family*	*Salix*	willow*
Empetrum	crowberry*	*Sciadopitys* (cf. *S.verticillata*)	Japanese umbrella pine
Ericaceae	heather family*	*Sequoia*	giant redwood
Fagus	beech	*Sphagnum*	moss*
Gleicheniidites senonicus	tropical/warm temperate fern		
Gramineae	grass family*	*Taxodium*	swamp cypress
Juglans	walnut	*Taxus*	yew*
Juniperus	juniper*	*Tsuga*	hemlock
Larix	larch		
Liriodendron	tulip tree		
Liquidambar	sweetgum		
Myrica	bog myrtle*		

* denotes representatives native to Ireland in Holocene. (Note many of the taxa listed have been introduced to Ireland but are not native).

- Rather than discuss the pollen diagram in detail (which will await a full synthesis and more detailed publication) the aim here is to outline the principal findings and put the biogenic material into a stratigraphic context.

The vegetational history and the age of the Pollnahallia organic silt and clay

Palynological analyses of the Geological Survey of Ireland's borehole 1 and the interpretation of those results have been discussed at length in Coxon and Flegg, 1987 and in Coxon and Coxon, 1997. The original work has been confirmed by the work on borehole 87/1 in that the pollen assemblages indicate a Late Tertiary (cf. Pliocene) age. The palynology suggests a vegetation cover dominated by swamp cypress, ericaceous, cupressaceous and coniferous trees, a diverse assemblage of tree types and assorted shrubs. Pollen zones 87/1-1 to 87/1-4 (i.e. the bulk of the biogenic sediment sequence) are characterised by their diverse assemblages dominated by swamp cypress, cypresses, heathers and pine. The landscape must have been magnificent and the vegetation cover diverse and, in the autumn, very colourful with an affinity to the modern vegetation of the swamps of eastern North America. The assemblages suggest that frosts must have been negligible and the climate (at least in the gorge at Pollnahallia) was warm and wet. A checklist of the taxa on the pollen diagrams is provided in this guide.

Zone 87/1-4 sees a decrease in the swamp cypress cover associated with a sedimentological change at 12.55 m and subsequently, in pab 87/1-5 there is a marked assemblage change associated with the facies change to laminated clays with sand horizons (at 11.00m in borehole 87/1). The change involves an increase in taxa indicating climatic deterioration (e.g. the rising values of Ericaceae and *Juniperus*) and the disappearance of a number of the thermophilous taxa. The lithological and palynological changes suggest that the top of the organic sedimentation may represent climatic deterioration at the end of the Pliocene and the beginning of the Pleistocene (see correlation below).

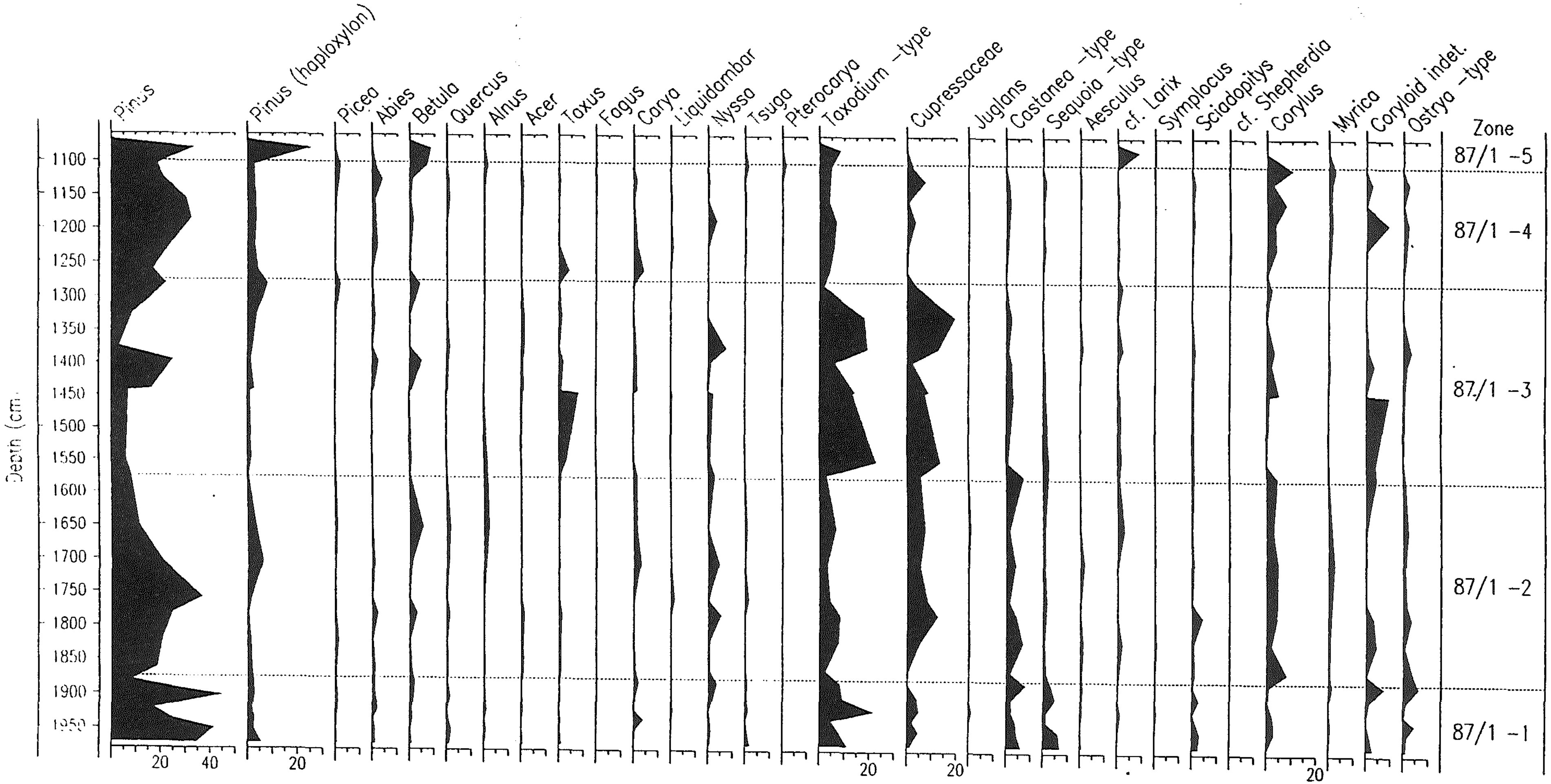
One striking element in the Pollnahallia pollen diagram is the exotic nature of some of the flora. Many of the taxa recorded are no longer native to Europe and indeed some have a distinctly disjunct modern distribution occurring only in North America and Asia. Figure P7 illustrates this point and highlights taxa from Pollnahallia and shows their modern distributions. The gradual disappearance of genera from NW Europe shown on this figure is discussed at length in Coxon and Waldren (1997) :

" ...the data show clearly a progressive restriction of certain components of a formerly more widespread northern temperate flora. Many of the continuously present genera have a wide northern temperate distribution, although they are represented by several species, often with sympatric distributions. Those genera which have been eliminated by successive glaciations have modern distributions in North America, central East Asia, or are disjunct between both of these areas. Apart from a few mainly tropical genera, most of which were eliminated from NW Europe at the onset of the Pleistocene, the flora has consistently been northern-temperate. There are, therefore, clear biogeographic trends in the Pleistocene record.

Reasons for the decline in the number of genera present are less easy to determine, but it seems clear that the more-ancient fossil tree genera have not been replaced by more recent colonists, and this probably also holds true at the species level. It may be that continuously present species have undergone speciation which usurped the Pliocene-Early Pleistocene element, but this is unlikely- many of the former are represented in Europe by few species (e.g. *Abies, Carpinus, Taxus, Corylus, Tilia*). Huntley (1993) has argued that the evolution of vicariant species (i.e. sympatric, closely related taxa) in southern Europe has occurred, following glacial retreat of ancestral taxa to different refugia in southern Europe, and this may explain the higher number of species to genera in Europe compared to temperate western or eastern North America. However, none of the vicariant taxa mentioned by Huntley (in *Quercus, Abies* and *Pinus*) extend as far as NW Europe: only two *Quercus* and one *Pinus* species occur. It seems more likely that the temperate forest vegetation of NW Europe, and possibly Europe as a whole, was considerably more diverse in species in the Late Pliocene/ Early Pleistocene than today. The small size of genera from the Pliocene-Early Pleistocene element suggests that either A. these genera have genetic

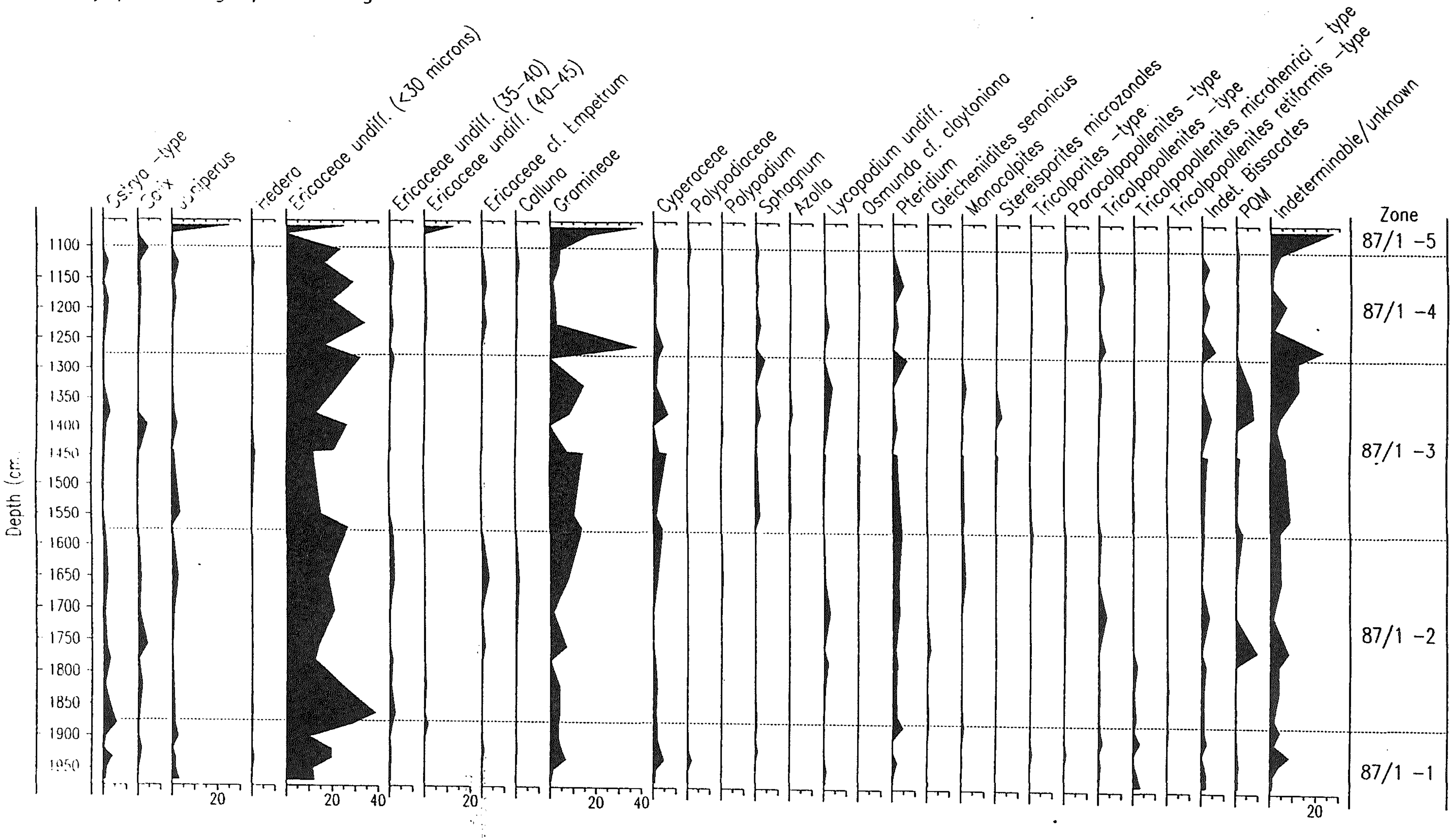
Pollnahallia borehole 87/1

summary percentage pollen diagram of selected taxa



Pollnahallia borehole 87/1

summary percentage pollen diagram of selected taxa



limits on speciation, which may affect their overall variation and hence ability to cope with adverse conditions. A second possibility **B**, is that these genera were formerly more species-rich and that widespread extinction in the Pleistocene has restricted the size of the genera. This seems much less likely, as the fossil taxa are similar if not identical with extant taxa with more restricted modern distributions."

Biostratigraphic correlation

A full account of the biostratigraphy will appear in due course and a summary of the correlation is made in Coxon and Coxon, 1997. The important biostratigraphical elements of the pollen diagram include the presence of typical Late Tertiary taxa; e.g. *Sequoia, Taxodium, Nyssa, Liquidambar, Castanea, Ostrya, Juglans, Sciadopitys, Carya* and *Pterocarya* . Such taxa are frequently found in Pliocene deposits in the Netherlands (Zagwijn 1960) and this, the absence of pre-Pliocene marker taxa and the apparent climatic deterioration recorded in the upper part of the sequence allows a probable correlation to be made to the Reuverian of the Netherlands (Coxon 1993), possibly Reuverian C.

The age of the limestone landscape

(from Coxon and Coxon 1997)

"The geomorphological and sedimentological investigations suggest that a complex system of gorges, depressions and enclosed passages in limestone exists in the area around Pollnahallia and Kilwullaun, and that Pliocene sediment lies both in the base of a gorge at Pollnahallia and in shallow surface depressions on the limestone at Pollnahallia and Kilwullaun. This finding is of considerable geomorphological significance.

Firstly, the approximate dating of the organic-rich silt and clay by biostratigraphical means to the Late Pliocene or Early Pleistocene implies that the limestone surface underlying the deposits is at least of this age. Thus karstification of the limestone of the area must have taken place before the Late Tertiary.

However, karstification of Carboniferous limestone during the Tertiary period has already been established at a number of sites, as outlined in the introduction, and what is unique about the Pollnahallia / Kilwullaun site is that unlike the other Irish karst infills, it represents not just the localised preservation of biogenic Pliocene material in karstic depressions but a more widespread cover of Tertiary sediments suggesting the preservation of a surface that is Pliocene or pre-Pliocene in age.

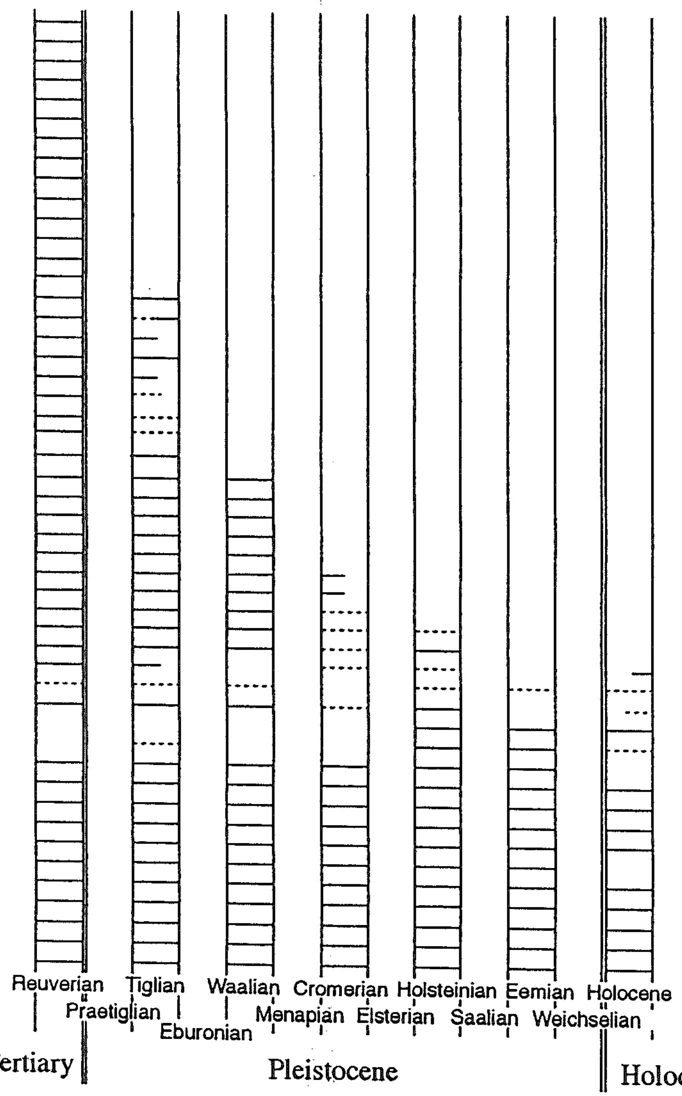
Several old, complex, partially unblocked cave passages of presumed preglacial or interglacial age occur on the western Irish limestone lowlands (e.g. Ballyglunin Cave, 13 km east-south-east of Pollnahallia, described by Drew (1973), and the Gort river caves in south county Galway - see Farr, 1984). The dating of the sand-filled cave passage at Pollnahallia to pre-Pleistocene times gives strength to the argument for a preglacial origin of other passages. Drew (1973) suggests five stages in the development of Ballyglunin cave, placing its origin at least prior to the last glacial, and possibly much earlier, and a pre-glacial origin is clearly a possibility.

Furthermore, the fact that surface as well as subterranean features at Pollnahallia appear to have survived the Pleistocene glaciations gives rise to the possibility that other surface landscape features of the western Irish limestone lowlands may retain a preglacial influence. In this context, the origin of turloughs is of interest.

The turloughs are one of the most distinctive features of the limestone lowland, but their origin is not yet firmly established. Williams (1964) envisaged them as glacial erosional and depositional features - many of them simply hollows in the glacial drift - which developed a karstic function postglacially. However, more recent work (Coxon 1986) suggests that although the turlough shape and extent is often determined by glacial deposition, actual bedrock hollows are present, and an alternative possibility to a glacial erosional origin is a solutional one. The depressions may originally have been single closed depressions such as dolines or cockpits, or more complex forms such as uvalas, which were subsequently modified by glacial erosion and deposition. Given that a well-developed network of closed depressions has not had time to develop in karstic areas of Ireland since the last glaciation, interglacial solutional processes may not have been prolonged enough to do more than reactivate and modify existing karst landforms, so if karstic processes are to be invoked, this is likely to place the origin of turloughs in preglacial time. The evidence for a remnant

Figure P7. The Pleistocene range and modern distribution of selected taxa from the Pleistocene of the Netherlands. (after van der Hammen *et al.*, 1971 and Tallis, 1990, from Coxon and Waldren, 1997) Taxa found at Pollnahallia are marked with a *.

Range of Genera in Pleistocene Interglacials of NW Europe (Netherlands)



	Genus	Modern Distribution	Spp. per genus	Disjunct genus	Habit	Modern European spp.
1	*Aesculus* *	N. America; S.E. Europe (?); E. Asia	15	Y	tree	1
2	*Diospyros*	N. & S. America; Africa; Asia	475	?	tree/shrub	0
3	*Elaeagnus*	N. America; Asia	45	Y	shrub	0
4	*Epipremnum*	S.E. Asia; W. Pacific	8	N	climber	0
5	*Halesia*	China; Eastern N. America	4 or 5	Y	shrub	0
6	*Karwinskia*	S.W. USA; Caribbean; S. America	14	N	tree/shrub	0
7	*Liquidambar* *	N. America; E. & W. Asia	4	Y	tree	0
8	*Meliosma*	Trop. America; Trop. & temp. Asia	20-25	Y	tree	0
9	*Pistacia*	Mediterranean; W., C. & E. Asia (dis); C. America	9	Y	tree/shrub	3
10	*Pseudolarix*	E China	1	N	tree	0
11	*Stewartia*	Eastern N. America; E. Asia	9	Y	tree	0
12	*Styrax*	Americas; Asia; S.E. Europe	100	Y	tree/shrub	1
13	*Zelkova*	Crete; W. & E. Asia; Japan; Taiwan	5	(Y)	tree	0
14	*Nyssa* *	Eastern N. America; E. Asia	5	Y	tree/shrub	0
15	*Actinidia*	E. Asia	40	N	climber	0
16	*Euryale*	N. India; China; Japan; Taiwan	1	Y	aquatic	0
17	*Liriodendron* *	N. America; Indo-China.	2	Y	tree	0
18	*Magnolia*	N. America; C. & E. Asia	~125	Y	tree/shrub	0
19	*Proserpinaca*	N & C America	5	N	aquatic herb	0
20	*Taxodium* *	N. America	3	N	tree	0
21	*Sciadopitys* *	Japan	1	N	tree	0
22	*Sequoia* *	N. America	1	N	tree	0
23	*Phellodendron*	E. Asia	10	N	tree	0
24	*Castanea* *	N. Temperate (except W. USA)	12	N	tree	1
25	*Ostrya* *	America; Europe; Asia	9	Y	tree	1
26	*Juglans* *	N. & S. America; S.E. Europe; Asia	15	Y	tree	1
27	*Tsuga* *	W. & E. N. America; Himalaya; China; Japan	9 or 10	Y	tree	0
28	*Carya* *	E. USA; C. & S.E. China	25	Y	tree	0
29	*Parthenocissus*	N. America; E. Asia; Himalaya	10	Y	climber	0
30	*Celtis*	Tropics; S. Europe; N. America	70	?	tree	4
31	*Eucommia*	C. China	1	N	tree	0
32	*Pterocarya* *	Caucasus to E. & S.E. Asia	10	N	tree	0
33	*Staphylea*	N. temperate	11	N	shrub	1
34	*Fagus* *	N. temperate	10	N	tree	1
35	*Ilex* *	Cosmopolitan	400	N	tree/shrub	2
36	*Vitis* *	N. hemisphere	65	N	shrub/climber	1
37	*Buxus*	Eurasia; Tropical & S. Africa; C. America	70	?	shrub/tree	2
38	*Taxus* *	N. Temperate; C. Malesia	2 or 3	N (?)	tree	1
39	*Abies* *	N. Hemisphere	50	N	tree	5
40	*Alnus* *	N. Hemisphere; Andes	35	N	tree/shrub	5
41	*Betula* *	N. Hemisphere	60	N	tree/shrub	4
42	*Carpinus* *	Europe; N. & C. America; E. Asia	35	Y?	tree	2
43	*Corylus* *	N. temperate zone	15	N	tree/shrub	3
44	*Picea* *	N. Hemisphere	35	N	tree	2
45	*Pinus* *	N. Hemisphere	110	N	tree	11
46	*Quercus* *	Widespread	600	N	tree/shrub	24
47	*Salix* *	Cosmopolitan except Australia	300	N	tree/shrub	65
48	*Tilia*	N. America; Europe; Asia	45	N?	tree	5
49	*Ulmus*	N. temperate	45	N	tree	6?

pre-Pleistocene landsurface at Pollnahallia, implying that there has been virtually no bedrock erosion in this area since the Pliocene, is clearly of great significance in this context. Equally, rather than having a postglacial origin, the lines of high permeability in the aquifer associated with the turloughs may represent the re-use of remnants of a subterranean drainage network created by extensive solution during the Tertiary, which is partially clogged by glacial drift and therefore inefficient at coping with high flows, resulting in the expulsion of water under pressure and surface ponding in the turloughs.

It is possible that turloughs are polygenetic features: some may be glacial hollows with postglacial flow routes, while others may have a more complex history, involving earlier phases of solution. The importance of the Pollnahallia site lies in the fact that it adds credibility to the hypothesis of a long, complex history for these characteristic landforms of the western Irish limestone lowlands.

The finding that the limestone surface over a considerable area (at least 3 km^2 and probably a considerably larger area) was already in its current form by the Early Pleistocene not only provides evidence of the landscape configuration at this time, but also brings into question the efficacy of the Pleistocene glaciations in modifying all of the elements of the Irish landscape. The glacial episode resulting in the deposition of the Headford till is possibly just the most recent in a sequence of glacial events to have affected the area over the last two million years, yet relatively shallow depressions contain organic clays and silt that have apparently survived these events. In addition to depositing till, the ice has apparently had a streamlining effect on local rock protuberances, and it has transported sizeable limestone rafts, but it appears to have eroded very little bedrock in this low-lying area of Galway. Identifying such selective glacial modification of the landscape is important when considering the age and development of Ireland's surface.

While any comment on the age of geomorphological features beyond the few square kilometres where the Pollnahallia organic silt and clay is found must be highly speculative, the fact that a fragment of Pliocene or pre-Pliocene surface has survived in this area gives rise to the possibility that the landscape retains some influences from this early period of karstification over a wider area.

In this latter respect it is interesting to compare the region around Pollnahallia with that of southern Derbyshire where the limestone surface contains numerous sand-filled karst depressions or Pocket Deposits (Ford and King 1969, Cox and Harrison 1979, Cox and Bridge 1977 and Harrison and Adlam 1984). Some of the Derbyshire Pocket Deposits contain organic materials dated to the Miocene -Pliocene boundary and are, like Pollnahallia, infilled depressions within limestone that contain sand, clay and organic deposits. The Derbyshire Pocket Deposits are believed to have had a complex history forming as a sheet of fluviatile sediments (fans) laid down in front of a retreating (Triassic) escarpment (Ford and King 1969 and Ford 1972). Contemporaneous and ensuing collapse of the underlying limestone lowered and preserved patches of the fan sediments in protected hollows which were subsequently capped by glacial sediments. The Pliocene sediments at Pollnahallia also appear to have been preserved within karstic depressions in the limestone surface and as such they may have, in part, a similar history to the Miocene-Pliocene fills of Derbyshire. Indeed, Ford and King (1969, page 65) suggest the existence of gorges within the limestone allowing subaerial water courses to fill with sediment as at Pollnahallia. Such similarity, both in age and in geomorphological setting, suggests that widespread mantles of weathered residues draped the limestone surfaces of parts of the British Isles by the Late Tertiary and were preserved within depressions in the limestone or across the surface of the bedrock (as at Pollnahallia) where subsequent erosion was ineffectual."

Conclusions

(from Coxon and Coxon, 1997)

"The dating of the organic sediments at Pollnahallia by biostratigraphical means to the Late Pliocene is of particular interest because these deposits are found not only in gorges and deep depressions but also in shallow depressions in the limestone surface over an area of approximately three square kilometres, indicating the preservation of a Pliocene or pre-Pliocene land surface in this area. Laminated silts that overlie the organic sediments grade up into widespread sand deposits and the latter appear to represent environmental change, possibly climatic deterioration, at the onset of the Pleistocene. Such a change in environmental conditions led to the mobilisation of weathered materials which can be identified in the aeolian silica sand deposits infilling the gorge at Pollnahallia. The general geomorphological context of the Pliocene sediments, their associated Pleistocene cover and examples of the borehole evidence have been schematically summarised on Figure 8.

In addition to giving an exciting glimpse of the Tertiary landscape, the site has provided important evidence concerning Pleistocene glacial activity in the locality, as the existence of Tertiary sediments at the ground surface implies that minimal glacial erosion has taken place in this area. This opens the possibility that the limestone landscape over a wider area of the western Irish limestone lowlands may retain influences from Tertiary karstification. The discovery of this Tertiary palaeosurface certainly adds credence to the theory that Ireland's surface retains many geomorphological elements inherited from the Tertiary Period."

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Auclogeen Spring (Corrandulla)

Locality 2.4

David Drew

This spring (see Drew, Coxon and Coxon, this Field Guide) forms the headwaters of the Cregg River. The waters are in part derived from sinks in the Abbert River some 12 km to the east. The spring emerges from a low limestone cliff and then flows over bog to Lough Corrib. It is likely that the spring is located on a former shoreline of Lough Corrib as lacustrine marls underlie the bog to the west of the spring. The spring is used as a group scheme supply for the surrounding area.

Marl deposit, Curraghmore Bog

Locality 2.5

Catherine Delaney

The Curraghmore marl deposit underlies the raised bog lying between the eastern shore of Lough Corrib and Claregalway (Figure 1). The deposit is thought to have formed during the Holocene when the southern part of Lough Corrib extended further eastwards. Gradual infilling of this part of the basin has resulted in the deposition of a thick wedge of marl (calcareous lacustrine sediment), overlying proglacial lacustrine clays. A transect of boreholes across the deposit shows that the lake sediments lie within a basin which deepens from east to west, with the marl deposit reaching a minimum depth of 9 m towards the centre of the deposit, and probably much deeper towards the modern lake. The depth of the basin does not vary uniformly, however, and highs within the basin were found immediately south of both the Cregg and Clare rivers.

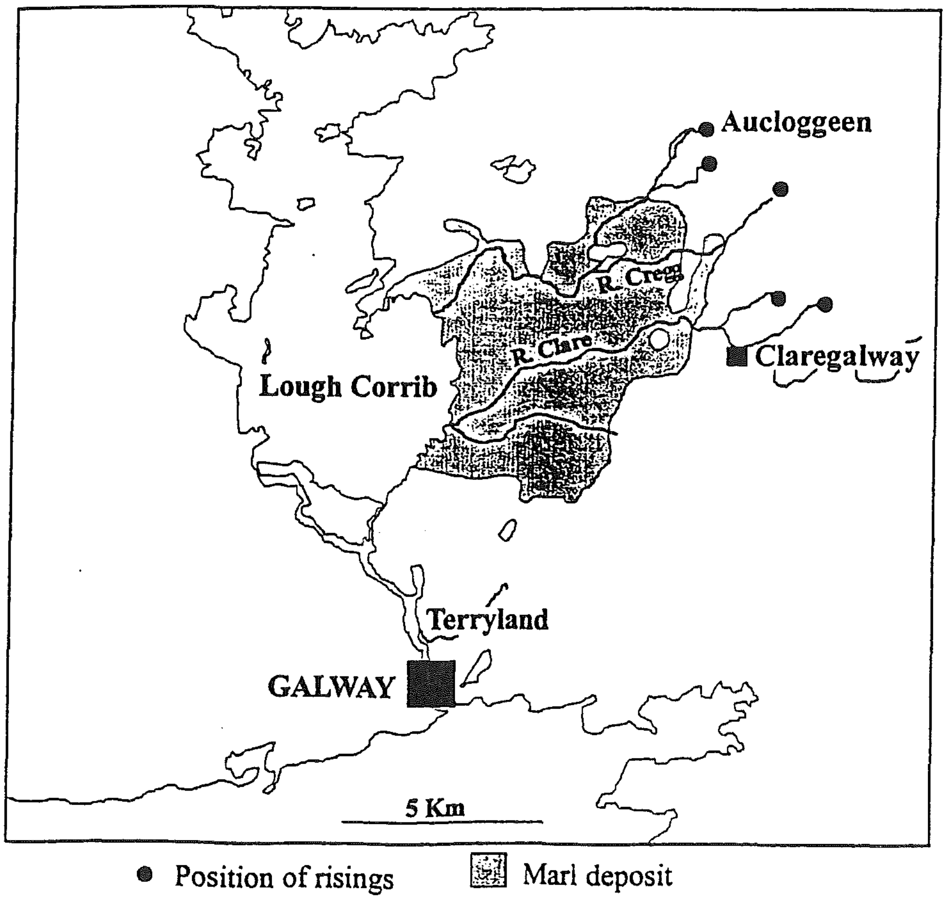

Figure 1. Extent of marl deposit underlying Curraghmore Bog, Lough Corrib

Two series of borehole transects N-S and E-W across the deposit has revealed some variability in the marl. The marl sediment ranges in size from silty clay through to silty sand, the particle size range reflecting the composition of the marl. S.E.M. work showed that the finer grained silts and clays are composed of crystalline material, thought to have formed due to a combination of bio-induced or physio-chemical precipitation. Sand-sized material is composed entirely of fragments of the calcareous outer coating which forms on Charophyte (Stonewort) stems. The calcified reproductive cells of these plants (oogonia) are also preserved. As Charophyte growth is confined to the littoral zone, the presence of untransported fragments of this material within core sediments is thought to be indicative of shallow water at the lake edge.

All boreholes showed a gradual coarsening upwards trend in particle size, caused by a gradual increase in Charophyte material upwards through the cores. This is as expected if the basin had infilled without any fluctuations in water level. However, many boreholes also contained discrete phases of rapid coarsening upwards (CU) of particle size. These CU sequences are between 0.1 and 0.5 m thick, and show a rapid change from silt-sized upwards into Charophyte-rich sandy marl, before a sudden return to fine grained sediments. In the northern part of the basin, three such CU sequences were seen in the upper part of each core. CU sequences were less common in the southern part of the basin, although single phases were detected in many cores.

The cause of this sudden increase in Charophyte material, followed by a return to a precipitation-dominated regime is not entirely clear. The most likely explanation is that the sediments are recording expansions and contractions in the plant population due to either variation in lake water level or to nutrient availability. Of these two possibilities, variation in water level is more likely, as some of the Charophyte material is found at depths of nearly 5 m in the marl, beyond the normal depth range of these plants. A drop in water level would have allowed the plant to expand outwards into the basin, a return to a higher water level would then have halted plant growth and caused a return to sedimentation by precipitation of calcium carbonate.

It is unclear how long the fluctuations in water level lasted, as the sediment has not been dated, fluctuations could have been seasonal or reflect a considerably longer time span. However, the rapid coarsening, followed by the abrupt return to fine-grained sediments seen in many boreholes indicates that changes in lake water level were relatively abrupt, and are unlikely to reflect long-term changes in climate. It seems more likely that changes in the drainage into and out of Holocene Lough Corrib caused the fluctuations.

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