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A STUDY OF SOME IRISH LOWER CARBONIFEROUS FISH MICROVERTEBRATES

A thesis submitted for the degree of Doctor in Philosophy

to the University of Dublin, Trinity College

VOLUME 1

by

Margaret Duncan

October 1999

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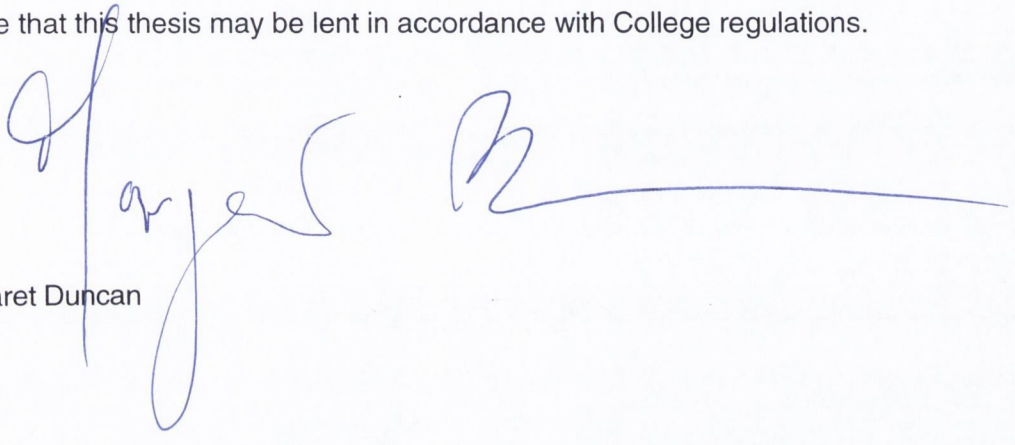

Margaret Duncan

A STUDY OF SOME IRISH LOWER CARBONIFEROUS FISH MICROVERTEBRATES

by Margaret E. Duncan

ABSTRACT

Fish microvertebrates (often referred to as ichthyoliths) are a common, but largely unrecorded, component of the faunas of the Irish Lower Carboniferous. Material from four study areas within the Dinantian (Carboniferous) of Ireland were studied with the aims of describing and illustrating the fish microvertebrates obtained from acid insoluble residues of limestones. The four study areas were Lyraun Cove, Hook Head, County Wexford (mixed carbonate/siliciclastic inner shelf; Tournaisian, Hastarian (*Polygnathus inornatus* conodont Biozone)); Urlingford, County Kilkenny (carbonate shelf, deeper, middle to outer part; Tournaisian, Ivorian (*Polygnathus mehli* conodont Biozone)); Kilbride, County Meath (Carbonate shelf, middle part; Ivorian, probably Freyrian (*Polygnathus mehli* conodont Biozone)); and Moyola River, Draperstown, County Londonderry (sabhka/tidal flat; probably Tournaisian, Freyrian (Pu miospore Biozone)).

The fish microvertebrates, commonly less than 2mm in overall dimension, are made up of disarticulated teeth and scales/denticles of chondrichthyan fish together with teeth, scales/denticles and bone fragments of osteichthyan and acanthodian fish. The fish microvertebrates are described using a form of open nomenclature at generic level. They are illustrated by computer generated plates from original photographs taken using the scanning electron microscope. There are many taxonomic problems inherent in describing disarticulated material in terms of the Linnean Binomial System.

At the taxonomic level achieved in identification, the fish microvertebrate assemblages appear to be stratigraphically long ranging and therefore have limited application in biostratigraphy. Most of the taxa, however, appear to be geographically widespread.

At the taxonomic level achieved in identification, the fish microvertebrate assemblages appear to be relatively insensitive to facies. The abundance of chondrichthyan, osteichthyan and acanthodian fish appear to increase from the deeper part of the carbonate shelf to the middle part of the carbonate shelf (where the greatest diversity of the chondrichthyan remains occur) and decease in towards the mixed carbonate/siliciclastic inner shelf and sabhka/tidal flat environments. Sarcopterygian remains were only recovered from the sabhka/tidal flat environment.

Enigmatic phosphatic elements referred to as "bars" which are of uncertain affinity, but probably not of vertebrate origin, follow a similar pattern of abundance and diversity to those of the chondrichthyan fish.

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The list of people who have contributed their time and encouragement to my project (and to me) is vast so to those I missed out, my apologies.

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CHAPTER 1: INTRODUCTION

1.1 INTRODUCTION

Almost every residue from acid etching of Irish Dinantian (Lower Carboniferous) limestones yields fish microvertebrates. However, these microfossils are not documented in the literature in the same way as the invertebrate faunas are; even where macrovertebrate faunas are documented, they usually appear at the end of the faunal listings in the form of "fish material/teeth/scales". This treatment is not confined to the Carboniferous Period in Ireland but to all geological Systems; the paucity of published evidence of fish microvertebrates and macrovertebrates in the Carboniferous rocks of Ireland cannot be taken to be evidence of their real abundances.

Fish microvertebrates have long been neglected, especially by biostratigraphers; this situation is, however, beginning to change. However, until the problems relating to nomenclature and taxonomy of fish microvertebrates are resolved, the full potential of fish microvertebrate studies in biostratigraphy and palaeoenvironmental analysis will not be realized.

1.2 DESCRIPTION OF FISH MICROVERTEBRATES

Fish microvertebrates are microscopic fish skeletal remains consisting mainly of phosphatic teeth, scale and bone fragments usually less than 2mm in overall dimension. This size limit is arbitrary and is not rigid: many slightly larger teeth and scales are described and included within the realm of fish microvertebrates rather than fish macrovertebrates whose dimensions are usually recorded in terms of centimetres rather than millimetres. In many cases fish microvertebrates provide the most ancient record of vertebrate taxa. This is not surprising since the preservation of more or less complete fossils of fish is unusual.

The term "ichthyolith" was first used to describe any fish remains (see section 1.6) but has now become incorporated into modern literature in a different, more restricted sense: although the literal translation is "fish stone", it is now used to refer to fish microvertebrates. The term "microvertebrate" is also in common usage and interchangeable with the term "ichthyolith". The term "fish microvertebrates" is preferred because it implies microscopic material of fish origin.

It is rare for fish microvertebrates to be visible to the naked eye on bedding planes, though there are well known occurrences of conodonts on bedding planes as well as accumulations of slightly larger fish teeth and scales. Indeed, material from one study

area (Moyola River) within this project falls within this category. It is more normal for fish microvertebrates to be recovered from acid insoluble residues.

1.3 AIMS OF THE STUDY

The aims of this study are three-fold:

- to describe and illustrate fish microvertebrates from Carboniferous (Dinantian) rocks in Ireland and to establish their taxonomic status

- to investigate the possibility of using fish microvertebrate assemblages for biostratigraphy

- to assess the feasibility of using such assemblages or individual genera as palaeoenvironmental indicators.

The majority of palaeoichthyologists world-wide have a zoological or macrovertebrate palaeontological background and, with a few notable exceptions, work principally on taxonomic problems. In most studies palaeoecological analysis has been of secondary importance; many of the palaeoenvironmental inferences in the literature are based on inadequate geological information. Therefore, the overall aim of this project is to examine fish microvertebrates in a geological context.

1.4 IRELAND AND THE CARBONIFEROUS SYSTEM

This section is a slightly expanded version of material in Sevastopulo and Wyse Jackson (1999, in press).

In Ireland, as in other parts of northwest Europe, the Carboniferous may be conveniently split into two divisions of generally contrasting lithofacies. The lower (Dinantian) division is dominated by carbonate rocks - the familiar Carboniferous Limestone of Ireland and Britain; the upper division (Silesian) consists almost exclusively of terrigenous rocks. The Silesian has been divided into the Namurian, Westphalian and Stephanian Series. However, international agreement has now been reached that the Carboniferous will in future, be divided into two divisions, as yet unnamed, whose mutual boundary falls within the Namurian Series of north-west Europe and at the Mississippian/Pennsylvanian boundary in North America. The two

Figure 1.1 Chronostratigrahic units and correlations between Ireland, Britain and the USA. Those units in bold type are those referred to in this thesis.
(compiled from George *et. al.* (1976), Riley (1993), Lees (1997) & Sevastopulo (1999 pers. comm.))

divisions are likely to have the status of Sub-systems. The base of the Carboniferous System has been defined in a stratotype section at La Serre, Montagne Noire, France at a level coinciding with the base of the *Siphonodella sulcata* conodont Biozone. This biostratigraphical datum cannot be recognized in Ireland because the rocks around the Devonian/Carboniferous boundary are of unsuitable facies. However, the boundary between the two miospore zones, the LN and VI Biozones, which has been identified in many sections in the south of the country, correlates very closely, possibly even exactly with the base of the Carboniferous.

An internationally applicable set of Carboniferous Series and Stages has yet to be agreed. Originally stages proposed by George *et al.* (1976) for Britain and Ireland (Figure 1.1) were used as a framework for a description of Dinantian stratigraphy. However, it is now apparent that the base of the Chadian Stage cannot be identified with confidence away from the stratotype section in Lancashire, England. The base of the Chadian was defined in the Craven Basin at the first lithological change below the reported entry of the foraminifera *Eoparastaffella* at the junction of the Horrocksford Bed and the overlying Bankfield East Beds of the Chatburn Limestone Group. However, this record of the earliest occurrence of *Eoparastaffella* has not been substantiated by later work (Riley, 1993). The first occurrence of *Eoparastaffella* appears to be some 300m higher in the section.

As a consequence neither the Courceyan nor the Chadian Stage can be used with precision. For this reason it is proposed to use the Tournaisian Series, comprising the Hastarian and Ivorian Stages as defined in Belgium, for the early part of the Dinantian in this work. The Hastarian and Ivorian were conceived as subdivisions of the Tournaisian Series. The Molinacian Stage in Belgium, which, although it was proposed to represent the lower part of the Viséan, actually includes a part of the upper Tournaisian (Lees, 1997). This leads to some problems with the concept of the Ivorian. The latter, following normal stratigraphical convention, should extend from its defined base to the base of the next youngest stage (i.e. Molinacian). Lees (1997) has referred to the pre-Viséan Molinacian as Freyrian, but this term has not been formally proposed or accepted. In this account Ivorian is used as originally intended, that is to correspond to the Upper Tournaisian of former literature. Freyrian is used as a useful, informal term to signify the latest Upper Tournaisian. The Arundian to Brigantian Stages are retained but the Viséan part of the former Chadian Stage is informally termed "Lower Viséan". It should be noted that the "Lower Viséan" in this sense has a more restricted stratigraphical range than the same term formerly in use in Belgium, where the notation V_1 would have included the early part of the Arundian Stage. "Lower Viséan" as used here is equivalent to the informal term "Late Chadian" suggested by Riley (1993). Sevastopulo (pers. comm. 1999) has decided to use the term "Lower Viséan" in descriptions of Carboniferous Stratigraphy in the forthcoming *A Geology of Ireland*

(Holland, in press). Chronostratigraphic correlations can be seen in Figure 1.1. Biostratigraphic age determinations in this study are expressed in terms of conodont or miospore Biozones where appropriate (Figure 10.1.).

1.5 HISTORY OF PREVIOUS WORK ON CARBONIFEROUS 'FISH MATERIAL' IN IRELAND

During the nineteenth century systematic detailed topographical and geological mapping of Ireland was carried out. Palaeontologists as well as geologists were employed in these projects and a wealth of invertebrate fossil fauna was well documented by officers of the Geological Survey such as W.H. Baily. At least seventy-eight references to the field observation of fish material from beds of Carboniferous age are contained in the *Memoirs of the Geological Survey of Ireland* published on various dates towards the end of that century; these Memoirs accompany Sheets 1-205 of the 1":1 mile survey covering the thirty-two counties of Ireland. However, although some specimens were named, many were referred to only as 'fish remains' or 'fish debris' (see Appendix III).

Richard Griffith (1784-1878), later Sir Richard Griffith, who was initially employed by the Royal Dublin Society to map coalfields and subsequently by the Valuations Office, started collecting fossil material as part of his compilation of a geological map of Ireland. Utilizing his position as Commissioner for the General Valuation of Rateable Property (Davies and Mollan, 1980) (Wyse Jackson, 1997) he encouraged his employees to collect geological information during their valuation surveys. As a consequence he built up a large collection of fossils (including fish) many of which were later described by Frederick M'Coy (1844). The collection was later donated to the Royal Dublin Society (now housed in the National Museum of Ireland, Dublin) and to Trinity College Dublin. Contemporary catalogues of the material (Wyse Jackson and Monaghan, 1994) show that although some of the fish specimens from Griffith's collection appear to have become wrongly identified over time, some of the specimens described by M'Coy can still be found within the National Museum of Ireland, while other material best described as 'non-identified fish material' is found within the collections of the Geological Museum in Trinity College.

Perhaps the best known collector of fossil fish, disarticulated and articulated, from that period in Ireland was William Willoughby Cole (later Lord Cole, later the 3rd Earl of Enniskillen) (1807-1886), whose name has become linked to the internationally known 'Armagh Collection'. He, together with Philip de Malpas Grey Egerton (later Sir Philip Egerton Bart., M.P., F.R.S.) (1806-1881), visited Neuchâtel in 1830 and met Louis Agassiz (Gardiner and Mason, 1974). Agassiz influenced them into becoming collectors of fossil fish and they decided to form distinct cabinets and share counter-part halves of

unique and valuable specimens. These early collections were later used by Agassiz during the preparation of *Recherches sur les Poissons Fossiles* (1833-44) but Cole himself never published on his collections. Agassiz visited Ireland in 1834 and named fossil material in the collection of another famous collector, Admiral Theobald Jones M.P. Jones continued his collecting from the Armagh quarries following Agassiz's visit and in fact supplied much material to Griffith, Enniskillen and others (Monaghan, pers. comm., 1997). Jones also presented material to the Geological Society in 1841, 1843, 1851 and 1852 (Cleevely, 1983). Details of the quarries where fish material was collected ca.1871 is given in Geological Survey of Ireland Memoir-Sheet 47.

In 1881 the Earl of Enniskillen offered his collection to the British Museum. Although financial arrangements were agreed only in 1883, this collection of 9,658 specimens (mostly fish material) was dispatched late in 1882. However the consignment was hijacked and one crate of fossils dumped into the River Dee, close to the Chester and Holyhead railway bridge. Many of the specimens were later recovered, but seventeen were lost (Gardiner and Mason, 1974).

On the death of Egerton in 1881, his Trustees offered the British Museum his collection of over 7,000 specimens, 5,500 of which were fish; of these at least 200 were types figured by Agassiz and others (Egerton, 1869)

In 1883, James W. Davis published a comprehensive monograph *On the fossil fishes of the Carboniferous Limestone series of Great Britain.* The compilation of locality lists and many of the subjects of the plates (particularly those related to Armagh) are based on "The Collection of Lord Enniskillen and M. Agassiz's Poissons Fossiles" (Davis, 1883).

Many specimens from the Armagh quarries are housed in various institutions in Ireland (see Appendix III) and although in many instances a lot of this material is catalogued without taxonomic identification, much was named in the last century and early in this century.

In the early part of the twentieth century, Louis B. Smyth, while working as a Lecturer in Palaeontology in the University of Dublin, collected not only invertebrate faunas from his study areas but also vertebrate material. While he identified some of the macro-vertebrate material and named the fossils within his faunal lists, much of the material now reposited in the Geological Museum in Trinity College Dublin is described as 'fish debris' from the area of Hook Head in Co. Wexford. Much of the material so labelled is, in fact, phosphatic nodules and pellets, which Smyth recorded in his papers (Smyth, 1930).

Trawling through literature published since the mid-nineteenth century reveals a dearth of published documentation relating to vertebrate fossil material in Ireland. The following is a list of publications additional to the *Memoirs of the Geological Survey* which refer to, or are based on Carboniferous fossil fish from Ireland:

1848	F. M'Coy	On some fossil fishes of the Carboniferous period. (McCoy, F., 1848)
1883	J.W. Davis	On the fossil fishes of the Carboniferous system of Great Britain. (Davis, J.W., 1883)
1889	J.W. Davis	Fossil Fish remains from Carboniferous shales at Cultra, Co. Down, Ireland. (Davis, J.W., 1889)
1892	J.W. Davis	On the fossil fish remains of the Coal Measures of the British Isles, Part 1 Pleuracanthidae. (Davis, J.W., 1892)
1893	R.H. Traquair	On a new Palaeoniscoid fish *Myriolepis hibernicus* sp. nov. from the Coal Measures of Co. Kilkenny. (Traquair, R.H., 1893)
1937	J.A. Moy-Thomas	The Carboniferous coelacanth fishes of Great Britain and Ireland. (Moy-Thomas, J.A., 1937)
1972	A. Brandon	The upper Viséan and Namurian shales of the Doagh outlier, Fermanagh. (Brandon, A., 1972)
1974	R.R. Horne	The lithostratigraphy of Late Silurian to Early Carboniferous and the Dingle Peninsula, Co. Kerry. (Horne, R.R., 1974)
1974	B.G. Gardiner & T.R. Mason	On the occurrence of the palaeoniscoid fish *Elonichthys serratus* in the Viséan of Fermanagh with a note on the Enniskillen and Egerton Collections. (Gardiner, B.G. and Mason, T.R., 1974)
1998	H. Falcon-Lang	The impact of wildfire on an Early Carboniferous coastal environment, North Mayo, Ireland. (Falcon-Lang, H., 1998)

On the specific subject of Carboniferous Fish Microvertebrates in Ireland, no published literature was discovered, though two undergraduate laboratory projects (University of Dublin (Harvey, 1980) (Lewis, 1981)) during the 1980s touched briefly on the subject, with a third in the later 1990's (Murray, 1997). This is somewhat surprising as many samples of Irish Carboniferous limestones have been dissolved with the aim of extracting conodonts for biostratigraphic purposes. Many of the samples also contained fish microvertebrate remains. The common occurrence of fish microvertebrates in conodont residues was one of the reasons for setting up this research project.

1.6 HISTORY OF RESEARCH ON LOWER CARBONIFEROUS FISH MICROVERTEBRATES

To give a background to research and publications on Carboniferous Fish Microvertebrates it is necessary to refer to some of the more notable works which predominantly feature macrovertebrates and make minor references to fish microvertebrates. The distinction between macrovertebrates and microvertebrates did not become significant until the latter part of this century with the realization that fish microvertebrates isolated from insoluble residues after acid digestion of limestones might prove useful biostratigraphic tools.

The term 'Pisces' and the name 'Agassiz' are almost synonymous in palaeoichthyology: Louis **Agassiz**'s *Recherches sur les Poissons Fossiles* (1833-1844) (Agassiz, 1833-1844) is the work that formed the basis of all research in the field during the mid-nineteenth century and is the platform on which twentieth century research has been built. However, finds of fossil fish were recorded before Agassiz's studies; it is interesting to note that first discoveries of early Palaeozoic fossil fish were made about the same time in both Scotland and the Baltic area (the latter which to this day is home to a high number of fish microvertebrate and macrovertebrate researchers). Fossils from the Baltic area were brought back to France by friends of Agassiz (Janvier, 1996).

The earliest recorded fossil fish from Scotland (*fide* Janvier 1996) were Carboniferous in age (sarcopterygians and petalodonts) and most pertinent of all, the term 'ichthyoliths' seems to have made its first appearance as a term used by local inhabitants of settlements near the fish localities, referring to any sort of 'fish remains'.

St. John and Worthen (St. John and Worthen, 1875) described and illustrated numerous fish macro- and microvertebrates from Illinois, USA in part of the series of the Palaeontology of Illinois. The material they described ranges in age from the Devonian to the Mississippian and Pennsylvanian. They described and illustrated many new taxa which are frequently referred to by fish researchers the world over. The taxa were based almost exclusively on disarticulated material which was illustrated at life size. Throughout this work the designation of genera and species as "nov. gen." or "n. sp" was not used; the authorship "St. J. and W." is here assumed to imply the designation of new taxa. The taxa included the following (using nineteenth century classifications that St. John and Worthen employed):

Hybodonts: some ten genera and fifty-eight species including *Phoebodus*, *Thrinacodus*, *Stemmatodus*;

Petalodonts: seven genera and fifty-six species;

a new species of cochliodont;

Ichthyodorulites: (a term used at that time to cover fin-spines and fin-rays) - eleven genera and forty-one species.

Many of the species described were assigned to genera erected by others such as Agassiz, M'Coy, Newberry and Worthen.

Traquair (Traquair, 1893; 1906) working on Scottish macroscopic and microscopic fish fossils during the late nineteenth and early twentieth century was one of the early researchers who described Carboniferous material in addition to that of other periods (and also material from Ireland outlined in the previous section).

Working in Russia about that time, **Trautschold** (Trautschold, 1860; 1883) was another major contributor especially in relation to the Devonian of Russia as well as the Carboniferous.

Newberry, together with **Worthen** described many fish macrofossils from Illinois (Newberry and Worthen, 1866). Later, **Newberry** (Newberry, 1889) was responsible for a major work on macroscopic fish from the Palaeozoic of North America ranging from the Upper Silurian (although only two pages are devoted to this age) through to the coal-measures of the Upper Carboniferous. In this monograph many new genera and species were proposed: examples are (using the classifications of the time of its publication) the genera *Sphenophorus*, *Holonema* (dipnoan); *Glyptaspis*, *Trachosteus* (placoderm); *Actinophorus* which was described as most closely allied to the Palaeoniscidae; *Mazodus*, *Stethacanthus* (elasmobranch); *Coelosteus* (crossopterygian). Many of these and other genera were represented by new species.

Eastman (Eastman, 1902; 1903) who was a major contributor to the study of Devonian fish, also contributed to the study of Carboniferous macroscopic fish especially from the western states of the United States.

Woodward (Woodward, 1903a; 1903b) published on Carboniferous macroscopic fish (and by some microscopic remains) such as acanthodians in the United Kingdom early in the twentieth century.

During first half of the twentieth century **Fournier and Pruvost** (Fournier and Pruvost, 1928) published on fish macrovertebrates from the Marbre Noir de Denée of Belgium. Most of the material is of macro-size from this unusual dark-grey to black limestone and includes some small 'cladodont' type teeth.

Moy-Thomas (Moy-Thomas, 1936, 1937; Moy-Thomas and Miles, 1971) published numerous works, again on both microscopic and macroscopic fish fossils, including a

text-book on Palaeozoic Fishes. **Gunnell** (Gunnell, 1933) in the 1930s wrote extensively on conodonts from Kansas and included many microscopic fish fossils, the majority of which were scales, each of which were given new specific names. **Harlton** (Harlton, 1933) also published on the micropalaeontology of the Pennsylvanian of the United States and included a number of microscopic fish fossils. Slightly later **Romer** (Romer, 1945) was a major contributor to the research on fish macro- and microvertebrates.

Within the second half of the twentieth century, starting in the 1970s there was an increase in interest in the fish microvertebrates of the Carboniferous period. This rise started slowly with work covering both micro- and macroscopic fish fossils from contributors such as **Gardiner and Mason** (Gardiner and Mason, 1974) and **Lund** (Lund, 1989; Lund *et al.* 1992) who in a series of publications on American fish fossils has documented the fauna from several locations, most notably the Bear Gulch Formation of Montana, which contains a marine *konservat lagerstätten* with numerous well preserved fish macrovertebrates (which give an insight into some microvertebrate fossils).

Zangerl, who is a prolific author on fossil fish (Zangerl, 1973; 1981; 1990), has also become the author of the chondrichthyan volume of the "Handbook of Paleoichthyology" which is one in a series of ten volumes (not all of which are yet in print). These volumes were initiated by Oskar Kuhn and have so far been edited by **Hans-Peter Schultze** as a comprehensive series on all known fossil fish covering mostly macroscopic material. However they do include microscopic specimens.

Many researchers who commenced publication in the 1970s and early 1980s are now major contributors in the 1990s. Several of these have worked as much or more on fish microfossils as macrofossils (not only of the Carboniferous). They include:

- **Dick**, who has studied Carboniferous Scottish sharks (Dick, 1978; 1981; Dick and Maisey, 1980)
- **Duffin**, who has made a revision of the hybodont genus *Lissodus* as well as other chondrichthyan remains and neoselachians. (Duffin, 1985; 1993a; Duffin *et al.* 1996; Duffin and Ward, 1983)
- **Forey and Young** (Forey and Young, 1985)
- **Hansen**, who has worked particularly on petaladontiform chondrichthyans from the Pennsylvanian of the United States (Hansen, 1985)
- **Janvier**, who is the author of many papers and of a comprehensive and valuable text on Early Vertebrates (Janvier, 1996; Janvier *et al.* 1984)
- **Mapes and Hansen**, who collaborated in an interesting publication on shark-cephalopod predation from the Upper Carboniferous (Mapes and Hansen, 1984)

- **Masson and Rust**, who have documented freshwater shark teeth and discussed their use as palaeoenvironmental indicators in upper Pennsylvanian rocks of Nova Scotia (Masson and Rust, 1984)
- **Turner**, who is a prolific researcher and author on fish microvertebrates from around the world including material from the Carboniferous, as well as the editor (with Alan Blieck) of "Ichthyolith Issues" - the newsletter of the International Working Group on Palaeozoic Fishes/Microvertebrates (Turner, 1982; 1990; Turner, 1993; Turner *et al.* 1993; Turner and Long, 1987)
- **Tway**, who used non-Linnean taxonomy in studies of microvertebrates in palaeoenvironmental analysis and discussed the thermal alteration of microvertebrates as well as other research (Tway, 1979; Tway *et al.* 1986)
- **Wang**, who has concentrated mainly on Chinese material (Wang, 1993)
- **Ward**, who has worked with Duffin on neoselachians of the lower Carboniferous of Britain and the Permian of the USA (Duffin and Ward, 1983)
- **Williams** who has written in particular on 'cladodont'-level sharks (Williams, 1985)
- **Zidek**, who has produced numerous publications on Mississippian xenacanths and symmorida from the United States and late Pennsylvanian chondrichthyans, acanthodians, actinopterygians from the United States (Zidek, 1993).

With the emergence of the International Geological Correlation Programme (IGCP) Project 328 and the subsequent Project 406 (see Chapter 11 for a full explanation of both Projects) in the 1990's more names can be added to the list:

- **Blieck**, who is a prolific researcher in fish of pre-Carboniferous ages, became the co-leader of the IGCP Project 328 and working with Derycke, the co-author of many papers on Lower Carboniferous material (Blieck and Lelievre, 1990; Blieck and Turner, 1995; Blieck, and Turner, 1996; Blieck *et al.* . 1998)
- **Coates**, who has studied actinopterygian and acanthodian fishes from the Viséan of Scotland (Coates, 1993; 1994)
- **Derycke**, who has concentrated mainly on Lower Carboniferous fish microvertebrates, especially sharks from western Europe and north Africa (Derycke, 1993; Derycke, pers. comm. 1994; Derycke *et al.* 1995a,b; Derycke *et al.* 1998)
- **Ginter**, who is involved in major research on the relationship of phoebodonts, and, with Ivanov, on fish material from Poland and Russia (Ginter, 1992; 1998; Ginter and Ivanov, 1996)
- **Hampe** whose major interest has been xenacanths of the Carboniferous and Permian (Hampe, 1989)
- **Ivanov**, who, although he has published much on Devonian fishes, is actively involved in research on fish microvertebrates from the lower to upper Carboniferous (Ivanov, 1996; Ivanov, 1998; Ivanov and Ginter, 1996)
- **Karatajute-Talimaa**, who has made a major contribution to research on microvertebrates, on scales in particular. Her work concentrated on Lower

Palaeozoic material but she has recently described Upper Devonian/early Carboniferous material (Karatajute-Talimaa and Mertiniene, 1998)

- **Lebedev**, who has concentrated on Upper Devonian and Lower Carboniferous fish microvertebrates, mainly from the Russian region (Lebedev, 1989; 1996; Lebedev and V'yuskova, 1993)
- **Richter**, who although mainly concerned with Permian fish fossils is also involved in research on Carboniferous fish microvertebrates, especially from Brazil (Richter and Breitkreuz, 1993)
- **Schneider**, who has mainly studied xenacanths from the Upper Carboniferous and Permian (Schneider, 1993)
- **Soler-Gijón**, who has worked on Upper Carboniferous sharks from Spain (Soler-Gijón, 1993A; 1993B)
- **Zajic**, who has studied Upper Carboniferous non-marine "ichthyoliths" from Bohemia (Zajic, 1993).

The list of researchers and publications referred to above is not intended to be comprehensive, nor do the publications cover all the work by the researchers listed; rather a selected number of references have been included pertaining to the Carboniferous period. However, it is obvious that the list is not a long one compared with the material available, or potentially available, for study (compared to the amount of research work ongoing and published from the Lower Palaeozoic) suggesting that fish microvertebrate research dedicated to the Carboniferous period is still in its infancy.

In addition this historical outline does not acknowledge the enormously valuable contributions of researchers working outside the Carboniferous period - Pander, Gross, Ørvig, Mark-Kurik, Märss, Poltnig, Schneider, to name a few.

1.7 TAXONOMIC METHODOLOGY

1.7.1 INTRODUCTION

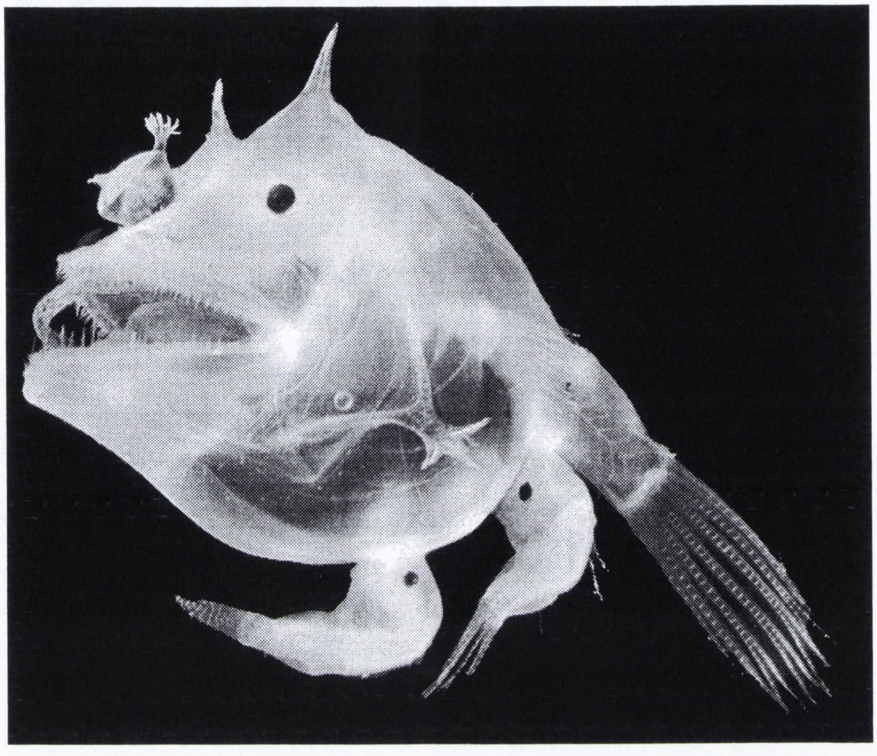
The mouth of a recent Deep Sea Angler fish (Figure 1.2a) and the lower jaw of a recent Porbeagle shark (Figure 1.2b) show examples of some of the diversity of teeth that may be housed within a single mouth at any one time. In addition great morphological and histological variability of exoskeleton exists (Karatajute-Talimaa and Mertiniene, 1998). When skeletal elements of differing morphology become disarticulated and scattered, their origin as parts of a single animal may be difficult to recognize. As the Code of Zoological Nomenclature dictates that taxonomic names apply to a whole animal, the naming of disarticulated and scattered fish fossils becomes difficult.

Taxonomic problems of this sort arise within many higher taxonomic groups, for instance echinoderms, conodonts and plants.

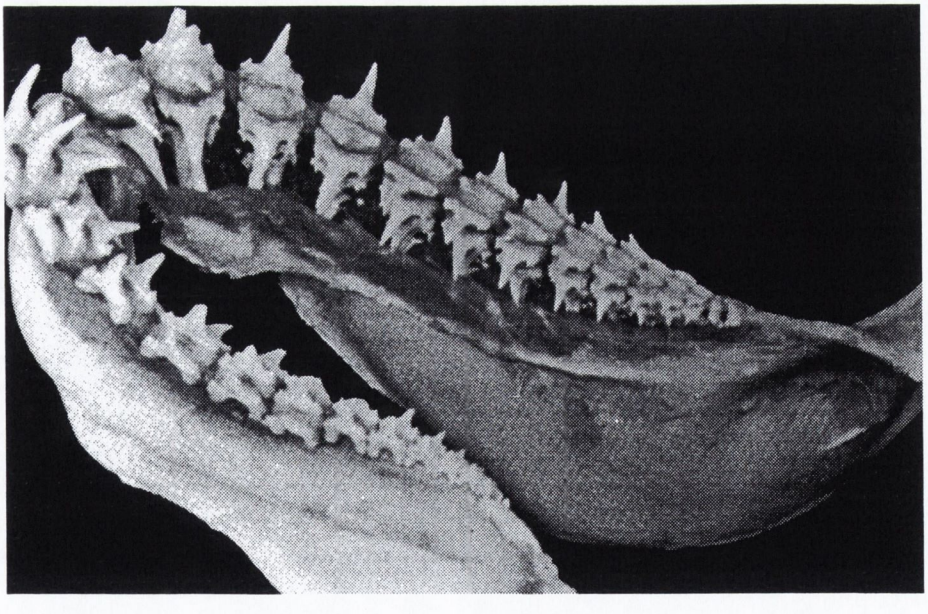
For example, some of the problems relating to the taxonomy of conodonts, which occur mostly as single conodont elements and rarely as conodont apparatuses, can be explained as follows. From their initial discovery until the middle of this century individual elements were given Linnean binomial names. With the realization that the individual elements were part of a more complex apparatus borne by an individual animal, it became clear that a single biological species of conodont animal was represented in the literature by several elements, each bearing a different generic and trivial name. Furthermore, morphologically identical elements, to which a Linnean binomen had been applied, occurred in more than one taxon of conodont animal. In the last thirty years, researchers of conodonts have worked towards establishing a taxonomy of conodonts based on the complete conodont apparatus (so called 'multi-element taxonomy') and have rejected this taxonomy of single conodont elements (so called 'form taxonomy').

The researchers of conodonts have been largely successful in this endeavour and it is worth considering whether this offers hope for workers on fish microvertebrates. The methods that have been available to conodont researchers are: (i) comparison of discrete individual elements with those found in rarely preserved conodont apparatuses (so called 'natural assemblages'), and (ii) statistical, essentially epidemiological, techniques which can determine recurring associations of individual discrete elements in different samples, often of slightly different stratigraphical age, geographical locality, or palaeoecological setting.

Despite the fact that natural assemblages of conodonts are extremely rare, the combination of the two methods has been very effective. However, in contrast to the situation with fish, the number of conodont elements and their arrangement and position within the apparatus have been found to be surprisingly conservative. The number of elements in the apparatus is in general relatively small. For example in the super-family Polygnathaceae (to which many Carboniferous taxa are referable) a consistent composition of seven different kinds of elements occur, most of which are paired - two pairs of pectiniform (Pa and Pb) elements, two dolabrate (M), four bipennate (Sc), two digyrate (Sb), two sharply bent bipennate (Sd), and a single alate (Sa) element (Aldridge, 1987). There is little evidence that these elements were shed during the life cycle and many of the distinctive elements (e.g. the Pa elements in ozarkodinids) which are most useful in distinguishing between species and genera occur as a single symmetrical pair. The array of S elements is more analogous to some fish dentitions in



A



B

Figure 1.2 A. Mouth of a Recent Deep sea Angler fish(Attenborough, 1992) and, B. the lower jaw of a recent Porbeagle shark (Steel , 1992) - both show examples of the diversity of teeth housed within a single mouth at a moment in time.

that it consists of three paired elements and one unpaired elements each of which differ only slightly from the other S elements in the ramiform basket. It is notable that establishing the complement of S elements in multi-element conodont taxa has always been more difficult than that of the Pa elements.

One way of tackling the problems of nomenclature of discrete, dispersed, fish microvertebrates is to dispense with a Linnean binomial system altogether, and to use a code which defines the morphological attributes of each individual microfossil (Tway, 1979). While this may provide a workable method for biostratigraphical analysis, it reveals nothing about the relationship of the 'animal' from which the microfossils were derived.

Many fish microvertebrates identified in publications world-wide have used the Linnean binomial system for isolated teeth, scales etc. Different examples can be taken to illustrate problems of varying degree in applying Linnean nomenclature.

Lissodus, (Chapter 7.3) a hybodont shark, has as its type species *Lissodus africanus* (*Hybodus africanus*). This species is based on the only articulated material known in the genus. The other species which have been assigned to *Lissodus* on the basis of their overall similarity to *L. africanus*, are distinguished from it on the basis of small differences in tooth morphology. The teeth are small with deep crowns, a labial buttress with an extension into the base in some instances, and a hybodontoid root with simple and large vascular foramina. The articulated specimen shows some variation of tooth morphology. The majority of the other material that has been assigned to the genus is based on isolated teeth which are morphologically similar to the type species. Species so defined range in age from Lower Carboniferous to Upper Cretaceous. A diagrammatic reconstruction by Duffin of *Lissodus nodosus* (Seilacher) based on isolated teeth shows considerable variation in the dentition of a single mouth. Without very large samples and an assumption that all the teeth in a sample were derived from a single taxon, it is very difficult to recognize individual species. The other reported skeletal material of *Lissodus* is fin-spines. It is not clear to what extent fin-spine morphology can be used as a diagnostic character in hybodont sharks.

Thrinacodus (type species *Thrinacodus nanus* (St. John and Worthen, 1875)) was based entirely on isolated material and no articulated specimens have ever been reported. Numbers of specimens recovered from a single sample are usually low (less than 4). Two distinct morphotypes of *Thrinacodus*, one symmetrical and one asymmetrical, have been described as different species. However, without reference to articulated material, which has not yet been found, it is not possible to be sure whether the two morphotypes are part of the same dentition or whether they actually do represent two different species. This problem is discussed in Chapter 7.1.

Many specimens of macroscopic teeth that have been described are similar to but much larger than some microscopic teeth. Examples are *Protacrodus vetustus* (see Chapter 7.5.3) and the rhizodontiform material described in Chapter 7.8.

1.7.2 PARATAXONOMY

Parataxonomy can be defined as a system that is outside an orthodox taxonomic system. Sylvester-Bradley (1958) proposed that .."*parataxa are artificial taxa, based on material deemed, by decision of the International Commission on Zoological Nomenclature, to be inadequate for diagnosis of natural taxa, and classified on arbitrary morphological grounds without regard to relationships*".., Melville (1979) defined a parataxon as ..."*a taxon based on a fragment or detached organ of an animal which can be classified at genus-group and species-group levels by comparison with other fragments or detached organs, but cannot be assigned to the same taxa at those levels as the whole animal to which they belong*". One of the problems in Melville's definition is the implication that the status of a fossil ascribed to a parataxon is related to the "degree" of completeness of the material (Bengtson, S., 1985) and hence Bengtson redefined a parataxon as a "*conceptual taxon belonging to a taxonomic system that by formal decision is outside the orthotaxonomic system covering the same group of organisms*". Therefore a system of parataxonomy allows for the allocation of Zoological Nomenclature at a future date should the discovery of a complete animal occur.

A parataxonomic approach would have simplified the study of the fish microfossils discussed below.

However, although parataxonomy is acceptable under the International Code of Botanical Nomenclature, so that there are separate taxonomic schemes for spores and pollen, leaves, stems, etc., it is specifically not permitted under the International Code of Zoological Nomenclature (ICZN, 1985).

1.8 USE OF OPEN NOMENCLATURE

1.8.1 Open nomenclature is a way of dealing with specimens whose identity cannot be determined exactly. Escaping the confines of closed nomenclature, it still permits specimens to be identified to a certain level, be it only to a probable generic level, rather than letting potentially valuable information be lost; or even worse, be wrongly assigned and incorporated into the literature in such a guise. The *International Code of Zoological Nomenclature* (ICZN, 1985) makes no provision for cases of Open Nomenclature (Bengtson, P., 1988) and hence it is the task of the individual to make informed decisions based on precedents found within the literature.

Over the years the use of **cf** and '**question mark**' have been the subject of more than one paper and opinions arising from these are still not consistent (Bengtson, P., 1988; Matthews, 1973).

Where **cf** is used, it means 'compared to' (ie: confer - compare to) (Bengtson, P., 1988) and it is placed preceding the generic or trivial name indicating that the determination is uncertain or provisional; the use of a **question mark** after a genus or trivial name suggests that the name is possible; the identification is even less confident than within the case of a single **cf** individual. Hence, according to P. Bengtson:

cf *Agenus aspecies*	a provisional assigned genus
Agenus **cf** *aspecies*	a provisionally identified species
cf *Agenus* **cf** *aspecies*	a provisionally assigned genus and provisionally identified species
Agenus **?** *aspecies*	genus uncertain
Agenus aspecies **?**	species uncertain
Agenus **?** *aspecies* ?	both genus and species uncertain

These decisions are subjective and each decision made within this work is explained and justified as an individual case. However, the overall decision to use Open Nomenclature at generic level has been taken to avoid the problems stemming from the practice of many workers in this century and before to give any fish microvertebrate not seen before, a new generic or trivial name (often both) with these 'names' becoming incorporated in the literature.

1.8.2 MORPHOTYPES

Fish microvertebrates particularly shark-type teeth, are almost invariably isolated specimens (though many individuals may occur in the same acid-insoluble residue). Variation of tooth type occurs not only between different types of shark but also within the individual mouth. Upper and lower jaw teeth may be of differing gross morphology; the gross morphology within tooth rows themselves may also differ. Such variation occurs not only in teeth but also in denticles and scales. Where a shark possesses denticles, these may vary depending upon area of the body they occur. Very few (if any) denticles are exactly identical. Within the bony fishes, the scales covering the whole fish vary in overall gross morphology depending upon the location of the scales, on the body, head, fin, etc.

Rather than referring a specimen to a species that has already been described or proposing a new species name for it, in most cases in this thesis a specimen or a group of specimens are described in terms of morphotypes (for example, *Lissodus*

Morphotype 1, Morphotype 2, etc.). This has the advantage of creating a name (Morphotype 1, etc.) as a shorthand for a morphological description, without inviting all the subsequent problems of synonymy that are likely to arise where individual elements are given Linnean binomina. Although the most parsimonious explanation is that the different morphotypes assigned to a genus found in a single sample are derived from a single species, without the information from a complete specimen this cannot be proved or disproved.

1.9 STUDY AREAS

The way research reported in this thesis has developed is as follows:
An initial literature review of all published records of fish material in the Lower Carboniferous of Ireland (the results of which are found in Appendix III) was undertaken.

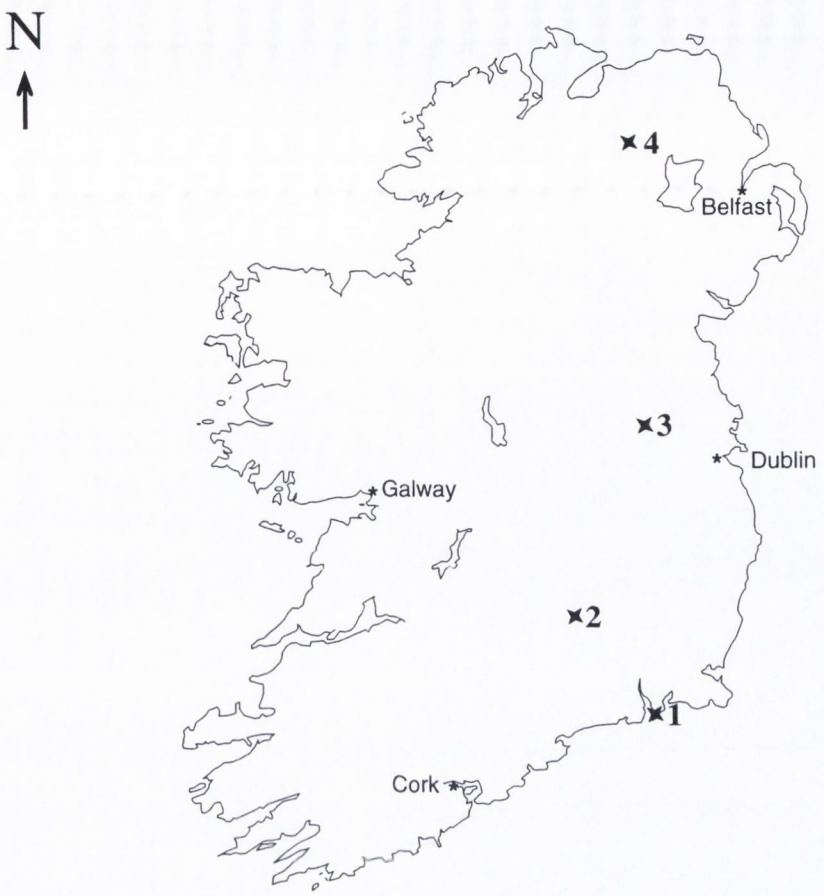
As a result of this survey, it was decided that fish-bearing beds reported from Hook Head, Co. Wexford by Smyth (1930), might provide a good initial target for analysis of the taxonomy and palaeoecology of fish microvertebrates. It transpired, however, that although it was possible to set the fish-bearing strata in a palaeoenvironmental context, the yield and diversity of fish microvertebrates was very small. In order to have a diverse assemblage to analyse, work then switched to limestones at Kilbride, near Nobber, Co. Meath, where Geraghty (1996), in the course of a conodont study, had recovered a rich fauna of fish microvertebrates. The Kilbride fauna was contained in limestones of moderately shallow water origin of late Tournaisian age.

Limestones in borehole cores at Urlingford, Co. Kilkenny provided a source of fish microvertebrates of late Tournaisian age, though from a deeper water environment than that of Kilbride.

At this stage for reasons of time, it became clear that all the detailed research would have to be restricted to Tournaisian faunas and that other material identified in acid insoluble residues would only be listed as a resource for future work.

To complete the spectrum of Tournaisian environments, material from the Moyola River, which is of marginal marine origin, was examined.

Details of the individual localities (the areas are in different parts of Ireland and represent differing palaeoenvironmental regimes - see Figure 1.3 for their locations within Ireland) are shown below:



1 Lyraun Cove
Lyraun Cove Shale Member
Porter's Gate Formation
Hook Head, Co. Wexford.

2 Urlingford Core
Upper Ballysteen Limestone
Nr. Urlingford, Co. Kilkenny.

3 Kilbride Quarries
Kilbride Limestone Formation
Nr. Nobber, Co. Meath

4 Moyola River
Mormeal Member
Altagoan Formation
Nr. Draperstown, Co. Derry.

Figure1.3. Location of Study Areas

1.9.1 LYRAUN COVE, HOOK HEAD, CO. WEXFORD

The oldest material (*Polygnathus inornatus* conodont Biozone) is of Hastarian age from Hook Head in south-east Ireland. Approximately two and a half to three kilometres from the tip of the Hook Head peninsula on the east coast is a small cove (Lyraun Cove) where the so called 'Fish Shales' (now the Lyraun Cove Member of the Porter's Gate Formation) are exposed (Smyth, 1930). It was decided to re-examine a portion of these 'shales' with the aim of extracting fish microvertebrates. Some five metres was logged at 1:1 scale and the remainder at 1:10 scale - a detailed description of the work carried out at Lyraun Cove is found in Chapter 3 of this work. This area was originally selected because of the historical record of 'fish material' (albeit macrovertebrate) in the hopes of extracting fish microvertebrates.

1.9.2 KILBRIDE QUARRIES, NEAR NOBBER, CO. MEATH

Near Nobber in Co. Meath two quarries in the Kilbride Formation were sampled by Geraghty (1996) for conodonts. The resulting residues were found to be rich in fish microvertebrates and it was decided that these residues should for this reason become the backbone of the overall project. Samples from these quarries fall into the *Polygnathus mehli* conodont Biozone (Ivorian, probably Freyrian) from a fully marine, shelf environment. The two quarries are described in Chapter 4.

1.9.3 BOREHOLE 3246/4 - NEAR URLINGFORD, CO. KILKENNY

Samples which had been processed for conodonts were found to contain moderately abundant fish microvertebrate. The sample horizons are from the Ballysteen Limestone Formation of Ivorian, pre-Freyrian age and represent relatively deep water. These core samples have been dated as the lower part of the *Polygnathus mehli* conodont Biozone. Details of this core material is given in Chapter 5.

1.9.4 MOYOLA RIVER, CLOSE TO DRAPERSTOWN, CO. LONDONDERRY.

The material from which specimens were isolated was kindly lent by the Ulster Museum and processed by the writer. The samples were derived from rocks of the Mormeal Member of the Altagoan Formation representing marginal marine environments of probable Ivorian (Freyrian), age from the Pu Biozone based on palynological assemblages reported by Owens *et al.* (1977) (see Chapter 6).

Although the four areas are close in age, they represent different palaeoenvironment and palaeoecological settings.

1.10 PALAEOGEOGRAPHY AND GENERAL DEPOSITIONAL ENVIRONMENTS

1.10.1 SETTING

Ireland in the Dinantian lay near the equator and was the site of a large epeiric sea bordered by land to the north and north-west; the shallow marine area extended eastwards to Central Europe and possibly westwards toward the marine provinces of Canada.

The closing of the Iapetus Ocean during the end of the Silurian and early Devonian had resulted in a period of deformation, rapid uplift and erosion and the creation of the 'Old Red Sandstone Continent'. This large continent which appears to have had an arid climate, dominated by fluviatile deposits was subjected to a period of fluctuating marine transgressions and regressions during the late Devonian/early Carboniferous with the sea encroaching mainly from a southerly direction. As these transgressions were diachronous, "Old Red Sandstone" facies sediments continued to be deposited ahead of the transgressive marine sequences.

1.10.2 HASTARIAN

In southern Ireland the overall Tournaisian transgression is expressed in the change from the Devonian/Carboniferous Old Red Sandstone fluviatile successions, to rocks deposited on tidal flats and in deltaic settings to sub-tidal marine limestones, sandstones and mudstones. The Lyraun Cove Member is of Hastarian age and represents shallow marine deposits not far from the contemporary shoreline. The distribution of facies suggests a deepening southwards of the early Carboniferous eperic sea.

1.10.3 IVORIAN

Continued transgression and subsidence led to a progressively deepening and northward advancing marine shelf or ramp during the Ivorian, culminating in the widespread development of Waulsortian carbonated mudbanks, which are believed to have grown in relatively deep water environments.

The Urlingford borehole samples are from limestones that occur between a shallow-water oolite (Lisduff Oolite Member), which marked a period of shoaling, and deep water Waulsortian limestones. These are interpreted as having been deposited at depths that were generally below storm wave base. The Kilbride Quarries samples are from a slightly younger horizon within the late Tournaisian and represent a shallower

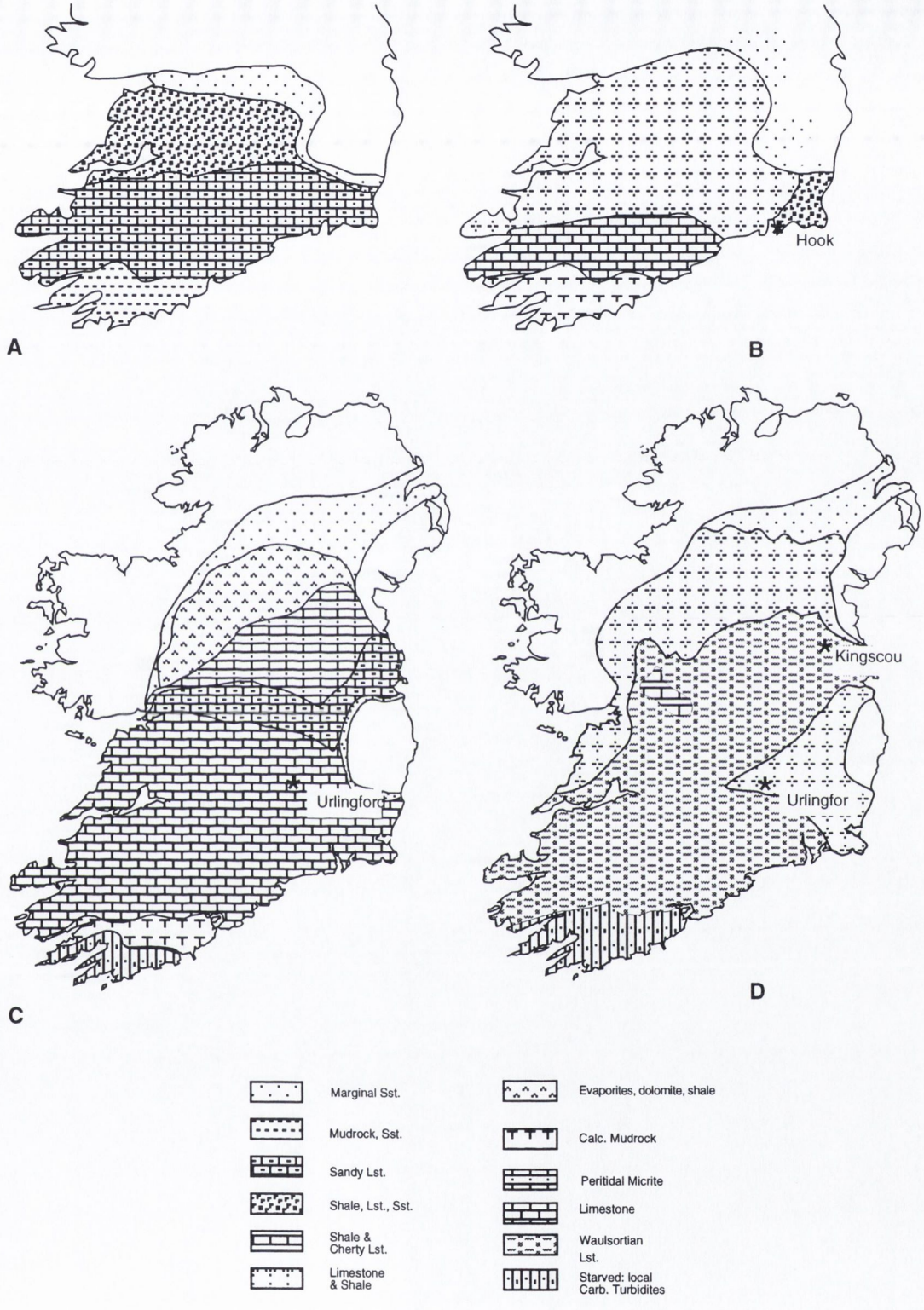


Figure 1.4. Dinantian Palaeogeography. A *Polygnathus spicatus* conodont Biozone (Hastarian); B *Siphonodella* conodont Biozone (Hastarian); C *Pseudopolygnathodus multistriatus/Polygnathus c. carina* conodont Biozone (Ivorian); D "Waulsortian". (After Sevastopulo, in press)

environment than the Urlingford samples; these limestones show evidence of having been deposited above storm wave base.

1.10.4 "FREYRIAN"

By the end of the Tournaisian the transgressions had reached the north of Ireland. In the area of the Moyola River, marginal marine, sabhka to non-marine conditions appear to have prevailed by the "Freyrian" influenced not only by the transgressing seas but by sediment influxes from the topographic highs to the south-east and north-west.

CHAPTER 2: METHODOLOGY

2.1. SAMPLING

Samples for this project were either donated as 'conodont picked residues', or were bulk samples on loan or bulk samples collected specifically for the project.

2.1.1 LYRAUN COVE SHALE MEMBER, PORTER'S GATE FORMATION, HOOK HEAD

Samples were collected from the Lyraun Cove Shale Member of the Porter's Gate Formation (previously referred to as the 'Fish Shales') from accurately logged sections - Section LC1 on a 1:1 scale and Section LC1A on a 1:10 scale. (see Chapter 3) From these logs, sample sites were selected and their locations accurately recorded. The majority of the samples from Section LC1 were taken from calcareous sandstone and those from Section LC1A from dolomitic limestone. Samples varied in weight but each was bagged, sealed and labelled separately to prevent cross-contamination.

2.1.2 KILBRIDE LIMESTONE FORMATION, KINGSCOURT OUTLIER

Samples from this formation were donated as 'conodont picked residues' (Geraghty, 1996)

2.1.3 UPPER BALLYSTEEN LIMESTONE, URLINGFORD

Samples were supplied as 'conodont picked residues' from Core number 3246/4 (see Chapter 5). The original samples had been selected from limestone beds within a limestone and shale succession.

2.1.4 'MOYOLA RIVER', MORMEAL MEMBER, ALTAGOAN FORMATION, CO. LONDONDERRY

Samples from the 'Moyola River' locality were loaned as bulk samples by the Ulster Museum. From these samples those containing obvious macro-material were put aside and the remaining material treated as a single bulk sample as no log was provided with the samples. Although the locality was given a single grid reference on information received from the Museum, the samples supplied appear to have come from more than one bed within the Mormeal Member.

2.2 PROCESSING

2.2.1 FURTHER PROCESSING OF SAMPLES

Only those samples not in residue form were processed further. Fish microvertebrates (like conodont elements) must be released from the rock samples. In this instance the acid-digestion method described first by Graves and Ellison (1941) was adopted but had to be modified as the method works best with pure limestone. Most of the samples were calcareous sandstones and dolomitic limestones, many of which contained shaley partings or mudstone lenses.

2.2.2 ACID-DIGESTION TECHNIQUES

It was decided not to crush the rock samples prior to immersion in acid and samples were therefore weighed as dry bulk samples and separated into sampling batches of 0.5-1.5kg each.

To avoid cross-contamination each sample was placed into a plastic sieve suspended in a polyethylene bucket, both of which were cleaned prior to the introduction of the samples.

Any encrusting material on the bulk samples was removed prior to acid-digestion using acetic acid and hot water and the cleaned samples were then gently washed and scrubbed.

Small test samples of less than 0.25 kg of the different rock types were processed to ascertain the most appropriate type of acid to use. The acids tested were formic acid (1 part concentrated (85%) acid to 3 parts calcium formate buffer to 9 parts water) and both hot and cold acetic acid (80%) to which varying amounts of hot or cold water were added; no buffer was used with the acetic acid. The buffering of samples has been discussed in relation to the use of acetic acid for dissolution by Jeppsson *et al.* (1985) and this method of buffering was applied to samples immersed in formic acid as it was found that those samples tended to be subject to etching rather than those immersed in acetic acid.

To achieve a workable method of disaggregating the calcareous sandstone samples, it was found that acetic acid to which very hot water was added (at a ratio of not less than 1:9) would start the process of dissolution of carbonate. Samples were suspended in buckets placed in colanders to allow the residue to fall gently to the bottom where the calcium formate/calcium acetate formed during the chemical reactions of the samples and

the pertinent acid could settle and help to prevent initial etching of phosphatic specimens. Buckets were placed in a fume cupboard for two days initially, with several further periods of two days where the sample continued to react slowly. After each two day period the residue at the base of the bucket was collected. Where bulk samples remained undissolved they were washed and immersed in buffered 85% formic acid (or unbuffered 80% acetic acid) in an attempt to achieve further dissolution. In many instances (where a high percentage of clay or shale was contained within the sample) a portion of the sample did not disaggregate using the acid methods and these samples were then washed thoroughly and replaced in the sieves and buckets to which a solution of Quarternary O (Zingula, 1968) (a tertiary amine compound no longer manufactured) and hot water was added and left for a period of up two weeks with intermittent gentle agitation. The resulting residues were collected.

Material from the 'Moyola River' locality which consisted of calcareous sandstones and dolomitic limestones proved less amenable to the method described above. A few test samples were run using hot acetic acid to which was added a solution of Quaternary O. The buckets were left for two days with intermittent gentle agitation. This method proved successful and the process was repeated every two days and the residue collected between each run. This method must be carried out in a fume cupboard as it can generate a high volume of froth which may overflow the bucket tops.

Calcium acetate and calcium formate crystals, which precipitate in some samples were removed by soaking the residues in mild detergent and hot water for about one hour before sieving.

2.2.3 SIEVING

Following each acid-digestion 'run' buckets were removed from the fume-cupboard and the residue sieved using a sieve stack made up of differing mesh sizes. A 125μm (120 mesh) was placed at the bottom, then a 250μm (60 mesh), a 500μm (30 mesh) and the 'suspending' basket sieve on the top.

Any large pieces of the sample were removed and put to one side for further acid-digestion and the contents of the bucket then poured gently through the sieve stack placed in a sink. Warm water to which a small amount of mild detergent had been added was then allowed to run gently through the stack using a rubber hose and rose attachment. Washing was allowed to continue until all the mud particles were washed away.

Contents of all the sieves were isolated into filter papers which were placed in an oven and allowed to dry. Once dry, these residues were suitable for picking and were stored in labelled, sealed glass vials to prevent cross-contamination.
Density separation using heavy liquids was not undertaken because of the high content of dolomite of the residues.

2.3 PICKING AND MOUNTING OF SPECIMENS

A picking dish was prepared using a glass Petri-dish (plastic Petri dishes were found to be prone to buildup of static electricity) the base of which was covered with graph-paper onto which numbered squares were drawn in ink. A fresh paper was used for each sample to prevent cross-contamination. A grain-thick layer of residue was spread on this surface and a very fine wetted brush used to remove the fish microvertebrates under a stereo-microscope from each square in turn and to place them into prepared cavity slides. White background cavity slides were prepared by covering the surface with a semi-permanent glue made up of gum tragacanth and water to which clove oil was added as a bactericide. Depending on the absorbency of the base of the cavity slide, a further coat of gum tragacanth was added. As gum tragacanth is water soluble, specimens can be easily removed with a small amount of water. Each slide was marked with the sample number, location and type of fish microvertebrate (i.e. scale, tooth, etc.) and where fish microvertebrates were abundant the slides were further divided into the types of tooth or scale. Once picked, the remaining residues were returned to sealed glass vials.

The fish microvertebrates were identified prior to selection for photography using the SEM.

2.4. SCANNING ELECTRON MICROSCOPE

Images made using the Scanning Electron Microscope (SEM) were used as an aid to fish microvertebrate identification and to enable more accurate measurement.

Fish microvertebrates selected for examination and photography by Scanning Electron Microscope were mounted on SEM stubs (using a very fine wet brush) and fixed to the stub using SEM stub-designated double-sided adhesive tabs from which they could be removed at a later date using a drop of water applied to each specimen.

Specimens were coated with a 250 Ängstrom thick layer of gold using a sputter coater. This gold coating prevents the build up of electrical charge on the surface of the

specimen when the stubs are placed into the SEM. It should be noted that stubs should not be left gold-coated for too long before being used in the SEM as a small build up of electrical charge can occur which appears on the resultant photographs as a 'bright patch' (frequently referred to as 'charging').

Stubs on which specimens had been mounted were placed in a Leica 360 Scanning Electron Microscope and a number of aspects of each specimen examined (e.g. dorsal or ventral, lingual, labial and lateral in the case of teeth). Images of each aspect were made and retained in digital format ('TIFF' format) rather than as single photographic images.

2.5. DIGITAL CAPTURE AND PLATE CONSTRUCTION

2.5.1 The traditional method of constructing plates has been to assemble by hand the component figures and to mount them. In many cases the illustration of each specimen figured has been edited by removing the background either by trimming with scissors or a fine blade, or by masking.

It is now possible to capture and store images from the SEM in digital form and to subsequently edit them. It was decided to use these techniques to construct the plates in this thesis. This method takes advantage of the advances in technology allowing analogue signals to be digitized and then integrated to get rid of amplified noise, and to be stored as 8-bit grey level TIFF format images, cutting out any need to scan images recorded on photographic film.

2.5.2 For plate composition an image editor Photoshop® version 4.0.1 and version 5.0.2 (produced by Adobe Systems Inc.) were used on a Macintosh computer. Individual images were opened directly from the SEM files which were transported from the Trinity College EM Unit using Iomega Zip Disks with a 100 megabyte capacity. As each individual image required greater than 750K of storage capacity, this method proved the easiest system for transporting, saving and working on images.

2.5.3 To remove any variation of density within the backgrounds of each image, each background was changed to a uniform black, the scale bar was removed from the header of the image and placed beside each individual specimen and the image cropped and saved as a Photoshop® file.

Individual images were then amalgamated into plates (although each figure was retained as an individual layer) and any variation of brightness/contrast adjusted at this stage to give a uniform appearance to each plate. The ability to vary the brightness and contrast of individual images is an important advantage of the method of plate production used

because where individual fish microvertebrates are imaged in different orientations the stage is not only rotated but frequently tilted up to 90° from the horizontal; hence the working distances rarely coincide exactly resulting in brightness/contrast inconsistency.

Once the position and orientation of each individual specimen image was established on the plate the scale bars were cropped and placed in a horizontal orientation (on individual layers) and notation added (on individual layers) to the plate itself rather than directly onto each individual specimen image.

2.5.4 Final plate printing was undertaken only when any problems of brightness, positioning of specimens etc. had been corrected from a draft set of plates. Draft plates were run off on a laser printer using the default dpi or a dpi of 600; all plates were kept as individual composite layers until the final print stage, though for the draft printing these may be temporarily amalgamated into a single layer per plate to allow for correction of image size.

Once finalized, the image layers for each plate were then flattened and the burn tool (used to adjust local densities) was applied using auto levels in RGB. An unsharpen mask filter of 30% with a radius of 1.5 was then applied to each plate in turn.

The plates were then printed at 360 dpi on "photosetting" onto A4 Epson 194g/^{m2} weight photography paper on an Epson Stylus Colour 900 printer.

2.5.5.1 Over seven hundred individual images were captured in this way and six hundred and seventy of these were selected to create the final plates. In the manner in which they were prepared using the software made available at the time, the quality of the plates is not consistently as good or better than those prepared using traditional methods and digital capture retention and editing of images using an image manipulating package is very time consuming. Updated software would give a better result and more consistent with the images viewed on screen prior to printing. The method, while it is considerably cheaper in terms of consumable materials, such as photographic paper, does not lead to any reduction in time required to produce a plate. An advantage is that some Journals (for example *Lethaia*) accept digital files for publication.

2.5.5.2 The "editing" of images was kept to a minimum (other than the correction of brightness/contrast control) to preserve the integrity of the specimen. Where any image was worked on to remove the few inevitable charge lines present or rogue foreign fibres, this has been noted on the plate containing such a specimen.

2.5.5.3 All the specimens figured are catalogued in Appendix I and in Appendix II - Curation of Specimens.

2.6 FIGURES

Most of the schematic drawings used in Chapter 7 (Systematic Palaeontology) were made by copying an image of a specimen from the programme used to create the plates (Photoshop®) into a drawing package (Aldus Freehand®) and tracing over the image to create an outline drawing, using some artistic license with regard to orientation and scale. The remaining drawings in Chapter 7 were made using a Camera Lucida and finalized using the above drawing package.

Other drawings were made from field observations and outline drawings made using a drawing package. All the maps, logs and tables were made using the same drawing package (Aldus Freehand®).

CHAPTER 3: THE SEDIMENTOLOGY, FISH MICROVERTEBRATES AND PALAEOENVIRONMENT OF THE UPPER BEDS OF THE LYRAUN COVE SHALE MEMBER, PORTER'S GATE FORMATION, HOOK HEAD, CO. WEXFORD.

3.1 INTRODUCTION

Hook Head is a narrow peninsula forming the most south-easterly extension of County Wexford (Figure 3.1.). The most southerly part is composed of Carboniferous marine rocks, to the north of which are rocks of the 'Old Red Sandstone' facies of late Devonian/early Carboniferous age, interpreted as alluvial coastal plain deposits.

Exposure is confined to low coastal cliff sections and to the foreshore. In many places the rocks are covered by storm driven shoals of beach cobbles and thick mats of seaweed depending upon the season of the year.

The Carboniferous strata were divided into two formations by Sleeman *et al.* (1974) - the lower Porter's Gate Formation which consists of two members, the Houseland Sandstone Member overlain by the upper Lyraun Cove Shale Member; and the upper Hook Head Formation, a thick limestone succession which includes the Bullockpark Bay Dolomite Member. Tietzsch-Tyler and Sleeman (1994) have renamed and divided the Hook Head Formation into two formations - a lower Ballymartin Formation and an upper Ballysteen Formation. The latter contains the Bullockpark Bay Dolomite Member at its base.

The sections at Lyraun Cove (Lyraun Cove Shale Member, Porter's Gate Formation) have been dated as lying within the *Polygnathus inornatus* conodont Biozone (Hastarian, Tournaisian, Dinantian) (Johnson and Higgins, 1971).

3.2 PREVIOUS WORK ON THE CARBONIFEROUS OF HOOK HEAD

The first detailed short account of Hook Head was by Haughton (Haughton, 1856) who mentioned that some beds within the successions at Hook Head were "literally covered with fragments of fishe's teeth" (*sic*). Less than ten years later Du Noyer (1865) described and illustrated the area in the *Memoirs of the Geological Survey*.

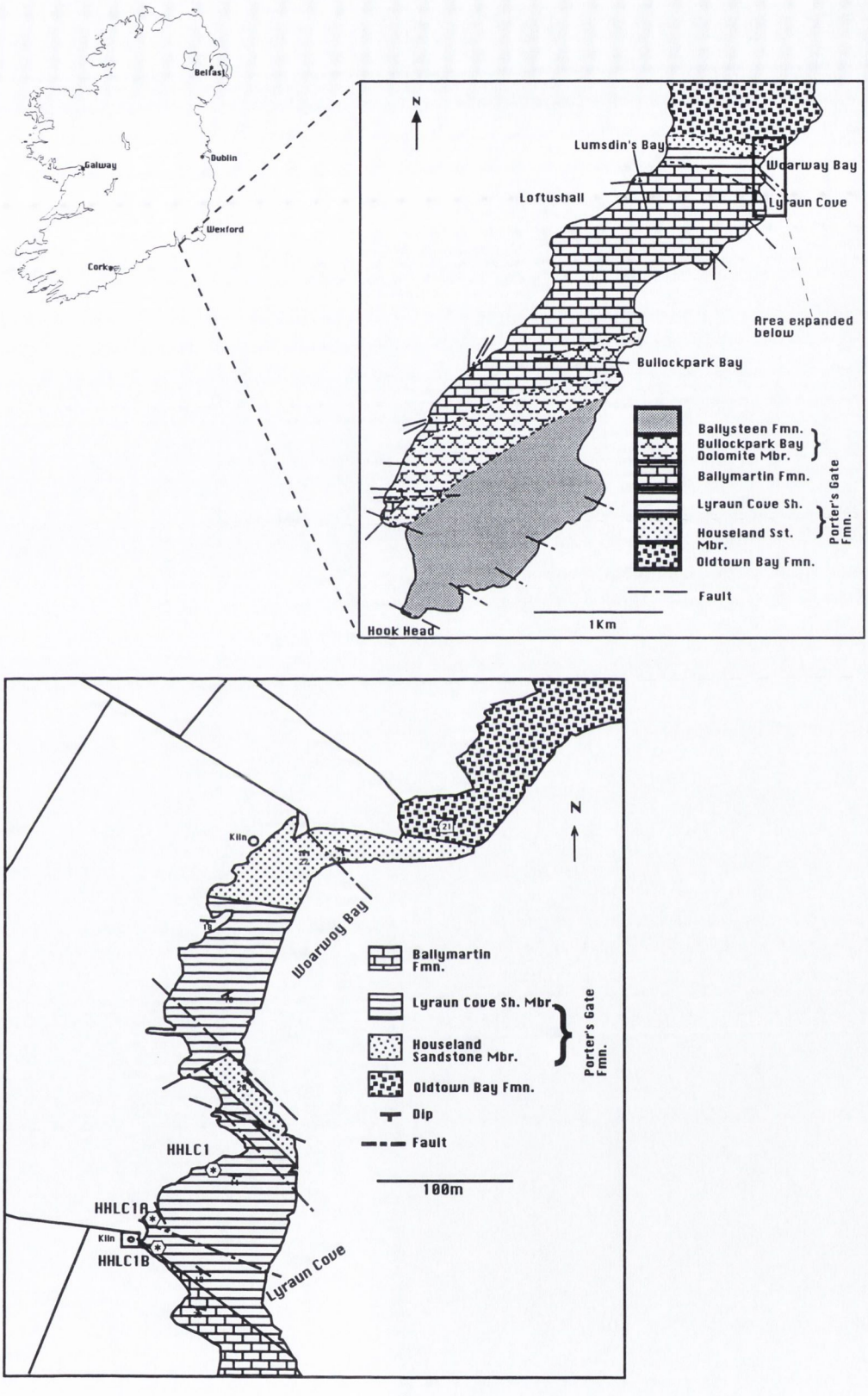


Figure 3.1. Location and geology of Sections at Lyraun Cove, Hook Head, Co. Wexford. (modified from Sleeman 1974)

Smyth (1930) described the Carboniferous rocks with particular emphasis on the invertebrate fauna that they contained and produced comprehensive faunal lists and descriptions of the fauna.

Another forty years passed before further detailed work on the Carboniferous strata was undertaken. Sleeman (1974) described in detail the stratigraphy, biostratigraphy, regional correlations, outline palaeoenvironmental interpretations together with systematic palaeontology. A précis of this work was published by Sleeman, Johnston, Naylor and Sevastopulo (1974), followed by work on the Porter's Gate Formation by Sleeman (1977), and a stratigraphy of the late Devonian to early Carboniferous rocks of the area (Sleeman *et al.* 1983).

The intervening and subsequent years were not barren and many individual works were published on bryozoans (Dresser 1960, Tavener-Smyth 1974); palynology (Higgs, 1975; Higgs *et al.* 1988) and conodonts (Johnston and Higgins, 1981). The most recent work in this area was carried out during the preparation of Sheet 23 - Geology of South Wexford of the Geological Survey of Ireland (Tietzsch-Tyler and Sleeman, 1994).

3.3 STRATIGRAPHIC NOMENCLATURE

During the history of writings on Hook Head, many of the names of the formations and members and indeed their boundaries, have changed considerably. Those identified within the most recently published map are used here together with their immediate predecessors.

Tietzsch-Tyler and Sleeman (1994) retained the Porter's Gate Formation, divided into the Houseland Sandstone Member and the Lyraun Cove Shale Member. However, the Hook Head Formation of Sleeman (1974) has been divided into two separate formations: the lower Ballymartin Formation; and the upper Ballysteen Formation which includes the Bullockpark Bay Dolomite Member (first described as a member of the Hook Head Formation) (Figure 3.2).

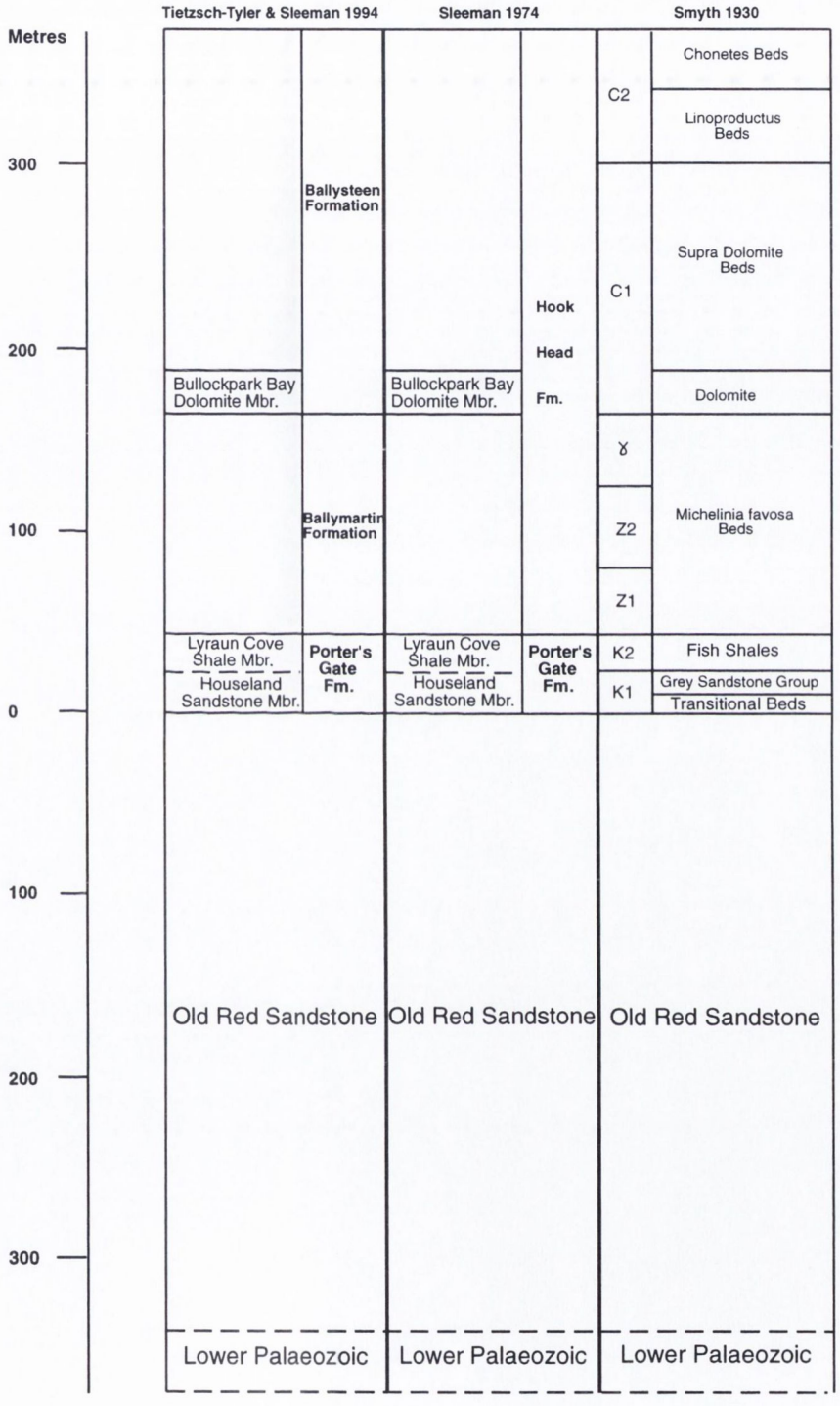


Figure 3.2. Stratigraphic nomenclature relating to the Hook Penninsula, showing the position of the Lyraun Cove Member (Fish Shale). (Conodont and miosporeBiozones can be seen at Figure 11.1.)

3.4 STRATIGRAPHY

3.4.1 PORTER'S GATE FORMATION

The Porter's Gate Formation has been described most recently in terms of vertical facies changes, sedimentary structures and trace fossils by Sleeman (1977). The formation is exposed on the east side of the peninsula at Woarwoy Bay and Lyraun Cove, and on the west side of Hook Head at Lumsdin's Bay and Loftushall Bay (Figure 3.1).

3.4.1.1 LYRAUN COVE SHALE MEMBER (Porter's Gate Formation)

A section of the Lyraun Cove Shale Member (the type section of which is in Woarwoy Bay) previously described by Smyth (1930) as the 'Fish Shales' was examined in detail. The sedimentology, trace fossils, invertebrate fauna and in particular, the vertebrate (fish) assemblages were investigated in an effort to interpret the palaeoenvironment and to assess the potential of using assemblages of fish teeth and scales (both macro- and microscopic) as environmental indicators.

The base of the member (Sleeman, 1974) which is at the southern-most end of Woarwoy Bay marks a change in lithology from the predominantly sandy Houseland Sandstone Member (Figure 3.1).

The base was defined by Sleeman (1974) at the junction between a 60cm thick limestone bed of the Houseland Sandstone Member and a 5m thick unit of sand-lensed mudstone. Overlying this is a distinctive bioturbated unit of sandstone and siltstone approximately 1.8m thick. The higher part of the member consists of mudstones and shales with beds of fine calcareous sandstone and occasional limestones.

3.4.1.2 LYRAUN COVE SHALE MEMBER - SECTIONS AT LYRAUN COVE (S 276 100)

The section (Section LC1) studied in detail is situated at the northern end of Lyraun Cove on a south-east facing cliff close to the Woarwoy Bay Fault (Figure 3.1). Some 6m west of this fault is a minor north/south trending fault. The section was measured to the west of this minor fault from 0.59m below the top of the 'bioturbated unit' mentioned above and extends above it some 4.8m to the eroded cliff top covered with glacial till and recent wash-off from the surrounding cultivated fields. Section LC1 (total thickness

5.4m) was logged on a 1cm:1cm scale normal to the local dip. See Figures 3.4a-c. for logs.

A short section (Section LC1A) c. 3.3m thick, assumed to be fault-bounded (although no actual fault planes are visible) on the east-facing seaward cliff appears to be isolated from Section LC1 and has been suggested by Sleeman (1974) from his work on the west coast at Loftushall Bay, to lie above Section LC1. The vertical extent of this section was estimated because much of the cliff base was obliterated by beach cobbles to a depth of about 1.5m. This section was logged on a 1cm:10cm scale. See Figure 3.5 for logs.

The uppermost part of the Lyraun Cove Shale Member is seen on the north-east facing cliff on the south side of Lyraun Cove, the top of the section being delimited by the base of the Ballymartin Formation (Hook Head Formation). The base of this formation is defined at the base of the first 20cm thick limestone, rich in productid and spiriferid brachiopods which occurs 2.1m below a distinctive 10cm thick haematitic ironstone used as a local marker bed.

Section LC1B covers the succession (c.5.3m thick) from the base of the cliff to the base of this 20cm thick limestone. This was also logged on a 1cm:10cm scale. See Figures 3.6 for logs.

The total thickness of the three sections logged is 14m. The addition of 5m of sand lensed mudstones at the base of the member and roughly 1.6m of the 'bioturbated unit' gives an estimated total vertical thickness of 20.6m. This may be compared to the minimum thickness of 22.5m for the Lyraun Cove Shale Member estimated by Sleeman (1974) from the poorly exposed, but largely unfaulted, section at Loftushall Bay. The difference in thickness (c.2m of section) may be accounted for by the covered base of the isolated section (Section LC1A) on the assumption that the faults inferred to isolate Section LC1A are of negligible throw.

3.5 DETAILED FACIES DESCRIPTIONS

The upper beds of the Lyraun Cove Shale Member were divided locally within Lyraun Cove into two facies rather than the single mudstone facies described by Sleeman (1977).

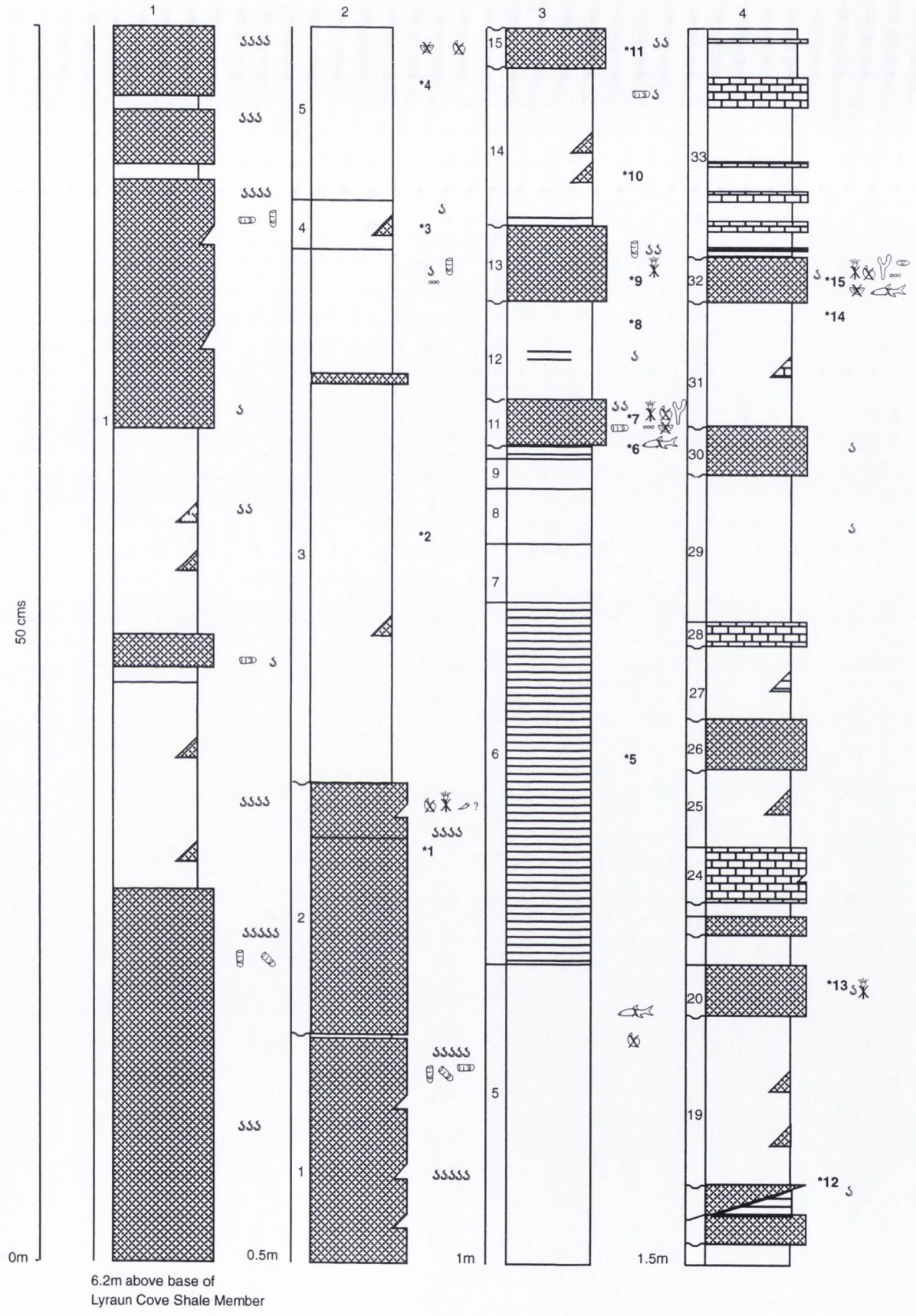


Figure 3.3a - Log from Section LC1, Lyraun Cove, Hook Head, Co. Wexford. See Figure 3.1 for location and key at Figure 3.6 - Log of Section LC1 continues overleaf.

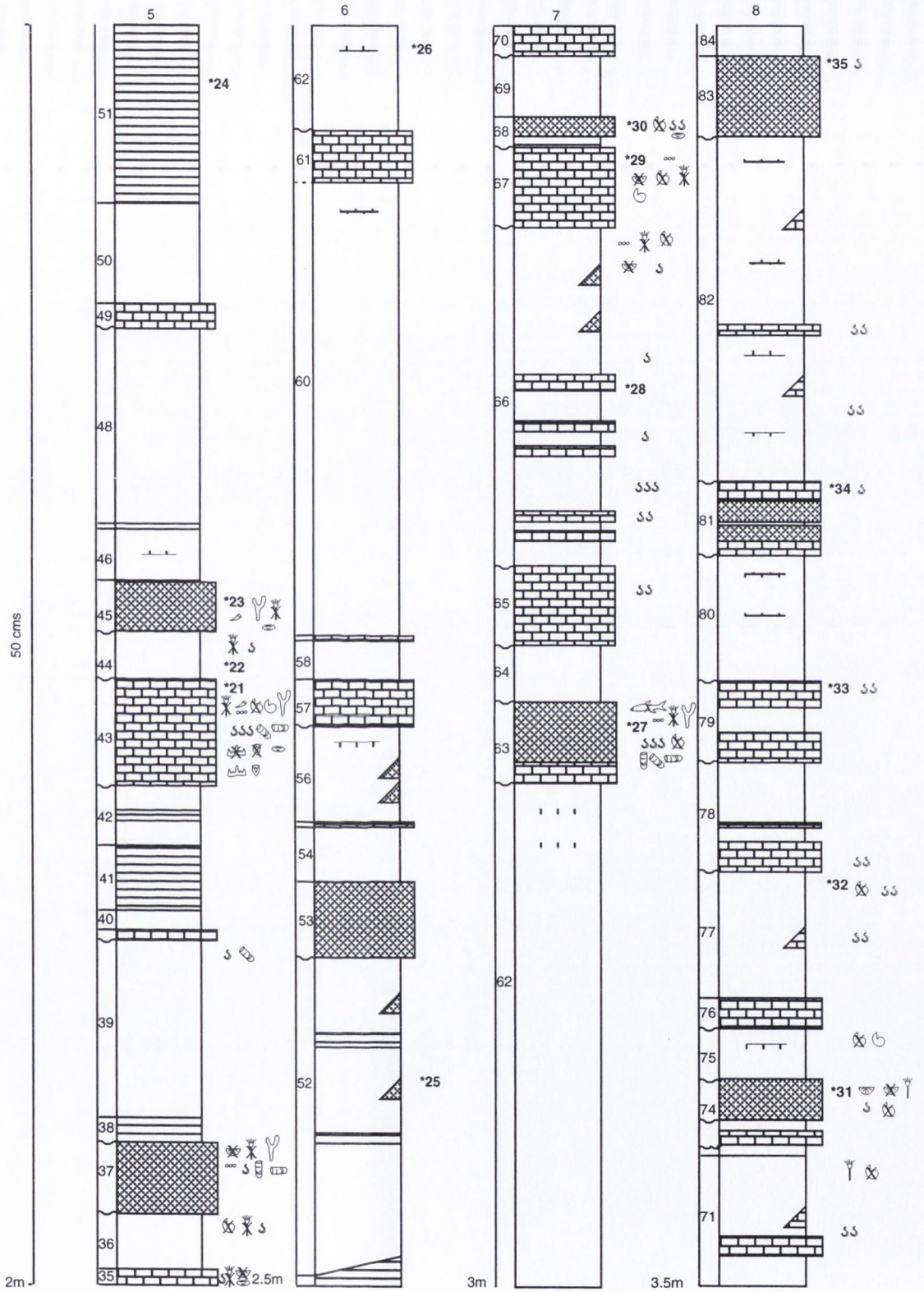


Figure 3.3b - Log from Section LC1, Lyraun Cove, Hook Head, Co. Wexford. See Figure 3.1 for location and Figure 3.6 for key. Log from Section LC1 continues overleaf.

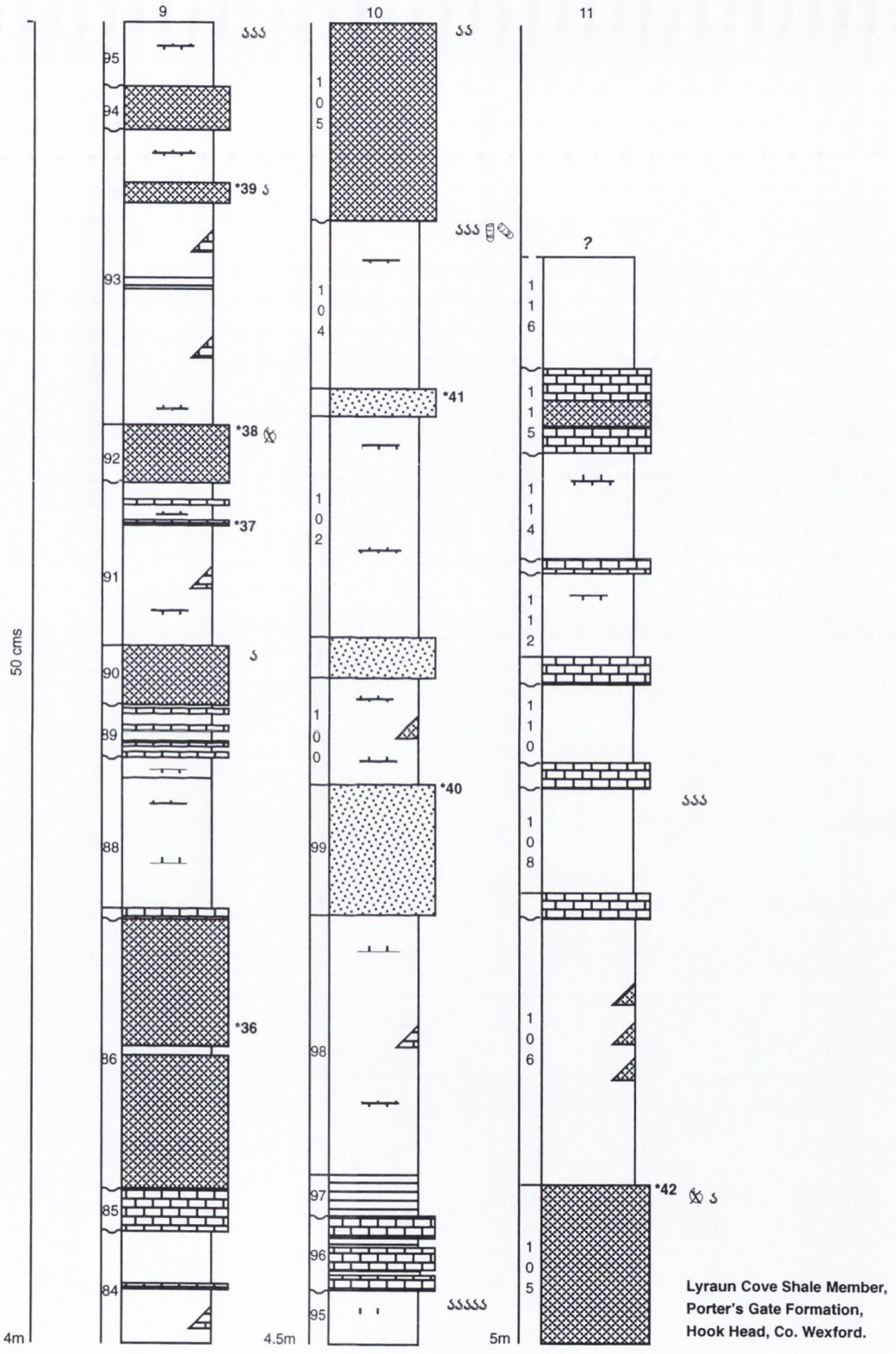


Figure 3.3c - Log from Section LC1, Lyraun Cove, Hook Head, Co. Wexford.
See Figure 3.1 for location and Figure 3.6 for key.

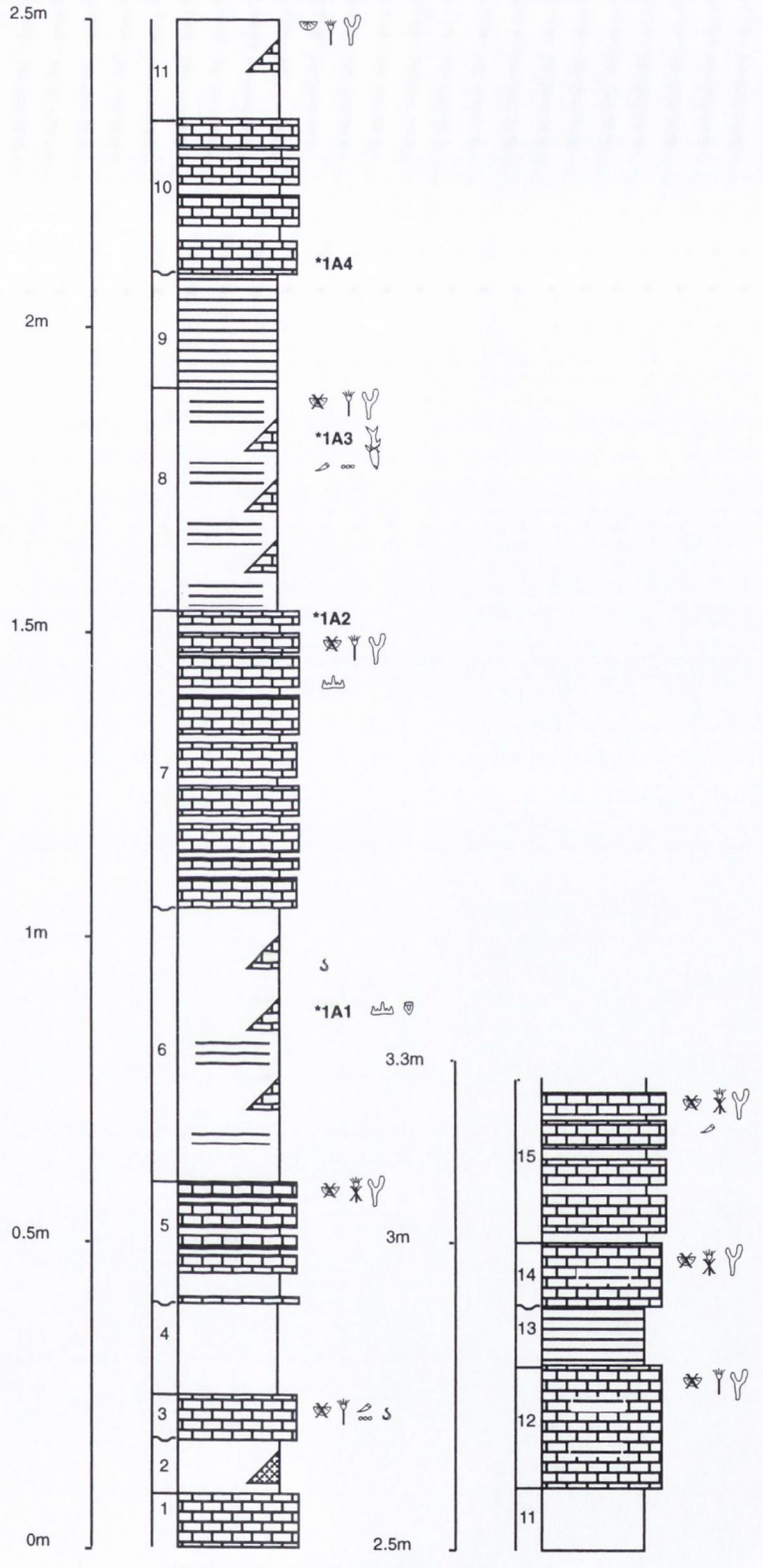
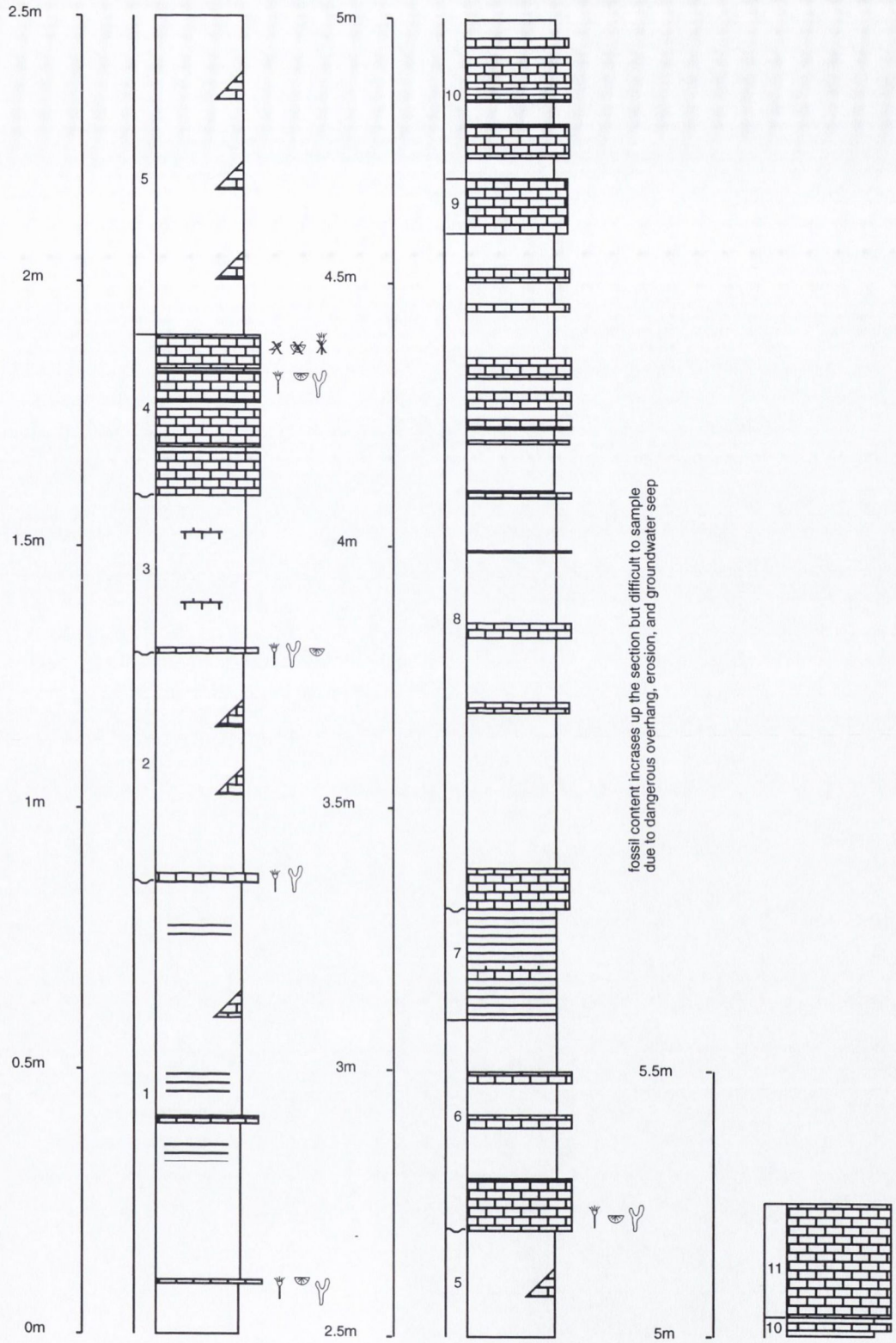


Figure 3.4 - Log from Section LC1A, Lyraun Cove, Hook Head, Co. Wexford.
See Figure 3.1 for location and Figure 3.6 for key.



Section 1B Lyraun Cove Shale Member, Porter's Gate Formation, Lyraun Cove, Hook Head, Co. Wexford.

Figure 3.5 - Log from Section LC1B, Lyraun Cove, Hook Head, Co. Wexford. See Figure 3.1 for location and Figure 3.6 for key.

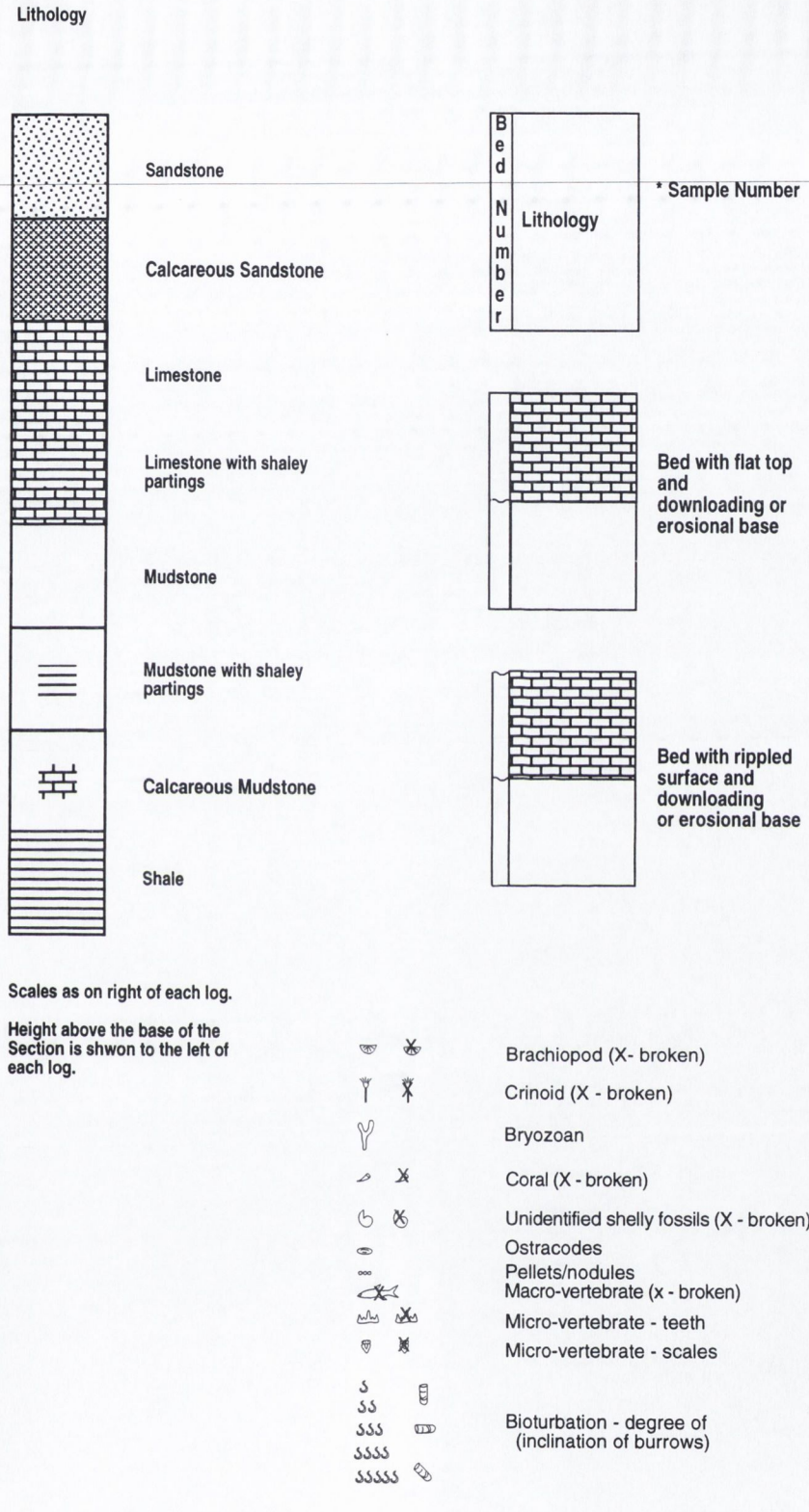


Figure 3.6 - Key to logs from the Lyraun Cove Shale Member of the Porter's Gate Formation, Hook Head, Co. Wexford. See Figures 3.3a-c, 3.4 and 3.5.

3.5.1 BIOTURBATED SAND/SILTSTONE FACIES - SECTION LC1

The 'bioturbated facies' of Sleeman (1974) is here renamed the Bioturbated Sand/Siltstone Facies since low intensity bioturbation occurs throughout much of the upper part of the Lyraun Cove Member and is not confined specifically to this facies. Section LC1 (Figure 3.3a-c) was measured from a horizon within a succession of interbedded calcareous sandstone and mudstone (Bioturbated sandstone/siltstone facies), beginning 6.2m above the base of the Lyraun Cove Shale Member. Only the higher two beds of the facies (Beds 1 and 2) have been numbered (Figure 3.3a). The greater part of the facies consists of calcareous sandstone and siltstone with many rippled surfaces; all the laminae and ripples are interrupted by burrows. Many of the burrows are horizontal to inclined and commonly cross over each other, they range in diameter from 32mm x 2mm to 3mm x 0.2mm. In cross-section most are elliptical (most likely as a result of post depositional compaction) (Figure 3.7.D-G). Vertical burrows, picked out by fills of siltstone and sandstone with occasional broken echinoderm ossicles also occur. In some cases these burrows become inclined close to the surface which is either their original orientation or is a result of compaction. *Teichichnus* burrows, which appear like an off-set stack of 'cut-in-half' pipes, occur in the mud-to-silt dominated parts of the facies. At the top of this facies is a bed of cleaner, more calcareous, crinoidal sandstone (bed 2) with a bioturbated surface. The contact with the mudstone facies above is abrupt.

3.5.2.1 MUDSTONE FACIES - SECTION LC1

This facies begins 69cm from the base of the section logged - some 6.9m above the base of the Lyraun Cove Shale Member above an erosional surface. It comprises non-calcareous mudstones interspersed with rare shales, thin calcareous sandstone beds, and towards the top, cleaner limestone beds. For the purpose of this study the mudstone facies in Section LC1 was logged on a 1cm:1cm scale.

The lowest beds of this facies (beds 3 and 4) comprise black semi-fissile mudstone with fine (<0.25cm) calcareous bands and rare calcareous sandstones which pinch and swell. Low intensity bioturbation was observed predominantly in the form of vertical burrows.

Bed 5 is a 20cm thick bed of black non-fissile mudstone containing broken skeletal fragments (brachiopod), identification of which are difficult due to post-depositional compaction.

Bed 6 represents the lowest occurrence of shale, a 15cm bed (a distinct marker locally in Lyraun Cove) of parallel-laminated black shale. This is followed by black non-fissile to semi-fissile black mudstone with parallel lamination which in Bed 10 yielded a broken chondrichthyan crushing tooth (Figure 3.7C).

Bed 11, occurring 1.33m from the base of the log is a calcareous sandstone. The surface of this sandstone contains many broken brachiopod valves; disarticulated, circular crinoid ossicles, lying articular surface up; phosphatic nodules; and broken phosphatic moulds of bryozoan. Acid residues yielded broken actinopterygian (possible palaeoniscoid) teeth and scales, conodont elements, and unidentified pieces of bone, together with some coprolites. Most of the above were found in the top 0.25cm of the bed in a fine silt 'crust'.

Bed 12 is a compacted, bioturbated (low intensity) mudstone overlain by 3cm of cross-bedded calcareous sandstone (bed 13) with a rippled top containing a few small crinoid ossicles. A series (47cm thick) of alternating non-fissile black mudstones and thin calcareous sandstone bands follow; many of them have rippled surfaces covered by a fine silt layer. Bioturbation is seen throughout these beds.

Bed 32 is a calcareous sandstone with a rippled surface on which lie disarticulated circular and pentameral crinoid ossicles, brachiopods (spiriferids), other unidentified brachiopods (convex up), bryozoans, ostracode valves (concave up) and quartz granules. Apart from the brachiopod valves, the average grain size is c.1mm. Phosphate occurs on the surface as internal moulds of bryozoans. Low intensity bioturbation is evident.

Beds 33 - 42 consist of thin limestones interspersed with mudstones. Scattered crinoid ossicles, draped by a layer of siltstone, occur on the upper surfaces of the limestones. Fine black shale beds are also interspersed towards the top.

Bed 43 is a calcareous sandstone/limestone bed, 4cm thick (HHLC21) with bioturbation at its base. This bed is very distinctive not only in lithology and fauna but also because it stands proud of the softer, more eroded beds above and below. The surface of this calcareous sandstone/limestone appears rippled but determination of the direction of the palaeo flow is made difficult due to surface erosion and lack of good 3-dimensional exposure. The fauna of this bed is locally diverse. Disarticulated crinoid ossicles are the most abundant elements: sub-circular to circular, pentameral and elliptical ossicles lie with

their articular surfaces up with much of their ornamentation preserved. The largest fossils are brachiopod valves which cover most of the surface and are convex up; however most of the valves are broken making identification difficult. Overlying the brachiopod valves is a fine siltstone cover in which are imbedded a lot of small ossicles, ramose bryozoa, echinoid spines, quartz grains, phosphate nodules and broken skeletal debris. Much of the larger phosphatic material (fish teeth and bone) appears to have been in place prior to this cover. The fauna includes two tabulate corals identified as *Vaughania vetus* and *Palaeacis axinoides* (Figure 3.7.B & A) which make their first appearance at this level.

Bed 44 is a thin black mudstone containing a few crinoid ossicles, overlain by a 2cm bed (bed 45) of calcareous sandstone very similar to bed 43 described above. The upper surface of bed 45 is covered by a thin film of siltstone partially obscuring quartz granules, small crinoid ossicles, and broken skeletal material. Within the upper parts of this bed there are more disarticulated crinoid ossicles, broken brachiopod valves and coral (*Vaughania*) whose abundance is less than in bed 43. Skeletal material is also considerably more broken. Horizontal burrows are a feature of the base of this bed.

Then follows some 12cm of predominantly mudstone with fine laminae of shale and a 0.5cm band of rippled limestone; the limited exposure of ripples suggests that current direction was from the north.

Bed 51 is a second substantial 9cm thick parallel laminated shale bed with a conspicuous horizontal calcite vein close to the base. Above this shale lie a series of non-fissile black mudstones (beds 52-62) containing lenses of calcareous mudstone, thin developments of shale, and some laterally continuous calcareous sandstone beds (again with rippled surfaces that suggest southerly directed palaeocurrents).

Bed 63 is a 3cm thick bed of iron-stained, calcareous sandstone with a rippled surface. As in many of the calcareous sandstone beds, a siltstone layer covers the surface but in this case shelly material is non concentrated immediately below the silt layer. The bed can be divided into 'three 'layers' - two fossil rich layers sandwiching a mud layer. The fossiliferous layers contain broken crinoid ossicles, possible brachiopod material, phosphate nodules, and phosphatic internal moulds of bryozoa. Also seen are stacked ostracode valves, concave up. This bed also marks the reappearance of bioturbation. The burrows are predominantly horizontal and only a few are vertical.

Beds 64-66 (Figure 3.3b) mark a return to compacted mudstones with intermittent calcareous beds which are burrowed sporadically throughout and become fossiliferous towards the top (crinoid ossicles, broken brachiopods and possible phosphate nodules).

Beds 67 and 68 each 3cm thick, consist of dolomitic limestone separated by shale laminae from an overlying 2cm of calcareous sandstone, both of which have a fine siltstone covering. The fauna of the lower dolomitic bed comprises large, but broken, convex-up brachiopod valves, overlain by fragmented skeletal material, disarticulated sub-circular to circular and pentameral crinoid ossicles and phosphatic material; the upper calcareous sandstone bed contains an abundance of shell fragments and stacked ostracode valves together with evidence of bioturbation. Beds 69-72 mark a return to sporadically bioturbated mudstone interleaved with calcareous lenses. These muds become fossiliferous towards the junction with a fine-grained limestone bed (bed 73). Bed 74 is a calcareous sandstone with a silt film covering crinoid ossicles, brachiopod valves and burrow infills and has a rippled surface. Overlying mudstones (bed 75) are somewhat more calcareous than those below, possibly due to an increase in shelly material. Any original lamination has been destroyed by burrowing. Limestone or dolomitic limestone beds with rippled surfaces are seen up to some 3.8m (beds 76-80) above the base of the log; at this level calcareous sandstone (bed 81) returns but although bioturbated at low intensity, appear to lack shelly fragments; bed 82 sees the return of black mudstones interspersed with calcareous bands that show low intensity bioturbation. Bed 83 is a calcareous sandstone with low intensity bioturbation on its upper surface; bed 84 returns to non-calcareous mudstones with limestone laminae and lenses topped by a thicker limestone (bed 85) neither of which show evidence of bioturbation.

Bed 86 comprises two calcareous sandstone laminae interleaved by mudstone and topped by a limestone bed (87); more calcareous mudstones then return becoming interleaved by limestone laminae at bed 89.

Bed 90 is a calcareous sandstone containing mud films and a rippled surface suggesting currents from the north. No macrofauna is visible. Scour marks are present on the base of the bed. This type of lithology is repeated as beds of up to 2cm thick, interspersed with partly calcareous, unfossiliferous, sparsely bioturbated mudstone for the next 25cm. Cross-bedding suggests southerly directed palaeocurrents. Above this, fine laminae of limestone appear together with a major increase in the intensity of bioturbation (bed 95).

Bioturbation appears to be absent for the next 25cm (beds 96-104) where beds vary from limestone with interleaved shale laminae to calcareous mudstones and fine grained micaeous sandstone. Bioturbation returns at the top of bed 104 (slightly calcareous mudstones). Bed 105 is a fine grained calcareous sandstone which generally lacks macrofauna except at the top where sparse shelly fragments occur.

The top 25cm of Section LC1 is a series of mudstones and calcareous sandstones (beds 106-116) fractured and slumped by recent erosion overlain by slipped glacial till and recent mud.

Throughout Section LC1, although some of the calcareous sandstone and limestone beds down-load into the underlying less competent beds, many have relatively flat bases and rippled upper surfaces.

3.5.2.2 MUDSTONE FACIES - SECTION LC1A

Section LC1A is an isolated section on the east-facing seaward cliff (Figure 3.1). The base of the section is obscured by beach cobbles. This section was logged just north of a minor fold. It is clear that Section LC1A is stratigraphically higher than Section LC1. The base of the section shows a number of relatively thin shelly limestone beds interspersed with parallel laminated mudstone and rare sandstone lenses. On the surface of Bed 3, three badly weathered specimens of *Vaughania* occur.

Bed 6 (Figure 3.4) is a 40cm thick bed of calcareous mudstone with shaley partings and fossiliferous limestone lenses. This is overlain by 50cm (bed 7) of fine limestone laminae with post-depositionally compacted mudstone and shale laminae. Each surface of the limestone laminae exposes broken brachiopods, crinoid ossicles and bryozoa.

Bed 8 marks a return to relatively thick (40cm) calcareous mudstone and shale laminae with occasional limestone lenses and beds of up to 4cm in thickness which contain broken brachiopod valves, bryozoan fragments, crinoid ossicles, a single *Vaughania* specimen, and phosphate material. At the top of this bed is a distinctive parallel laminated shale (bed 9). The upper part of the section (beds 10-15) consists of limestones interbedded with mudstones (the mudstones tend become more shaley towards the top of the section). Macrofauna increases with the introduction of the cleaner limestones.

The section ends some 3.3m above the observed base into glacial till and where bedrock is overlain by soil.

3.5.2.3 MUDSTONE FACIES - SECTION LC1B

Section LC1B was measured on the north facing cliff at the south side of Lyraun Cove (Figure 3.1) to the east of the cliff-top kiln and to east of the field run-off dyke. Since Section LC1B cannot be matched with any part of Section LC1A, it is presumed that there is no overlap between the sections.

The lower 75cm of this section (Figure 3.5) consists predominantly of parallel laminated mudstone with shaley partings, thin beds and lenses of fine grained limestones some of which are fossiliferous.

Above bed 4 are interbedded mudstones and limestone with bed 4 exhibiting the first conspicuous fossiliferous limestone in the section. The proportion of limestone increases towards the top of the section. Bed 11, a 20cm thick limestone was used to define the base of the Hook Head Formation (the lower part of which is now referred to the Ballymartin Formation. Approximately 2m above the top of this limestone bed is a distinctive red haematitic limestone which is used as a local marker bed.

3.6 PALAEONTOLOGY

3.6.1 INVERTEBRATE MACROFAUNA

Circular crinoid ossicles and fragments of brachiopod valves are found as low as Beds 2 and 4 (60cm and 90cm respectively) of Section LC1. It is not until some 1.3m above the base of this Section that skeletal material becomes more abundant with the advent of numerous circular crinoid ossicles, unidentified echinoid fragments, fragments of brachiopod material and bryozoa. The majority of the material was sufficiently fragmented to make accurate identification difficult. At 1.9m above the base of the section the brachiopods, although fragmented, can be identified to the genus *Spirifer* and *Schelwienella*, which occur together with sub-circular to circular crinoid ossicles, bryozoa and ostracode valves. Some 10cm higher, a few pentameral crinoid ossicles appear.

2.2m above the base of Section LC1 is Bed 43 and above it, Bed 45 (Figure 3.3b). The macrofauna is at its most diverse within these beds. It includes circular, pentameral

and elliptical (probably *Platycrinites* sp.) crinoid ossicles, fenestrate and ramose bryozoa, and brachiopod valves (broken specimens identified as *Spirifer* sp. and *Schelwienella* sp.). Two tabulate corals *Palaeacis axinoides* (Figure 3.7A) and *Vaughania vetus* (Figure 3.7B) make their appearance and are perhaps confined to these levels in Section LC1 (a single *Vaughania vetus* occurs in Section LC1A). Both the discoid *Vaughania* and the wedge shaped *Palaeacis* are abundant on the surface of these beds but do not occur in Bed 63 1m above, where the rest of the fauna is similar (Figure 3.3b).

Fragmented skeletal material, identified as crinoid ossicles, brachiopods and occasional stacked ostracode valves occur up to 3.7m from the base of Section LC1, at which level the occurrence of abundant skeletal material decreases.

In Section LC1A the macrofauna is again restricted mainly to the limestone beds where fragmented spiriferid, orthotetid schelwienellas and unidentified brachiopods, crinoid ossicles, ramose bryozoan, together with phosphate nodules, occur. On a number of surfaces some worn specimens of *Vaughania* occur. The macro-fossils are generally dispersed throughout these dolomitic limestone beds and lenses rather than being concentrated on particular surfaces and the quartz content is low. Some crinoid stems occur within the calcareous mudstones.

The faunal content of Section LC1B is similar to that of Section LC1A; the abundance of the skeletal material increases in tandem with the increase in limestone. It should be noted that much of this section in Lyraun Cove is difficult to sample due to its overhanging nature and extensive weathering of the overlying strata.

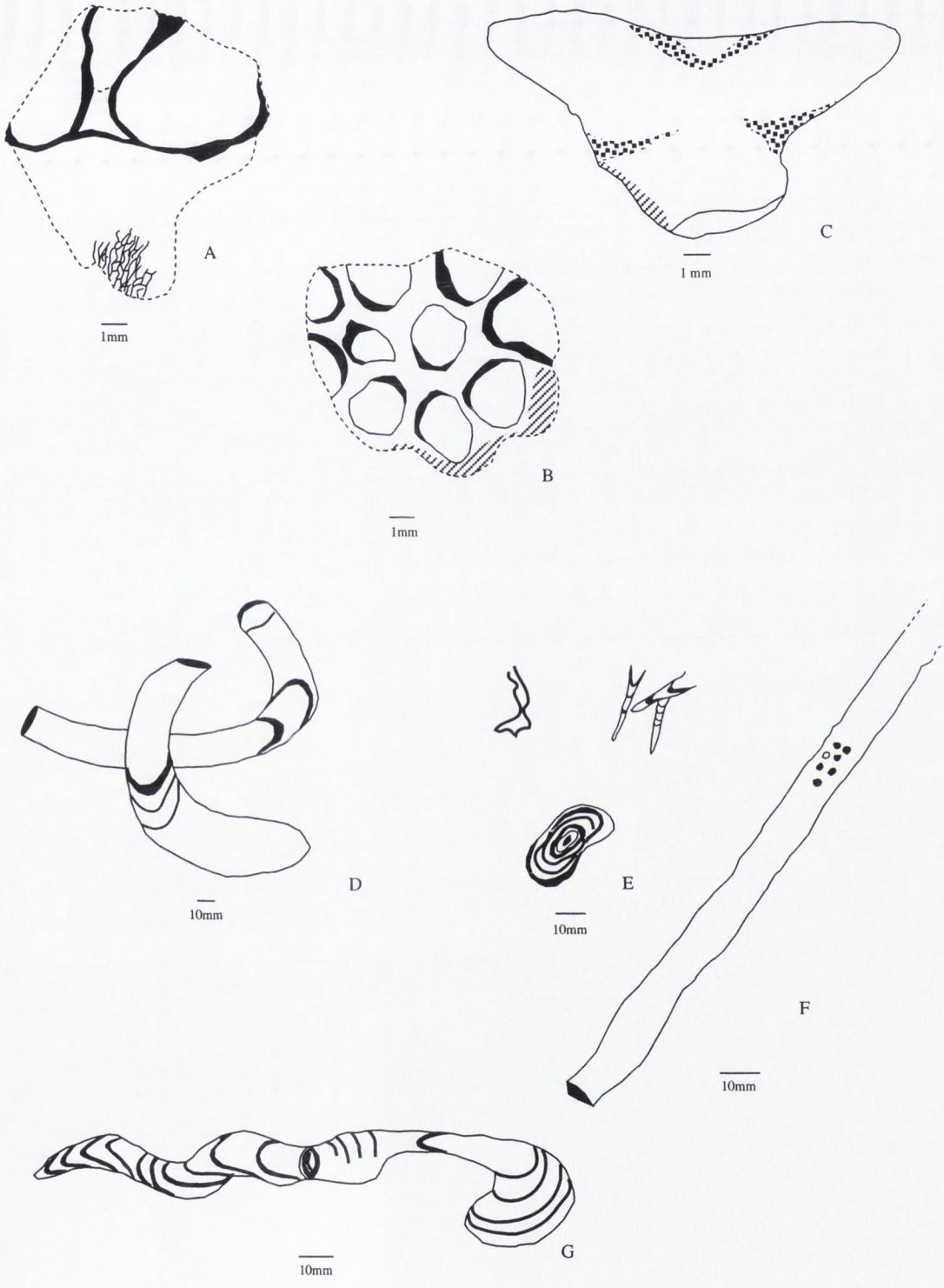


Figure 3.7. Drawings of fossils and trace fossils from the Lyraun Cove Shale Member. A. *Palaeacis* (TCD 36858); B. *Vaughania* (TCD 36862); C. Chondrichthyan crushing tooth (TCD 36863); D. Cross cutting horizontal burrows; E. Small *Planolites*-like burrow with flared burrows and top of vertical burrow; F. Straight horizontal burrow containing crinoid ossicles; G. Horizontal burrow. (A & B from bed 43, C from bed 10 and E-G from bed 1 of Section LC1)

3.6.2 INVERTEBRATE MICROFAUNA

Eight thin sections from the samples from Section LC1 were prepared, primarily to confirm the lithology, but also to ascertain whether they contained any significant microfauna. Three of these contain no micro/macrofauna. From a number of calcareous sandstone beds evidence of brachiopods, crinoids, bryozoans and ostracodes was obtained, consistent with the field observations.

From Bed 43 where the first major concentration bed was recognized in Section LC1 in the field, thin section examination revealed (in addition to the observed macrofauna) evidence of ostracodes and salebrids (microproblematica). No evidence of foraminifera was obtained from any thin section from Section LC1.

In Section LC1A, thin sections were again examined to confirm field observations of the lithology of the limestones - which proved to be packstones with a relatively high amount of dolomitic cement. The fauna observed included crinoid ossicles, broken brachiopod valves, *Rhombopora* and fenestrate bryozoans, echinoid spines, salebrids and ostracodes in varying concentrations. A number of vermiform gastropods were also recorded.

3.6.3 VERTEBRATE MACROFAUNA

Although Haughton (1856) suggested that the beds of the Lyraun Cove Shale Member are "literally covered with fragments of fishe's teeth", this unfortunately does not now appear to be the case. Their original existence cannot be disproved as Smyth (1930) described the Member, which he called The Fish Shales, as being "characterized by frequent Elasmobranch teeth and black phosphate nodules". He was however, referring to outcrops on the west of the peninsula together with the low tidal rocks of Woarwoy Bay and Lyraun Cove. Smyth suggested that the "*fauna is scant, consisting of fish teeth and spines,* Vaughania, Palaeacis *and an Orthotetid*" naming the vertebrate material in his faunal lists as teeth and spines from *Sandalodus morrisii* Davis and *Deltodus sublaevis* Agassiz.

During this study these so called "fish shales" appeared to contain conspicuously few macrovertebrates; only a single fractured chondrichthyan crushing tooth was recorded from Bed 12 of Section LC1 where it was imbedded in a thin mudstone/shale bed. The fractured nature of this tooth prevented identification below the level of Class.

Much of the phosphatic material on the surface of many of the beds within Section LC1 and LC1A from Lyraun Cove could not be attributed to original vertebrate material (see below).

3.6.4 PHOSPHATIC MICROFAUNA AND MACROFAUNA

As suggested above, not much of the phosphatic material observed in the field is directly of vertebrate origin. Apart from the rare fish teeth (and the historical records of teeth and spines) the phosphatic material appears to consist of nodules/pellets and possible coprolites, together with moulds of bryozoans, small gastropods and possible tubisalebrids (*incertae sedis*).

3.6.4.1 SECTION LC1

Forty-two samples were taken from the field for microscopic examination; of these fifteen (HHLC1 -1, 2, 3, 4, 6, 7, 9, 15, 20, 21, 23, 27, 28, 30 and 31 - figures correspond to sample numbers marked by an asterisk on the left-hand side of each log section Figures 3.3-6) were selected as possible candidates for dissolving. However, it proved very difficult to obtain residues from these samples using various methods (formic acid, acetic acid, industrial detergent and 'Quarternary O'). Some residues were obtained from all fifteen samples but only seven produced any phosphatic remains. These were HHLC1 - 6, 7, 15, 21, 23, 27, 28 - figures correspond to sample numbers marked by an asterisk on the left-hand side of each log section Figures 3.3-6.

Much of the phosphatic material in the residues proved to be of non-vertebrate origin such as nodules/pellets and possible coprolites together with replaced valves of ostracodes, and internal moulds of bryozoans and tubisalebrids.

The vertebrate material consists of unidentifiable bone fragments, acanthodian scales, actinopterygian teeth and scales and a few chondrichthyan scales/denticles; fragmented conodont elements also occur.

3.6.4.2 SECTION LC1A

The situation with relation to Section LC1A is similar; five samples were collected from this section - two separate samples from Bed 6, and one each from Beds 7, 8 and 10. Acid insoluble residues were obtained from all samples, and material in the form of a single *Thrinacodus incurvus* ferox morphotype tooth; two teeth described as

Chondrichthyan Pavement Dentition, actinopterygian teeth, together with acanthodian scales, fragmented actinopterygian scales and a number of bars were isolated from residues.

3.7 PHOSPHATE DEPOSITS

Phosphate forms a minor part of plant and animal soft parts as well skeletal bones and the shells of some invertebrate (for example brachiopods of the Lingulata) hard parts. It is one of the essential elements for life and is a primary nutrient in the marine environment. Although many sedimentary rocks contain a small amount of calcium phosphate as apatite, bone, teeth and scale fragments, phosphatic brachiopods, conodonts and coprolites, the concentration of phosphatic material in the upper beds of the Lyraun Cove Shale Member is considerably greater than average.

Apart from phosphatic teeth, scales and bone, a high percentage of the phosphate in the upper beds of the Lyraun Cove Shale Member appears in the form of nodules/pellets and possible coprolites, as well as replacement of other minerals. In the upper part of the Lyraun Cove Shale Member skeletal material of ostracodes and gastropods is replaced by phosphate, which also occurs as internal moulds of bryozoa, gastropods and ostracodes and salebrids. To form, there must initially have been enough available phosphate concentrated within the sea water to find its way into the sediment (Bearman, 1989) and hence to replace the original skeletal material such as calcium carbonate and to create the moulds.

Various mechanisms for the formation of phosphatic deposits have been put forward. These include the effect of upwelling currents which may occur in coastal areas where wind may drive surface waters off-shore allowing deep water to rise and move on-shore. This can lead to high organic productivity and concentration of phytoplankton in the surface waters which may lead to phosphate enriched sediments. Bacterial decay of organic matter within sediments allows phosphate to be precipitated in pellets and coprolites and to replace calcareous and siliceous skeletons, eventually creating nodules of phosphate. Modern upwellings are a feature of mid-latitude continental margins controlled by high pressure atmospheric systems mainly along the west side of continental masses (Burnett, 1983).

Phosphate nodules and pellets also appear to be features of areas of low net sediment accumulation (Folmi, 1990).

Once phosphate has been formed, reworking by storms and oceanic currents can winnow the fine non-phosphatized sediments thus concentrating the denser nodules/pellets, coprolites and replaced skeletal material together with original phosphatic skeletal material in single beds frequently associated with transgressive-regressive shelf and shore zones.

In the upper beds of the Lyraun Cove Shale Member examined here, there is no clear evidence of which mechanism was implicated in the formation of the phosphates. It is obvious that the concentration of phosphate within the ocean must have been enough to allow early replacement of non-primary phosphate skeletal material and to form nodules and pellets. These, together with primary phosphatic skeletal material and non-phosphatic invertebrate fauna, were winnowed and concentrated on the surface of the thin calcareous sandstone and limestone beds.

3.8 DEPOSITIONAL ENVIRONMENT

3.8.1 HOUSELAND SANDSTONE MEMBER AND LYRAUN COVE SHALE MEMBER

The Houseland Sandstone Member of the Porter's Gate Formation which underlies the Lyraun Cove Shale Member shows evidence of high energy shallow water conditions in the form of mega ripples of large wave length (Sevastopulo, pers. comm. 1999) and well washed oolitic grainstone at the top. The lower part of the Lyraun Cove Shale Member marks a substantial drop in energy levels. Sevastopulo (in press) has suggested that this reflects a rapid sea-level rise.

3.8.2 UPPER BEDS OF THE LYRAUN COVE SHALE MEMBER

3.8.2.1 Bioturbated Sand/siltstone Facies

The occurrence of this facies within the upper part of the Lyraun Cove Shale Member implies a source of siliciclastic sediment close enough to Hook Head and energy levels high enough for sand to be transported to this location. Sleeman *et al.* (1983) recorded conglomeratic levels in the Lyraun Cove Shale Member near Wexford town, some 20 km northeast of Hook Head, which suggests that the contemporary shore line was not much further to the north. The trace fossil assemblage of the sand/siltstone facies with conspicuous *Teichichnus* (*Cruziana* facies of Seilacher (1967)) is consistent with an interpretation of the palaeoenvironment as a shallow water shelf.

3.8.2.2 Mudstone Facies

The Mudstone Facies is dominated by non-calcareous mudstones and with rare intervals of shale, thin beds of calcareous sandstone and sandy limestone, many of which contain skeletal material and are cross bedded also occur. Bioturbation is a persistent feature throughout this facies; it decreases in intensity with the loss of skeletal material. Deposition of the mudstones appears to be the result of slow deposition of mud from suspension following storm activity. This could create episodic sedimentation rates and allow for the apparent intense bioturbation which occurs sporadically through the mudstone and shale beds. The ichnofauna has not been identified fully but appears to have been created by suspension feeders taking advantage of the quiet energy conditions as well as the probably enrichment of the sediment in organic material. The traces most closely resemble *Planolites* (Figure 3.7E) burrows which are found within the *Cruziana* ichnofacies of Seilacher (1967) or the *Glossifungites* ichnofacies where they are often referred to as facies-crossing traces (Ekdale *et al.* 1981). Sedimentary features indicative of emergence have not been identified.

Although skeletal material is concentrated within the calcareous sandstone, limestone and dolomitic limestone beds, this is not invariably the case and some material appears in the slightly calcareous mudstones. However, it is the calcareous sandstone, limestone and dolomitic limestone beds that are of particular interest.

On the weathered surfaces of some of the calcareous sandstone beds, chondrichthyan remains have been identified, such as the teeth and spines of *Sandalodus morrisii* Davis and *Deltodus sublaevis* Agassiz, identified by Smyth (1930), together with unidentified tooth and spine fragments.

During preparation of material from these beds using acetic acid and Quarternary 'O' to obtain residues, a chondrichthyan crushing tooth together with osteichthyan scales, bone and a few teeth were isolated. The majority of the phosphatic material has been identified as nodules/pellets, coprolites, internal moulds of bryozoa, replaced ostracode valves and fragments of replaced skeletal material. Only in the residues obtained from the dolomitic limestone beds within Section LC1A are there any chondrichthyan remains that are specifically identifiable (*Thrinacodus incurvus* ferox morphotype teeth).

The majority of the calcareous sandstone and limestone beds show a similar evolution. They overlie a mudstone bed with frequent traces of burrowing activity at their base shown by sandstone piped down into the mudstone. Rare broken skeletal fragments are dispersed through the bed together with phosphate nodules. The larger, less

fragmented skeletal elements, usually brachiopod valves, lie convex up near the surface of each bed with disarticulated, disc-shaped crinoid ossicles with their short dimension normal to bedding, scattered over them. Accompanying the crinoid ossicles are larger rounded quartz grains (up to granule grade); rare ostracode valves - individual and stacked; phosphatic internal bryozoan moulds; nodules/pellets; and, in some beds, both fenestrate and ramose bryozoa. A siltstone film lies over the whole surface. It is from this surface that any of the larger pieces of phosphatic material and fish remains now stand proud. In two of the beds the tabulate corals *Vaughania* and *Palaeacis* occur weathering out through the covering siltstone film. The base of the beds show parallel lamination with cross bedding appearing towards the top. Many of the beds appear to have low amplitude current-rippled surfaces.

It is here suggested that these beds represent intermittent storm transport of sediment allowing an influx of sands from a distant shoreline to be deposited under enough wave activity to concentrate the sands and skeletal material.

These beds appear to represent condensed layers (Condensed Facies - see Chapter 10) which possibly record many periods of non-deposition, reworking and erosion; possibly the last communities to occupy the seafloor are over-represented except for the more resistant phosphatic material.

The benthic biota although restricted (there are for instance no rugose corals and the crinoid fauna is not very diverse) is indicative of normal marine salinity and is typical of Carboniferous shallow marine shelves.

The palaeoecology of the invertebrate fauna is suggestive of a shallow water marine environment. Through some mechanism (perhaps localized upwelling) phosphate must have been concentrated enough within the waters to allow the sediment to become sufficiently enriched to allow nodules/pellets to form and the invertebrate skeletal material to be replaced by phosphate.

During storm episodes the lighter and non-phosphatic sediments were winnowed, concentrating the phosphatic nodules and pellets together with the coarse invertebrate skeletal material, fish material and granule-grade sand grains.

The calcareous sandstone beds are gradually replaced upward in the succession by increasingly lime-rich dolomitized beds and although the fauna is comparable, it is distributed throughout the beds. The mudstones also become more calcareous. It is suggested here that this replacement of sandstone by limestone is related to a gradual increase in water depth and distance from any substantial sand source, but that the

environment was still above storm wave base. The thin limestones which generally have the fauna distributed thought the bed, also exhibit, in some instances, a winnowed surface similar to those of the sandstone including the reappearance of *Vaughania* - a shallow water discoid tabulate coral. These beds also appear to be the result of periodic storm episodes.

In summary, the upper beds of the Lyraun Cove Shale Member appear to have been deposited on a shallow, open marine shelf below normal wave base with a strand line to the north of the area (Sevastopulo, 1981). Mudstone deposition was interrupted sporadically by storm episodes which led to the transport of sand seaward. Although the small amount of fish material recovered is largely from the concentrated levels at the top of sandstone beds, there is no evidence that it was derived from environments different from that represented by the remainder of the Lyraun Cove Shale Member.

CHAPTER 4: KILBRIDE QUARRIES, KINGSCOURT OUTLIER

4.1 INTRODUCTION

The Kilbride Quarries were sampled by Davida Geraghty as part of her work on the composition of conodont apparatuses (Geraghty, 1996). The quarries are excavated into the sides of a low hill. As the acid insoluble residues from this sampling contained a large amount of vertebrate material in addition to conodonts, the residues were made available for this study. Some samples yielded more than two hundred conodont elements per kilogram. Fish microvertebrates were more abundant than conodonts.

The two quarries (Irish grid reference N 845 848) are situated close to the town of Nobber, Co. Meath sited on the edge of the 'Kingscourt outlier' (Figure 4.1). The northern back face of the lower quarry and the southern back face of the upper quarry are separated by an area of no exposure. The lower quarry now contains a silage pit. The basal bed of the upper quarry is inferred, by projecting the dip, to lie close above the top bed of the lower quarry.

4.2 PREVIOUS WORK

During his time as Commissioner for the General Valuation of Ratable Property Richard Griffith (later Sir Richard Griffith) encouraged his employees to collect geological information whilst undertaking their valuation surveys in an effort to compile his independent Geological Map of Ireland (Griffith, 1839). One of the areas surveyed was the Kingscourt outlier; the faunal lists from some of the areas within the outlier were published in 1860 (Griffith, 1860).

During the middle of the nineteenth century both Robert Kane (1845) and John Hamilton (1852) made reference to the area around Kingscourt. Later the Geological Survey published maps and a memoir of the area with the contributions on the palaeontology by W.H. Baily.

Jackson (1955) in an unpublished Ph.D. thesis provided the first modern treatment of the Carboniferous stratigraphy. Although the Dinantian part of Jackson's thesis was never published, he made available a stratigraphic column which was reproduced by George *et al.* (1976). In the thesis Jackson described and figured *Rhadinichthys monensis* (Egerton) and *Rhabdoderma ardaghense* from the Namurian of the Ardagh Stream sections.

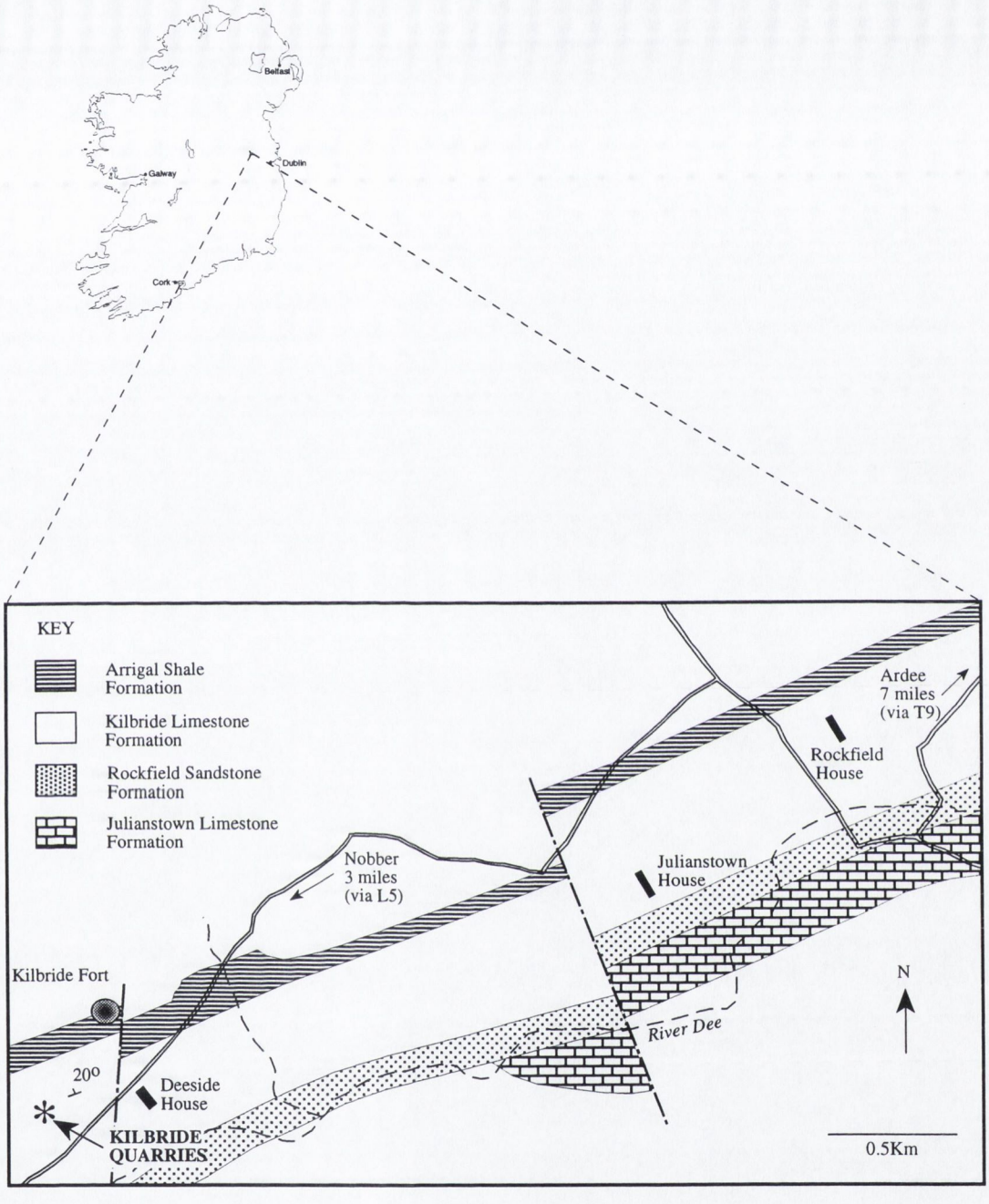


Figure 4.1. Location of Kilbride Quarries including the general geology of the area. (Modified from Johnston (1976)).

Austin and Aldridge (1969) provided a faunal list of conodonts from samples of the Kilbride Limestone (on a roadside cutting close to Nobber). Johnson (1976) in an unpublished thesis provided a map and revised stratigraphy of the southern part of the outlier, including the Kilbride Quarries and established the conodont biostratigraphy of the Tournaisian rocks of the region. von Bitter *et al.* (1986) described the conodont *Mestognathus praebeckmanni* from the upper part of the Kilbride Limestone Formation. George *et al.* (1976) attempted to place previous biostratigraphical data in the framework of the then newly described Dinantian stages. In the first edition of the *Geology of Ireland*, the area is described in a chapter on the Lower Carboniferous (Sevastopulo, 1981). Strogen *et al.* (1995) have described the Dinantian stratigraphy of the Kingscourt outlier based on new information for borehole cores.

4.3 STRATIGRAPHY

4.3.1 Jackson (1955) divided the Dinantian of the southern part of the Kingscourt outlier into the following units (in ascending order): Basal Grit; Porcellanous Limestone; Rockfield Sandstone; Orthotetid Limestone; Kilbride Limestone; and Arrigal Beds. Johnson (1976) modified Jackson's stratigraphical scheme by combining the Orthotetid Limestone and Kilbride Limestones, he named the combined unit the Kilbride Limestone Formation.

Strogen *et al.* (1995) in their revision of the Dinantian stratigraphy of Kingscourt outlier divided the succession into four groups which have been recognized elsewhere in the east of Ireland: the Navan and Cruicetown Groups (both of Tournaisian age); and the Fingal Group and its lateral equivalent the Milverton Group (both of Viséan age) (Figure 4.2). Within the area of the Kilbride Quarries, only the Navan, Cruicetown and Fingal Groups are present. The Kilbride Limestone Formation is the uppermost Formation of the Cruicetown Group and overlies the Slane Castle Formation. Overlying the Kilbride Limestone Formation in this area is the Dee Member of the Tober Colleen Formation, the lowest formation within the Fingal Group (see Figure 4.2 for comparative stratigraphy).

The two quarries (Kilbride quarries Irish grid reference: N 845 848 - Sheet 13) are situated just south-west of Kilbride Fort and south-east of Nobber, Co. Meath. They lie within the Kilbride Limestone Formation of both Johnston (1976) and Strogen *et al.* (1995) and the "Kilbride Shelly Limestone' of Jackson (1955). (Figure 4.2)

4.3.2 The age of the Kilbride Limestone Formation has been assessed by several authors. Jackson (1955) using the zonal scheme of Vaughan (1905) considered that the brachiopod fauna was of ZC age. Austin and Aldridge (1968), on the basis of conodonts, considered the formation to be of C1 age. The C1 zone of Vaughan (1905)

included both the late Tournaisian and Lower Viséan of current stratigraphy (Riley, 1993). Johnston (1976) recovered both *Scaliognathus anchoralis* and *Mestognathus praebeckmanni* cf. *beckmanni* from a level above the Kilbride Quarries in the upper part of the Kilbride Formation. This assemblage is now known to indicate a later Tournaisian ("Freyrian") age. George *et al.* (1976) assigned the Kilbride Limestone of Jackson to the Chadian and the underlying Orthotetid Limestone to the Courceyan Stage. Strogen *et al.* (1995) assigned the bulk of the redefined Kilbride Formation to the Courceyan Stage with its upper part extending into the Chadian.

The conodonts recovered by Geraghty (1996) from the Kilbride Quarries were assigned to the *Polygnathus mehli* conodont. Although no microfauna diagnostic of the "Freyrian", such as the foraminifera *Valvulinella* or the conodont *Mestognathus praebeckmanni*, has been found in the quarries, there is a strong possibility that the succession is of "Freyrian" age: in the 1960's when the Quarry was still active, a grey-green clay band identified by the late J.S. Jackson as derived from a volcanic ash, could be seen in the lowest part of the quarry (Sevastopulo, pers. comm. 1999). Clay bands of this type have now been recognized widely within the Midlands close the top of the Waulsortian Limestones (Sevastopulo, in press), at horizons which are certainly of "Freyrian" age.

4.3.3. Quarry 1 is a slurry pit and the lower part of the section shown on the log in Figure 4.3 is now covered. The quarries have not been worked for many years and so the lithological detail is difficult to ascertain from the quarry face which is encrusted with lichens except on some joint surfaces where solution has occurred. On these few cleaner exposures, the limestones can be seen to be skeletal packstones with a high content of coarse disarticulated crinoid ossicles. Thin sections made from the samples collected for investigation of acid insoluble residues corroborate the identification of the limestones as coarse crinoidal packstones (see below).

Discrete limestone beds, many of them with conspicuous bed-parallel pressure solution seams and stylolites, are interbedded with more rubbly weathering, shaly limestones. The latter consist of nodular limestone and shale, the texture probably reflecting the presence of large burrows. The uppermost beds in Quarry 2 are dolomitized (Figure 4.4).

There is a small stratigraphical gap between the upper beds seen in Quarry 1 and the lowest beds in Quarry 2. Projection of the shallow dips northward suggest that approximately 2m of section is unexposed between the two quarries.

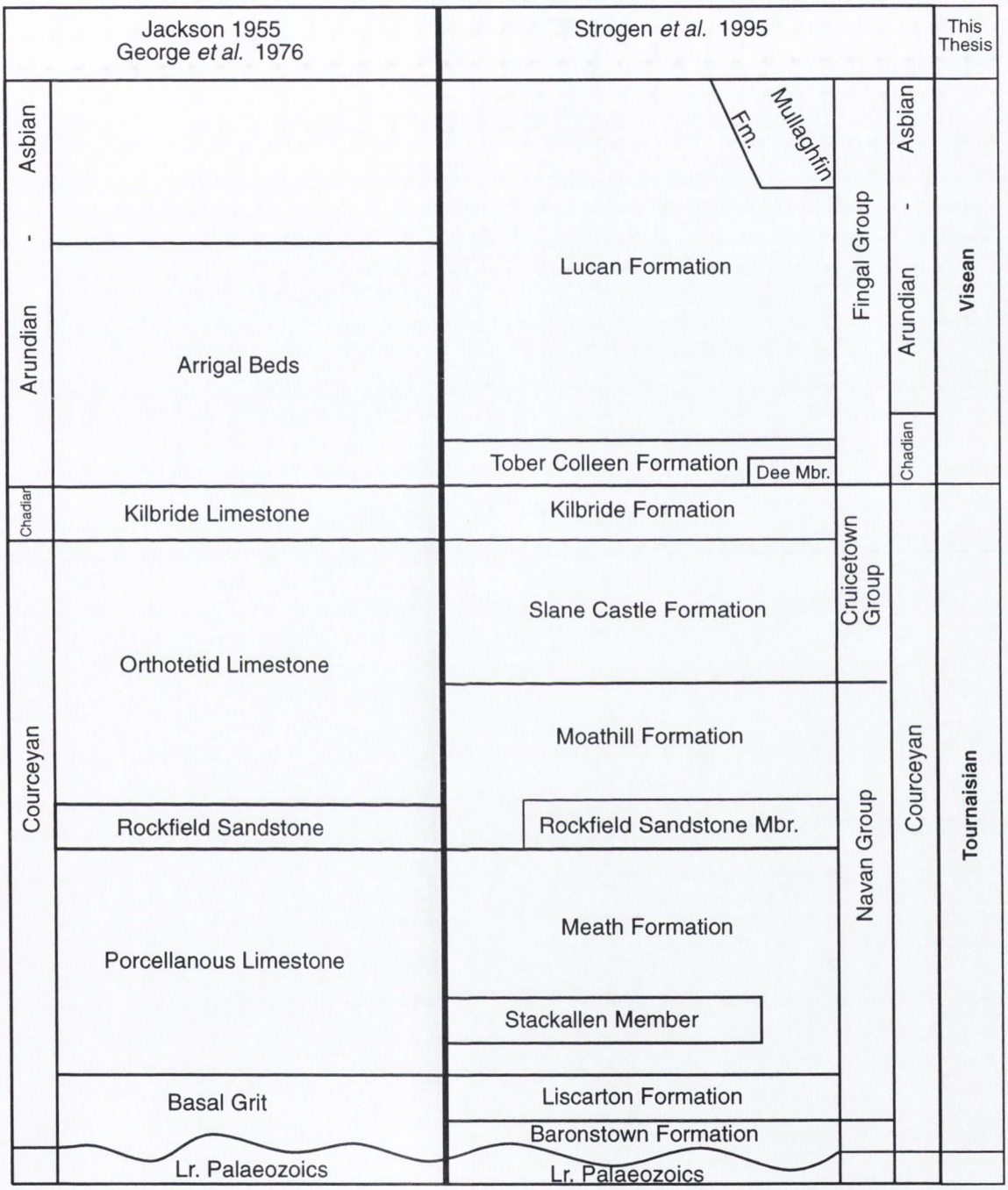


Figure 4.2. Stratigraphy of the south part of the Kingscourt Outlier showing correlation of groups and formations recognised by Strogen *et al.* (1995) and those proposed by Jackson (1955). Kilbride quarries lie within the Kilbride Limestone Formation.

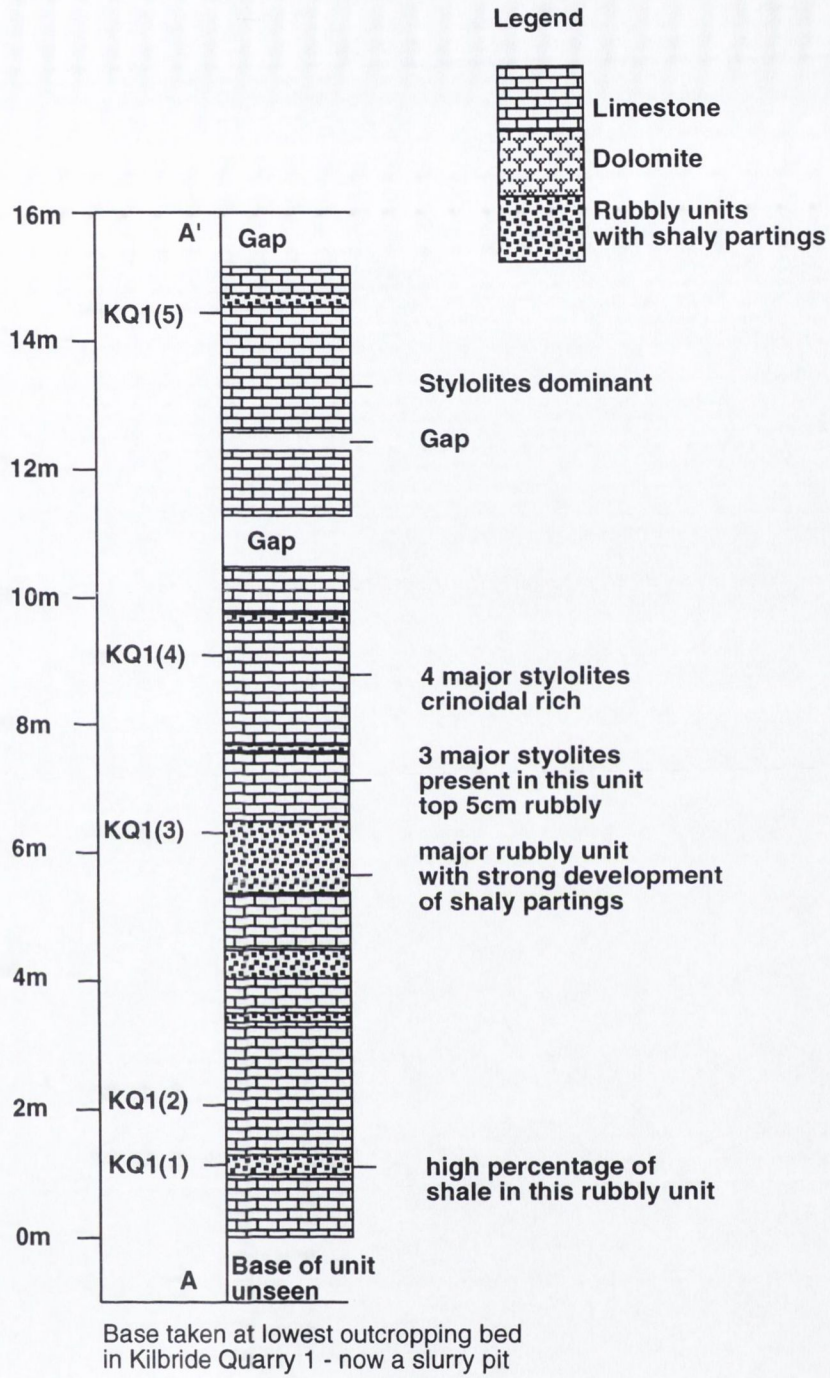
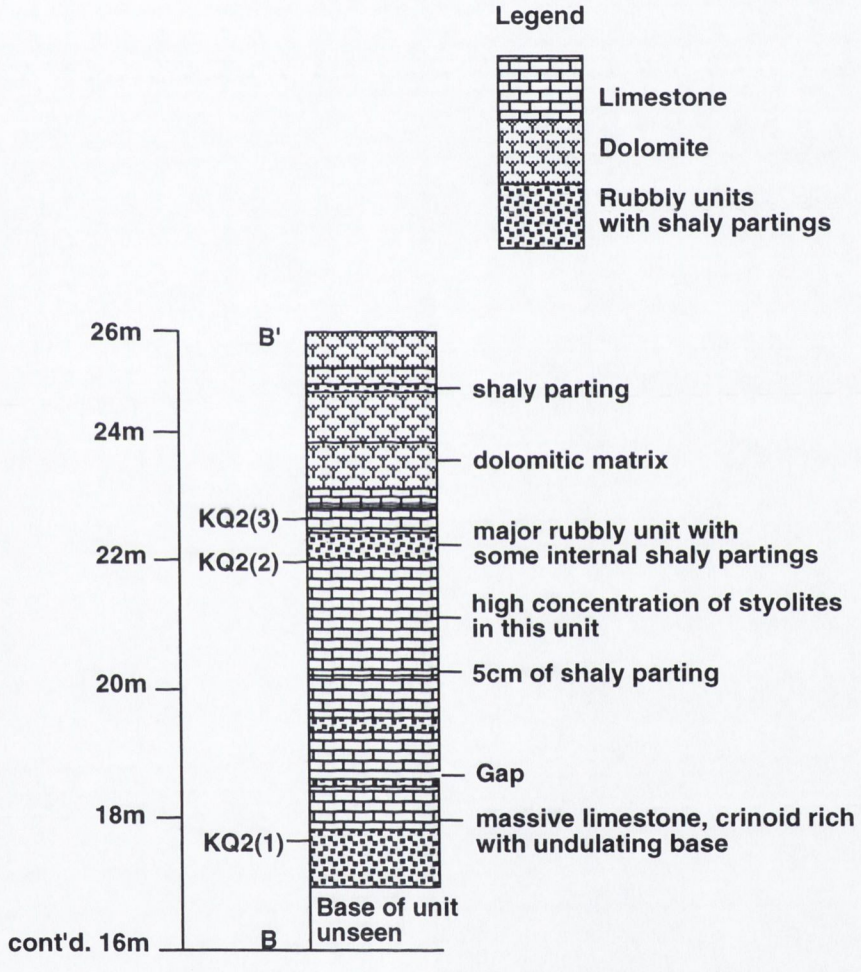


Figure 4.3. Log of Kilbride Quarry 1, (the southern quarry) near Nobber, Co. Meath (Irish Grid N 845 848) showing sample points (sample number prefixed KQ1) (After Geraghty, 1996)



Base of unit not seen in the field but inferred to lie closely above the top bed of Kilbride Quarry 1.

Figure 4.4. Log of Kilbride Quarry 2,(the northern quarry) near Nobber, Co. Meath (Irish Grid N 845 848, showing sample points (sample numbers prefixed KQ2) (After Geraghty 1996)

Yields of fish microvertebrates range from zero in sample KQ1(1), taken from the lowest rubbly horizon in Quarry 1 (Figure 4.3), to several hundred teeth per Kg of limestone in sample KQ1(2), a shale-free crinoidal packstone (Figure 4.3). However, there does not appear to be any obvious correlation between rock type and yield of fish microvertebrates.

4.4 PALAEONTOLOGY (from thin section and hand sample)

The description of the fish microvertebrates recovered from the acid insoluble residues is given in Chapter 7, whilst the conodont faunas from the same residues are described in Geraghty (1996).

The invertebrate fauna of the Kilbride Limestone which according to Jackson (1955), is abundant and diverse, includes brachiopods, bivalves and gastropods. In hand samples (from the quarries) the limestones are relatively coarse grained, grey, crinoidal packstones (frequently exhibiting stylolites). The 'rubbly' horizons appear to be strongly burrowed.

Thin sections (TCD numbers 36885-36891) were examined from the seven bulk samples that contained both conodonts and fish microvertebrates.

The skeletal components identified in each thin section are shown in Figure 10.1 (under the heading of Kilbride Quarries-Invertebrate Fauna). Bryozoans (broken fenestellid mats, ramose and encrusting forms), brachiopod shells, crinoid ossicles and ostracodes occur in almost all samples, while echinoderm spines, plurilocular foraminifers, and molluscs have a more sporadic occurrence. The microbiota consists of possible red algae (aonjgaliids including *Mametella)*, calcispheres, foraminifers (*Earlandia*, endothyrids, and *Tetrataxis*) and abundant salebrids (*incertae sedis*), particularly *Tubisalebra*.

4.5 DEPOSITIONAL ENVIRONMENT

The presence of crinoids, brachiopods, bryozoans and echinoderms suggest that the salinity was within normal marine values; the presence of possible red algae (*Mametella*) suggest that the water depth was probably within the photic zone with a maximum depth of up to c.100m (this depth obviously depends on many factors not least the clarity of the seawater itself and the consequential ability of light to penetrate). The occurrence of plurilocular foraminifers appears to confirm the relatively shallow water palaeoenvironment because in the late Tournaisian they appear to be restricted to moderately shallow water (Lees and Miller, 1995, figure 21, p.218). The lithological

character of the limestones is consistent with a moderately shallow water environment. The dominance of coarse skeletal packstones and the occurrence of thin shale partings suggests that current activity was not strong or persistent enough to winnow the mud-grade sediments. A setting which would be consistent with the lithological and faunal/floral evidence is a fully marine shelf at water depths below fair-weather wave base but above storm wave base. The position of the Kingscourt outlier relative to the contemporary late Tournaisian shore line to the north and the deeper water Waulsortian carbonate mudbanks to the south (Figure 1.4D) lends support to this interpretation.

CHAPTER 5: URLINGFORD CORE, URLINGFORD, CO. KILKENNY

5.1 INTRODUCTION

Core from a borehole drilled by Tara Exploration plc. (BH3246) located 4.4 km west of Urlingford Co. Kilkenny (Irish Grid S 237 634) (Figure 5.1) was logged by Dr. M. Philcox and samples were taken for biostratigraphic purposes. The acid insoluble residues from these samples contained not only conodonts but also other vertebrate material No thin sections or hand samples of the material taken from the core were available at the time of writing and the stratigraphy and biostratigraphy has been taken from published articles relating to the area. The samples were selected (Philcox, pers. comm., 1996) from limestone beds within the upper part of the Ballysteen Limestone Formation. The number of fish microvertebrates is relatively small; this is a reflection of the small sample size and the low diversity of the fauna is probably a consequence of this. However, since any worthwhile biostratigraphical tool for Dinantian rocks in Ireland will need to be applicable to samples obtained from boreholes, the Urlingford core provides a test of the practical use of fish microvertebrates in biostratigraphy.

5.2 PREVIOUS WORK

Little previous work has been published on the area from which the core was taken. A detailed description and correlation of areas with equivalent lithostratigraphy are contained in a publication on the Lower Carboniferous of the Irish Midlands (Philcox, 1984). The stratigraphy of the host rocks of the zinc-lead ore deposits in surrounding areas is well known. Doyle *et al.* (1992) have described the Tournaisian stratigraphy at Galmoy situated approximately 9 km due north of Urlingford and Hitzman *et al.* (1992) that of Lisheen 11 km north-west of Urlingford.

5.3 STRATIGRAPHY

The borehole collared in strata above the Waulsortian carbonate mudbank facies and was drilled to a horizon within the Ballysteen Limestone Formation (Figures 5.2, 5.3).

The evolution of nomenclature of the Tournaisian succession is shown in Figure 5.2. Philcox (1984) following Shephard-Thorn (1963), assigned all the strata between the Ringmoylan Shale Formation and the Waulsortian Limestone to the Ballysteen Limestone Formation. This was divided into Lower, Middle and Upper divisions and in

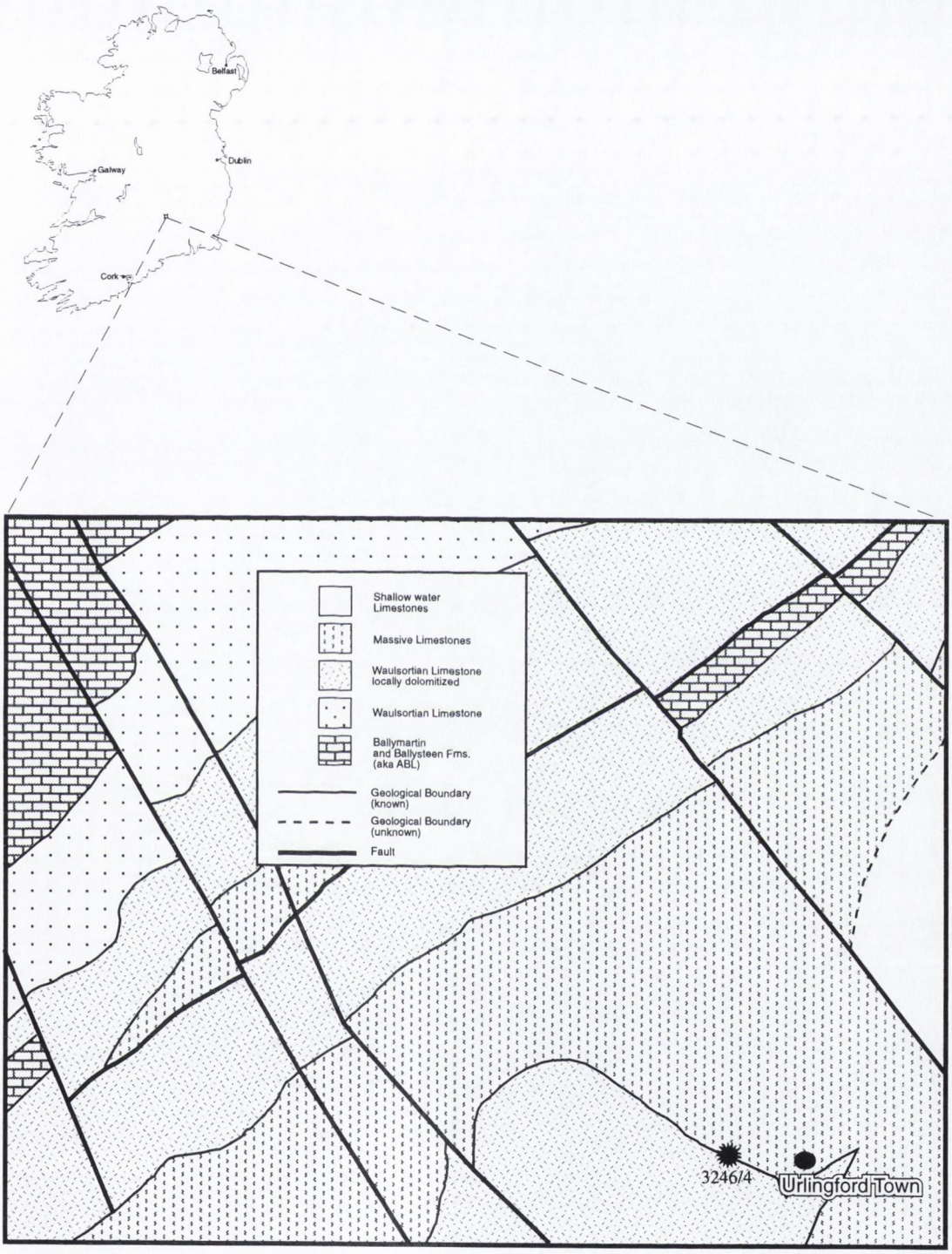


Figure 5.1. Local Geology of the area surrounding Urlingford, Co. Kilkenny. (After Hitzman, 1992)

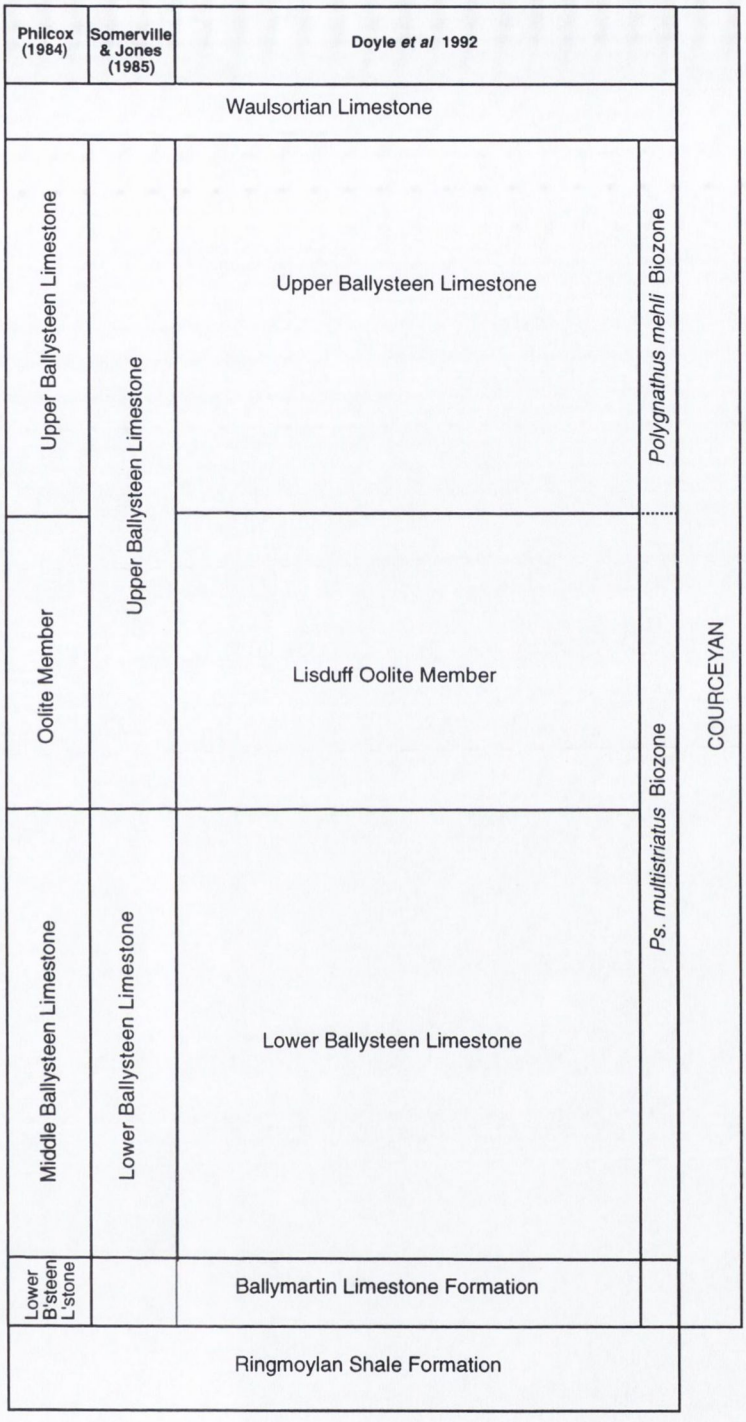


Figure 5.2. Stratigraphy of theTournaisian (Courceyan) rocks from the Galmoy Zn-Pb deposit area close to the location of the Urlingford Core 3246/4 (after Doyle *et al.* 1992), and comparison with the stratigraphical nomenclature of Philcox (1984) and Somerville and Jones (1985).

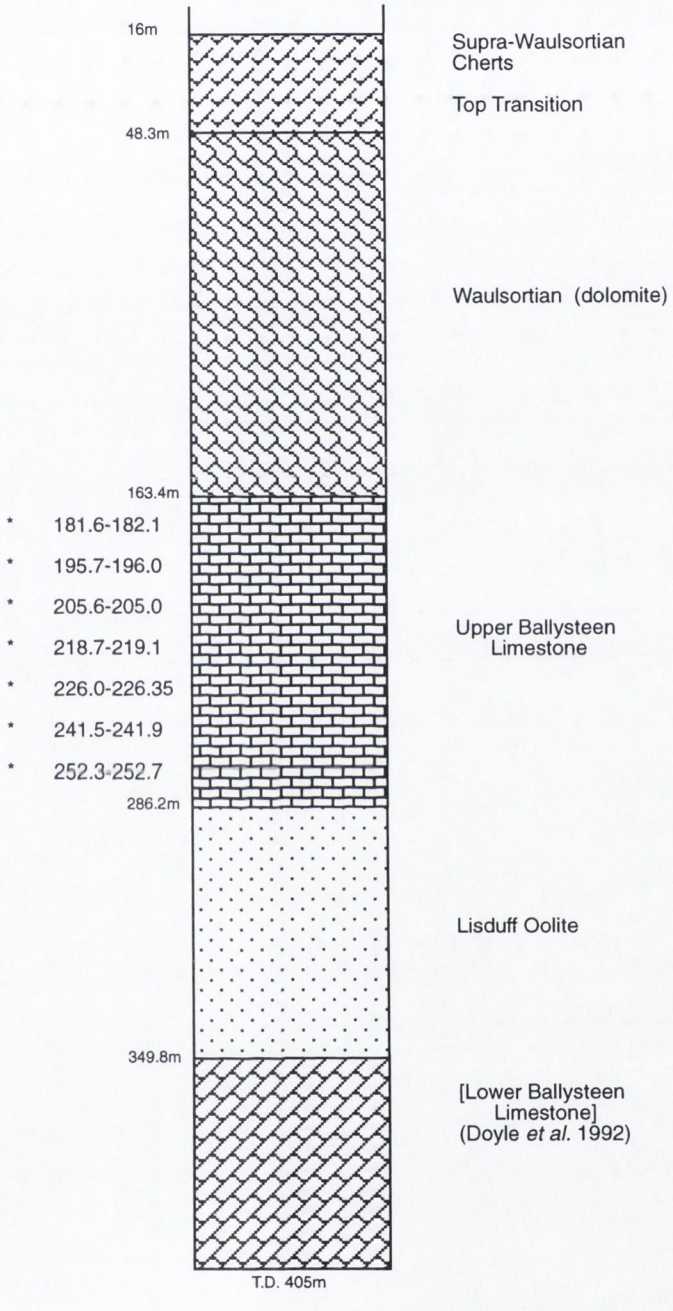


Figure 5.3. Dip-corrected stratigraphic column for Urlingford Core 3246/4 (modified from Philcox 1992) showing the position of samples.

the south-east of the county, where the Urlingford cores were drilled, a prominent Oolite Member was recognized between the Middle and Upper divisions. Somerville and Jones (1985) named the original Lower Division of the Ballysteen Formation, the Ballymartin Point Formation and referred to the former Middle Ballysteen Limestone as the Lower Ballysteen Limestone. Sleeman *et al.* (1997) named the Oolite Member the Lisduff Oolite Member. Doyle *et al.* (1992) and Hitzman *et al.* (1992) have used this revised stratigraphy and Doyle *et al.* (1992) have illustrated the relationship of the lithostratigraphical divisions to the conodont Biozones (Figure 5.2).

The borehole (BH 3246/4) spans the interval from just above the top of the Waulsortian to the Lower Ballysteen Limestone. The lithological succession according to Philcox (pers. comm., 1998) is as follows. The borehole collared in cherty limestones (of which 48.3m were drilled) and then intersected 115m of Waulsortian facies which was pervasively dolomitized. The Upper Ballysteen Limestone, from which the samples were obtained, consists of thinly bedded crinoidal wackestone, interbedded with dark grey, weakly to moderately calcareous variably fossiliferous shale. The Lisduff Oolite Member consists of ooid and skeletal grainstones. The Lower Ballysteen Limestone is made up of shales and fossiliferous calcarenites. Doyle *et al.* (1992) showed that the Lisduff Oolite Member occurs at the top of the *Pseudopolygnathus multistriatus* conodont Biozone and that the Upper Ballysteen Limestone containing conodonts of the *Polygnathus mehli* Biozone. These biostratigraphical ages appear to be consistent in southeast Ireland (Sevastopulo, pers. comm. 1999).

5.4 PALAEONTOLOGY AND DEPOSITIONAL ENVIRONMENT

As no thin sections or hand samples were available from the core, the only information on the invertebrate faunas is from previously published material. The vertebrate fauna other than the conodont fauna from the acid insoluble residues is described in Chapter 7 of the work. Doyle *et al.* (1992) and Philcox (1984) describe the Upper Ballysteen Limestone as having abundant crinoids and bryozoans.

The Lisduff Oolite within the Urlingford Core 3246/4 suggests a shallowing sequence at the top of the *P. multistriatus* Biozone. The Upper Ballysteen Limestone appears to show a return to deeper marine environments with the occurrence of finer grained mudstones increasing towards the contact with the overlying Waulsortian Limestone, which are believed to represent deep water carbonate buildups (Lees and Miller, 1995).

Overall the strata from which the Urlingford Core samples were taken are suggested to represent a deepening marine environment at least at the horizons close below the

Waulsortian Limestone and were deposited probably at depths below storm wave base.

CHAPTER 6: MOYOLA RIVER

6.1 INTRODUCTION

Material in the form of unprocessed rock samples were kindly offered for this study by the Ulster Museum, Belfast, Northern Ireland. The material is from within the Mormeal Member of the Altagoan Formation, situated one and a half kilometres south-east of Draperstown (H792/947 - Sheet 19 GSNI) (Figure 6.1) and is thought to be from the horizon described by Portlock (1843). Portlock describes the small number of beds exposed along the Altagowan River (*sic*) as ..."*the shales are rich in fossils of a few species, particularly in the several varieties of* Modiola, *and the limestones occasionally contain a* Serpula, *here named* Serpula sub-annulata."... ..."*Entering the Moyola, calcareous shales again appear, and in them is found the remarkable group, consisting of* - Holoptychius Portlocki *(Ag.) (*sic*),* Gyracanthus formosus, G. tubercalatus,"... etc. (Portlock, 1843, p. 564) which he likens to a group found in the Burdiehouse limestone (*sic*) in Scotland. However, the position of the samples within the Mormeal Member is uncertain as the material was supplied without accompanying logs of the section, nor were any logs available from the lender. No conditions were set in relation to the loan and with the permission of the Ulster Museum, it was decided to select samples for acid digestion. The resulting insoluble residues were used for the project. A number of thin sections were made, whilst the remainder of the material was left in its original state in order to examine the specimens on the surface. The surface material although initially appearing to be intact, was found under microscopic examination to be extensively fractured. Consequently, it was decided not to dissolve as much of the material as had originally been intended. For example, many of the surface scales were composed of original material that showed a maze of micro-fractures which were annealed with carbonate cement. Thus much of the material subjected to acid digestion although appearing entire was recovered from the residues in small pieces.

6.2 PREVIOUS WORK

The Tournaisian rocks of the north of Ireland have long been the subject of discussion in relation to their age and to their extent northwards. In Co. Londonderry the rocks have been described by Portlock (1843) and later by Egan (1881) in an explanatory memoir of Sheet 27, the succession exposed at the Altagoan River were assigned to the Upper Calciferous Sandstone. During the twentieth century little has been published on the area. Owens *et al.* (1977) published on the miospore assemblage from the Altagoan Formation while Cameron (pers. comm., 1983) described the geology of the area around Moneymore which included reference to the Altagoan River and in particular Altagoan

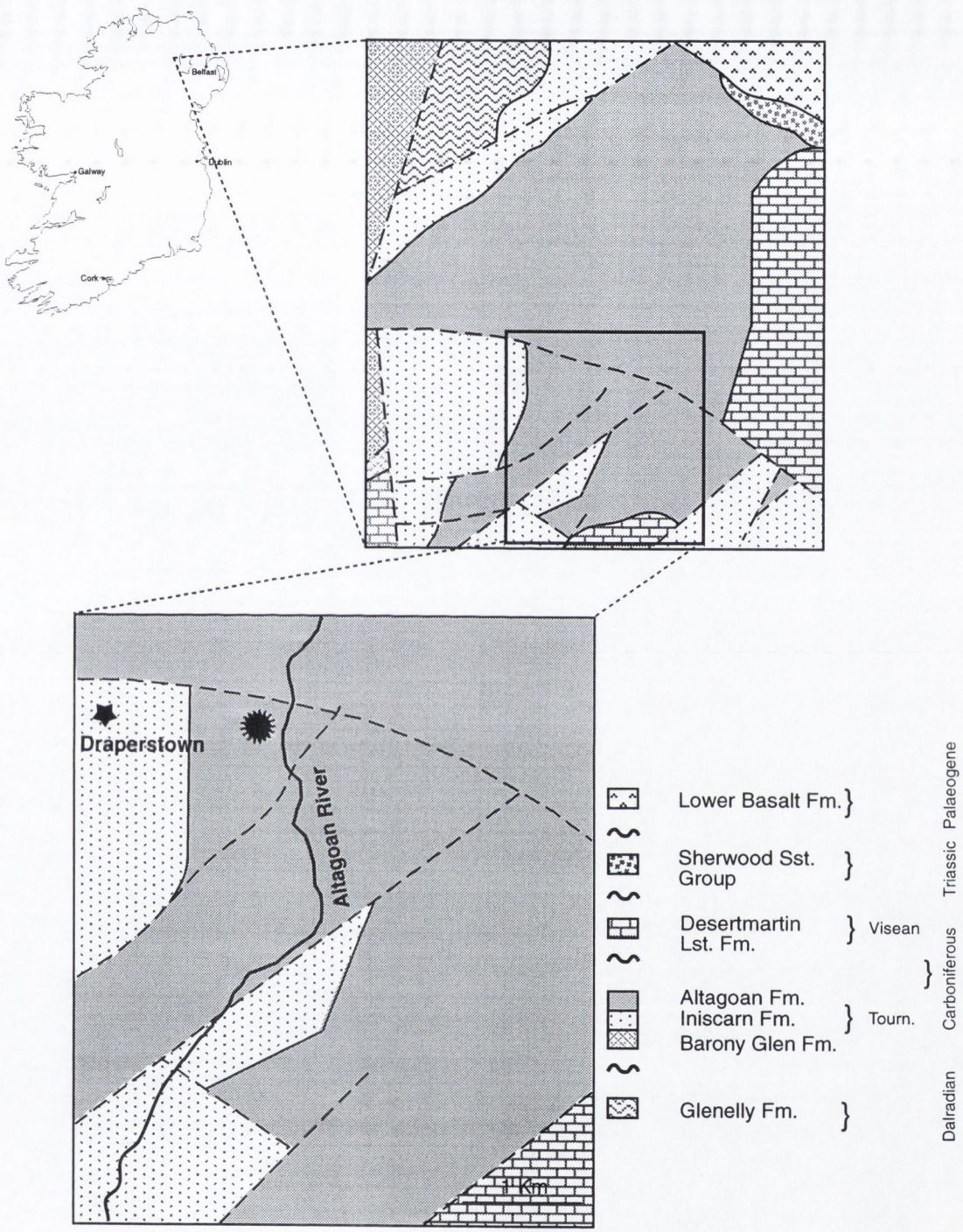


Figure 6.1. Geology of the area around the north-west of Lough Neagh with the local geology of the area around Draperstown, Co. Londonderry. (after Geological Survey of Northern Ireland 1:250,000 (1997))

Bridge some 1.5 kilometres east of Draperstown. Currently a revised Sheet 19 is under construction by the Geological Survey of Northern Ireland.

6.3 STRATIGRAPHY

6.3.1 In the Altagoan River area (slightly east of Draperstown) the rocks were previously described by Portlock (1843) and assigned by the Geological Survey of Ireland to the Upper Calciferous Sandstones (Egan 1881).

The Geological Survey of Northern Ireland (Cameron and Old, 1983) subdivided the Lower Carboniferous rocks (Tyrone Group) into two formations - a lower Iniscarn Sandstone Formation (equivalent to the nineteenth century Lower Calciferous Sandstones) and an upper Altagoan Formation (equivalent to the nineteenth century Upper Calciferous Sandstones)(Figure 6.1). Only the Altagoan Formation is described here.

6.3.2 ALTAGOAN FORMATION

The Altagoan Formation has been divided into two members in the Altagoan River region both in Surveyors notes (GSNI 1983) and by Mitchell (pers. comm. 1999): the lower Drumard Member and the overlying Mormeal Member. The stratotype of the formation and the Mormeal Member in particular is located in the Altagoan River south of the Altagoan Bridge, east of Draperstown (Figure 6.1).

6.3.2.1 DRUMARD MEMBER

The Drumard Member is at least 300m thick based on available outcrop but both the upper part of the Member and the contact with the overlying Mormeal Member are not seen and it is supposed that this is not the true thickness. The Drumard Member has a gradational boundary from the underlying upper conglomeratic beds of the Iniscarn Sandstone Formation. Typically the Member consists of fine-grained red sandstone often containing rip-up clasts, siltstone and mudstone (Mitchell pers. comm. 1999).

6.3.2.2 MORMEAL MEMBER

The Mormeal Member is composed mainly of grey to green (occasionally mottled purple/brown) sandstone, siltstone and mudstone, but also contains stromatolitic limestone and evaporite beds. According to Mitchell (pers. comm. 1999) it contains the lowest occurrence of shelly fossils in the succession. Bulk samples loaned for this

thesis are similar to exposures along the south bank of the Moyola River. These are fine-medium grained, sometimes lenticular, sandstones made up of intercalated dark grey micaeous silty sandstone and pale grey calcareous sandstone, together with dark green siltstone and dark grey mudstone. The bulk samples appear to come from a mixture of the micaeous silty sandstone and the pale grey calcareous sandstone described in this thesis as calcarenites with calcite pseudomorphs of evaporitic minerals.

Owens *et al.* (1977) recorded a miospore assemblage from the Mormeal Member which they assigned to the CM miospore Biozone, even though it contained small numbers of *Lycospora pusilla*. Higgs *et al.* (1988) reassigned this assemblage to the Pu miospore Biozone. The small numbers of *Lycospora pusilla* suggests that the assemblage is derived from a horizon low in the Pu Biozone. Riley (1993) equated the boundary between the CM and Pu Biozones within the base of the Chadian, but at present there is little direct evidence for the correlation with chronostratigraphy or biostratigraphy based on marine fossils. On balance, it seems likely that the CM/Pu boundary occurs within the upper part ("Freyrian") of the late Tournaisian (Sevastopulo, 1999, pers. comm.).

6.4 PALAEONTOLOGY

The fish microvertebrate fauna is described in Chapter 7. The Mormeal Member contains fragmented bivalves, ostracodes, serpulid worm tubes (seen in thin sections made during this thesis) and confirmed by field observations by Mitchell (pers. comm. 1999) as well as some plant remains and vertebrate material. Nearly all the vertebrate material appears, when examined under the microscope, to have been fractured either during lithification of the sediment or prior to it. Many particles of obviously large scales occur but are too damaged to be of any practical use, a few fractured but semi-complete teeth occur together with small scales. All the vertebrate material is highly fragile and acid digestion has dissolved the carbonate cement that was keeping together many of the particles. In one instance part of a Sarcopterygian dentary was exposed on the surface of a sample. Compaction of the sediment is obvious under binocular microscope with scales being squashed and taking up the outline of the under lying and over lying grains. These grains are predominantly quartz and feldspar together with numerous clay minerals (chlorite, muscovite etc.), the grain size of these minerals is frequently the same size as the fractured vertebrate material (excluding the larger pieces).

6.5 DEPOSITIONAL ENVIRONMENT

During the Carboniferous in Ireland there were pulsed, northwards transgressions of the sea over the established "Old Red Sandstone Continent"; the earliest of these started to reach areas of the north of Ireland by the late Tournaisian.

The Altagoan Formation for the most part represents an alluvial plain but in its upper part shows late influence of a marine incursion. The majority of Drumard Member appears to have an alluvial signature, with only the upper most part exhibiting any marine influence. The upper Mormeal Member, in particular, shows evidence of hypersaline inter- to supratidal environments with evaporitic horizons and cyanobacterial laminated limestones, indicating a sabhka-like environment which may have been crossed by intermittent channels. The latter may have been a transport route for the terrigenous material found within the Member.

CHAPTER 7: SYSTEMATIC PALAEONTOLOGY

7.1 Glossary of morphological and descriptive terms used in the systematic palaeontology:

Terms used in the systematic descriptions within this chapter are explained in more detail within the glossary. The majority of terms are in common use but some are introduced in this study. Reference is made to illustrations in which morphological features are well displayed.

Apical button: point of articulation on surface of tooth.

Basal foramen: opening in base of tooth, which may have housed nutrient vessels, usually sited on the ventral surface, (Plate 35; Figure 7.12).

Bifurcating ridges: raised ribs in the enameloid surface of the crown which branch repeatedly from the apex of a cusp towards the crown-base interface, (Plate 40; Figure 7.13).

Blade: very narrow median crest of a linguo-labially compressed tooth, (Plate 27).

Canal opening: opening in a tooth which may have housed nutrient vessels, (Plate 3; Figure 7.1).

Central Crest: median crest linking the cusp apices located centrally in a labio-lingually compressed tooth crown.

Chondrichthyan: cartilaginous fish, characterised by a prismatic calcified layer covering the endoskeleton and a pelvic clasper in the male.

Cladodont: a group of elasmobranchs characterised by their tooth, scale and fin morphology. The cladodont tooth has a single major cusp with smaller lateral cusps above a broad base.

Crenulated cusp ridge: raised ribs normal to or oblique to the base, with transverse crenulations in 'bar' types, (Plate 77; Figure 8.1).

Crown-base interface (CBI): junction of the crown and base, commonly marked by a horizontal ridge-like structure, (Plate 15; Figure 7.5).

Curving ridges: raised ridges in the enameloid of the crown from the area of the apex to the crown-base interface on some cusps.

Cusp ridge: raised ribs normal to or oblique to the base in 'bar' types, (Plate 77; Figure 8.1).

Diverging ridges: raised ridges in the enameloid of the crown from the area of the apex which diverge from the apex to the crown-base interface on some cusps.

Dorsal: the upper surface of tooth or base (also known as occlusal).

Elasmobranch: Sharks, skates and rays. Chondrichthyan fish divided by most authorities into four orders.

Expanded pits/foramen: enlarged openings in the exterior of the tooth (usually the base) which may have been the site of nutrient vessels, (Plate 16; Figure 7.5).

Foramen/foramina: non-specific opening from the exterior of the tooth towards the interior.

Horizontal (double) ridge and groove structure: raised horizontal rib or ribs in the enameloid of the crown which separate the crown and the base at the crown-base interface, (Plate 16; Figure 7.5).

Hybodont: member of a group of elasmobranchs distinguished by their tooth, scale and fin morphology. Hybodont teeth are low and elongate, ornamented by sinuous ridges in the enameloid of the crown with many nutrient canal openings in the base.

Inter-ridge grooves: grooves between the raised ribs in the enameloid of the crown.

Labial: the side of the tooth facing towards the outside of the mouth (i.e. towards the 'lips').

Labial buttress (also known as a **Labial peg**): a prominent growth on the labial surface of the crown between the upper and lower faces, usually placed medially, which may extend into the base creating a **labial root buttress**, (Plate 16; Figure 7.5).

Labial root buttress: a support in the base for the **Labial buttress** or the equivalent of the labial buttress but confined to the base of the tooth, (Plate 16; Figure 7.5).

Labio-dorsal: the upper surface of the crown or base (or overall tooth) viewed from the labial aspect (opposite of **linguo-dorsal**).

Labio-lateral: the side of the tooth viewed from the labial aspect (opposite of **linguo-lateral**).

Labio-ventral: the underneath of the tooth viewed from the labial aspect (opposite of **linguo-ventral**).

Lateral base extension: an extension of the base to the side well beyond the extent of the crown in 'bar' types, (Plate 77; Figure 8.1).

Lateral cusps: cusps that flank the principal or main cusp, (Plate 3; Figure 7.1).

Linguad: related to the lingual.

Lingual: the side of the tooth facing towards the inside of the mouth (i.e. towards the 'tongue').

Lingual base hook: a hook like extension of the base on the lingual aspect either medially, or to left or right of centre in 'bar' types.

Lingual buttress: a prominent growth on the lingual aspect of the crown between the upper and lower faces, usually placed medially.

Linguo-dorsal: see labio-dorsal

Linguo-labially compressed: the compression of the tooth from both lingual and labial sides creating an elongated tooth.

Linguo-lateral: see labio-lateral.

Linguo-ventral: see labio-lateral.

Lumen: a cavity.

Main cusp: the highest cusp on the crown, commonly, but not always, medial, (Plate 24; Figure 7.8).

Median crest: a raised ridge of enameloid on the crown of the tooth which extends the length of the tooth from lateral edge to lateral edge and incorporates the apices of the cusps, (Plate 27; Figure 7.9).

Middle cusp: the central of a number of cusps.

Node: small raised areas on either the lingual or labial side of the crown, usually close to the crown-base interface, (Plate 24; Figure 7.8).

Non-differentiated cusps: cusps that are not clearly delineated, (Plate 24; Figure 7.8).

Oblique ridges: raised ribs in the enameloid of the crown which are oblique to the length of the tooth.

Odontodes: dermal units that are the basic components of the superficial layer of the exoskeleton in generalized gnathostomes, formed from a single papilla.

Phoebodont: a tooth type with three main cusp in the crown equal in size or with the central cusp slightly smaller (accessory cusps may be present between the main cusps); base directed lingually usually at right angles to the crown.

Placoid scale: minute scale with a crown of dentine, acellular bone base and a pulp cavity in sharks, rays and chimaeras.

Principal cusp (abbreviated to **Pc**)**:** the largest and main cusp (especially within the phoebodonts where it is usually not the central cusp), (Plate 3; Figure 7.1).

Secondary auxiliary cusp (abbreviated to **2yaux**)**:** small cusp commonly between the principal and the secondary cusp, may or may not be paired, (Plate 35; Figure 7.12).

Secondary cusp (abbreviated to **2y**)**:** a pair of cusps placed at either side of the main cusp, (Plate 35; Figure 7.12).

Tertiary cusp (abbreviated to **3y**)**:** a pair of cusps placed at the outside of the secondary cusps usually at each lateral edge, (Plate 35; Figure 7.12).

Ventral: the lower surface of tooth or base, i.e. the underneath surface.

Vertical ridges (cusps) raised ribs in the enameloid surface of the crown extending from the apex of a cusp towards the crown-base interface, (Plate 40; Figure 7.13).

7.2 *Thrinacodus incurvus* ferox and nanus morphotypes

Class CHONDRICHTHYES Huxley, 1880

Subclass ELASMOBRANCHII Bonaparte, 1838

Order Incertae sedis

Family PHOEBODONTIDAE Williams, 1985

Genus *Thrinacodus* St. John & Worthen, 1875
Type species: *Diplodus incurvus* Newberry & Worthen, 1866

1982 *Harpago* Turner; Turner, 113, figs. 2-4
1983 *Harpagodens* (Turner); Turner, 38
1985 *Harpagodens* Wang & Turner, 226, pl. 2 figs. 11-12
1988 *Harpagodens* Derycke, pl. 1 figs. 1-2
1989 *Harpagodens* Wang, 105, pl. 28 figs. 6&7; pl. 29 figs 2a&b; pl. 30 figs 1-2
1990 *Thrinacodus (Harpagodens)* Long, fig. 5L-M
1990 *Thrinacodus* Ginter, 76, pl. 3 figs. 2-4
1991 *Thrinacodus* Ginter, 12, pl. A figs. 6-8
1991 *Thrinacodus* Kietzke & Lucas, 18, figs. 2D-H
1991 *Thrinacodus (Harpagodens)* Turner, fig. 6, pl. 2, fig. G
1992 *Thrinacodus* Derycke, 30, pl. 1 fig. 3
1993 *Thrinacodus* Turner, fig. 8.7, F.
1993 *Thrinacodus* Duffin, 1, pl. 1 & 2
1995 *Thrinacodus* Derycke *et al.*, 472, pl. IIIB, IVA.
1996 *Thrinacodus* Ivanov,418, fig. 4a-e
1996 *Thrinacodus* Ginter & Ivanov, 267, figs.1, 2a-d, 7

The genus *Thrinacodus* was proposed by St. John and Worthen (1875), with the type species *Thrinacodus nanus* from the upper fish bed of the Kinderhook Division, Burlington, Iowa, U.S.A. The genus is known only from isolated teeth which have been found in rocks of late Devonian (Famennian) to late Early Carboniferous (Serpukhovian) age. The taxonomy of *Thrinacodus* is complicated because of probably synonymies, involving at the generic level *Diplodus*, and at the specific level *Diplodus incurvus*, *Thrinacodus nanus* and *Thrinacodus ferox*.

Description of the genus *Thrinacodus* St. John and Worthen: St. John and Worthen (1875) described the genus as follows: "*Teeth of small size. Base posteriorly*

produced in a long, sometimes twisted, vertically flattened, or laterally compressed, clavate plate, longer than wide, anterior face narrow, and abruptly beveled from the basal line of the crown; posterior extremity more or less obtusely rounded; inferior surface narrow, plane and faintly excavated; superior surface gently convex, concave antero-posteriorly, or corresponding to the curvature of the inferior surface. From the antero-superior extremity of the base spring three more or less relatively stout, nearly equal, trenchant, acutely pointed recurved cusps, the exterior pair divergent, the central one more or less vertical, slightly sigmoidally curved, transverse section sublenticular, compressed in front, rounded behind, with simple cutting edges, and more or less strongly costate in either face.

The generic peculiarities of the teeth here referred to, as contrasted with Diplodus, *Agassiz, with which they are most intimately allied, consists in the relative more slender base, which lacks both the antero-inferior protuberance and the postero-superior pad-like prominence characteristic of the above genus. The coronal cusps are also nearly equal in size, the cutting edges are destitute of crenulations, and their anterior and posterior faces more or less strongly ridged vertically. The form of the trident-like cusps are very like that of* Cladodus, *being slightly constricted basally in front and faintly defined from the base behind.*

As here defined, the genus includes the forms originally described by Messrs. NEWBERRY *and* WORTHEN, *under the name* Diplodus incurvus *and* D.duplicatus, *of the Keokuk limestone, which seem to be indistinguishable from a form not uncommon in the upper Burlington limestone.*" (St. John and Worthen, 1875, p.289)

Diplodus Agassiz (1843) with the type specimen *Diplodus minutus* from the Burdiehouse Limestone near Edinburgh, Scotland (very poorly preserved) is similar to *Thrinacodus* but differs as described above. However, *Diplodus incurvus* Newberry and Worthen is here considered to be a senior synonym of *Thrinacodus nanus* St. John and Worthen (1875) and is thus the type species of *Thrinacodus.*

Turner (1982) proposed the genus *Harpago* for the type species *Harpago ferox* Turner (1982). *Harpago* was pre-occupied and was replaced by *Harpagodens* by Turner (1983). Long (1990) regarded *Harpagodens* as a subgenus of *Thrinacodus*. Ginter (1990) treated *Harpagodens* as a junior synonym of *Thrinacodus*, the practice followed here.

At the specific level, the taxonomy is complicated by the question of whether symmetrical forms of *Thrinacodus* (e.g. *Thrinacodus nanus*) occurred in the same fish as asymmetrical forms (e.g. forms described as *Thrinacodus ferox*). While this question cannot at present be answered conclusively, the balance of the evidence suggests that

in Carboniferous examples, at least, left- and right-handed asymmetrical forms and symmetrical forms did co-occur in the same fish. Therefore the practice followed here is to recognize the asymmetrical and symmetrical forms of *Thrinacodus* as different morphotypes of a single species; the morphotypes are named using the trivial names that were first applied to them. The synonymy for the species *Thrinacodus incurvus* is a combination of that for the incurvus morphotype and that for the ferox morphotype.

Remarks on the Genus *Thrinacodus* St. J. and W.: St. John and Worthen described *Thrinacodus nanus* as follows: ..."*Teeth minute.*"... ..."*with coronal cusps nearly equal in size*"... and a base ..."*moderately produced posteriorly, or apparently sub elliptical in outline*"... However, a paragraph later they qualified the description suggesting that their description stood for their specimens which show the crown entire and that within the collections are several imperfect teeth: ..."*apparently referable to the same species, which show the base considerably produced posteriorly, flattened and slightly twisted precisely in the same manner as in the allied forms occurring in the succeeding Burlington and Keokuk divisions. In case of this identity, the laterally elliptical outline of the base, as described above, is probably due to mechanical abrasion.*"... (St. John and Worthen, 1985 p.289-290)

Those forms described in this work as *Thrinacodus incurvus* nanus morphotype are those with a symmetric to slightly asymmetric elliptical outline; those with more flattened and twisted base are referred to as *Thrinacodus incurvus* ferox morphotype as described below.

In a discussion on the relationships of *Phoebodus*, Ginter and Ivanov suggested that two 'varieties' of *Thrinacodus* teeth can be distinguished: asymmetrical and symmetrical. This is consistent with both the findings of St. John and Worthen and Turner. However, St. John and Worthen implied in their description *of Thrinacodus nanus* that the "principal teeth" are the symmetrical ones with the asymmetrical teeth as the variations, while Turner, in her description of *Thrinacodus ferox (Harpago ferox)*, suggested the opposite with the asymmetrical teeth as the "principal teeth", since they numerically dominated the samples. A similar observation to Turner's has also been made in this study where asymmetrical to symmetrical teeth occur in a ratio of 10:2, and also within samples from Eastern Europe where a similar ratio has been observed (Ginter pers. comm. 1997). From this study seven asymmetrical teeth with the principal cusp to the right (when viewed from the labio-lateral side with the crown to the bottom) and three asymmetrical teeth with their principal cusp to the left were recovered from the same sample. A further two asymmetrical teeth with the principal cusp to the left were recovered from another locality, and a single asymmetric tooth with the principal cusp to the right was recovered from a third locality - neither of the two latter localities yielded symmetrical or near symmetrical teeth.

It seems most probable that the left- and right-handed teeth belong to the same species, as it is difficult to imagine a jaw containing either all left-hand or all right-handed teeth. The more likely reconstruction is that the left-handed teeth were located on one side of the jaw and the right-handed on the other. It is also probable that the *Thrinacodus incurvus* nanus morphotype teeth (described below) were housed in the same jaw as the *T. incurvus* ferox morphotype. However, this opinion must be qualified by the opinions given by Ginter and Ivanov (1996) where they find that symmetrical teeth with a ..."*typical phoebodont-type crown seems the older one. Only this variety has been found thus far in the Late Famennian deposits of the* trachytera *to* expansa *(?Early* praesulcata *Zones), in the samples constrained by conodonts (Long, 1990); (Ginter, 1990).*"... It is unclear if they believed that symmetrical teeth only may have been found in a single jaw from a stratigraphically early occurrence of the genus, and that asymmetrical teeth are a later development. They also suggested that the asymmetrical teeth of *Thrinacodus* appear for the first time in the *praesulcata* Biozone and dominate the Lower Carboniferous (Wang and Turner, 1985) faunas; with rare occurrences of the symmetrical teeth in the Carboniferous ..."*may be because they were retained only in a special part of a jaw (symphyseal, as suggested by Turner 1982)*."...

Taking into account the varying opinions, the most reasonable conclusion is that during the Early Carboniferous, at least, the two *Thrinacodus* morphotypes were housed within a jaw and thus the specific name applied to them should be the same. *Thrinacodus incurvus* has priority. However in order to distinguish between the symmetrical and asymmetrical forms, they are referred to in this thesis as *T. incurvus* ferox morphotype and *T. incurvus* nanus morphotype.

Thrinacodus teeth have been described from the late Famennian of Mae Sariang, near Mae Sam Lap close to the Thailand/Burma border (Long, 1990); late Famennian of Ostrowka, Holy Cross Mountains, Poland (Ginter, 1990; Ginter and Ivanov 1996); late Famennian of Tafilalet, Morocco (Derycke, 1988; Derycke, 1992); Famennian of Broken River, Charters Towers, Queensland, Australia (this includes the type material of *Thrinacodus ferox* (*Harpago ferox*) but the dating is not precise) (Turner, 1982); ? Late Devonian of Sacramento Mountains, south-central New Mexico, USA (Kietzke and Lucas, 1992); Devonian/Carboniferous boundary (Dihua and Wangyou Formations of Changshu County, Gizhou Province, China (Wang, 1993); Devonian/Carboniferous boundary at La Serre, Montagne Noire, Hérault, France (Derycke *et al.* 1995a); Late Tournaisian to Early Viséan of Bingleburra Road, New South Wales, Australia (Turner, 1982); Early Carboniferous (Viséan) of Derbyshire, England (Duffin, 1993a); upper Early Carboniferous (early Namurian - Serpukhovian) of the Moscow Region (Ginter and Ivanov, 1996). Thus it appears that *Thrinacodus incurvus* (this thesis) has a range (as presently known) from the late Famennian to the early Namurian.

7.2.1 *Thrinacodus incurvus* ferox morphotype

Type species: *Thrinacodus incurvus* St. John & Worthen, 1875

(Figure 7.1A,B, Plates 1-10)

1982 *Harpago ferox* Turner; Turner, 113, figs. 2-4
1983 *Harpagodens ferox* (Turner); Turner, 38
1985 *Harpagodens ferox* Wang & Turner, 226, pl. 2 figs. 11-12
1988 *Harpagodens ferox*? Derycke, pl. 1 figs. 1-2
1989 *Harpagodens ferox* Wang, 105, pl. 28 figs. 6&7; pl. 29 figs 2a&b; pl. 30 figs 1-2
1990 *Thrinacodus ferox (Harpagodens)* Long, fig. 5L-M
1990 *Thrinacodus ferox* Ginter, 76, pl. 3 figs. 2-4
1991 *Thrinacodus ferox* Ginter, 12, pl. A figs. 6-8
1991 *Thrinacodus ferox* Kietzke & Lucas, 18, figs. 2D-H
1991 *Thrinacodus ferox (Harpagodens)* Turner, fig. 6, pl. 2, fig. G
1992 *Thrinacodus ferox* Derycke, 30, pl. 1 fig. 3
1993 *Thrinacodus ferox* Turner, fig. 8.7, F.
1993 *Thrinacodus ferox* Duffin, 1, pl. 1 & 2
1995 *Thrinacodus ferox* Derycke *et al.*, 472, pl. IIIB, IVA
1996 *Thrinacodus ferox* Ivanov, 418, fig. 4a-e
1996 *Thrinacodus ferox* Ginter & Ivanov, 267, figs.1, 2a-d, 7

Diagnosis of original type species *Harpago ferox* (later to become ***Thrinacodus ferox*** following the precedent rule): .."*An elasmobranch with microscopic tricuspid fang-like teeth; cusps rounded in cross section, curved linguad over the base, almost equal in size; central cusp tending to be larger, symmetrically arranged like a trident when small (below about 1mm in length), varying to asymmetrical with either right or left lateral cusp strongly developed; smaller middle cusp and opposite lateral cusp smallest when teeth are larger (1-2mm). Only cusps covered with shiny striated enamel. Striations at the proximal ends of the cusps may anastomose. Each tooth with a long, almost rectangular base which is twisted through about 50° along its length and can have an obliquely tapering lingual end. Canal openings can occur on upper and lower surfaces of the base. Minor foramina just below the cusp-base contact on the labial surface. Dermal denticles simple, horn-like; crowns curve posteriorly and have small openings near the base.*" (Turner, 1982, p. 118-119)

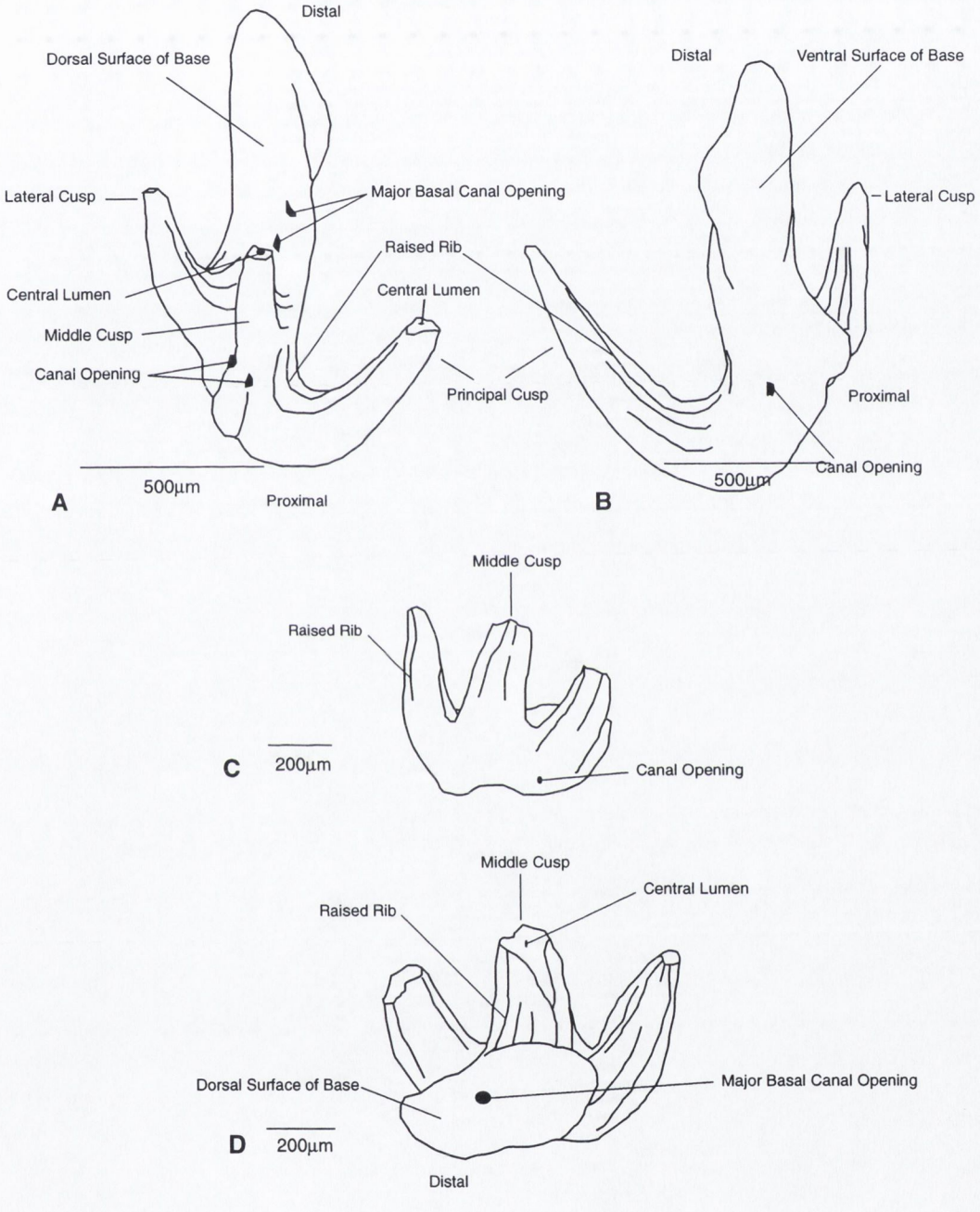


Figure 7.1. *Thrinacodus incurvus* ferox morphotype. A - labio-lateral view (dorsal base), based on TCD 36794. B - linguo-lateral view (ventral base), based on TCD 36799. *Thrinacodus incurvus* nanus morphotype C- labio-ventral view; D - linguo-dorsal view, both based on TCD 36808. (see plates 1-12)

Material: Thirteen isolated, illustrated teeth, some complete: Specimen Numbers: TCD 36792-36801, TCD 36803-36805. A number of isolated associated dermal denticles (TCD 36994) and some broken cusps (TCD 36984) not illustrated.

Description: Asymmetric teeth vary from 0.7mm to 1.94mm in length from the base of the principal cusp to the distal margin of the base and from 0.47mm to 1.5mm across the widest extent of the cusps (though it must be noted that only in specimen TCD 36799 are the cusps entire - most have broken tips).

The asymmetric teeth TCD 36792-36801 & 36803-36805 occur in both left- and right-handed forms. They are tricuspate but each cusp varies in length and width curving lingually and may also curve latero-lingually. The principal cusp initiates at the proximal base growing down slightly and then curving sharply right or left latero-lingually; the middle cusp initiates above the level of the principal cusp growing out and then curving lingually; the left or right lateral cusp commonly initiates above the level of the middle cusp (otherwise at the same level) and curves latero-lingually. Unless strongly abraded, each cusp shows raised ribbing from tip to base, more pronounced on the lingual and lateral areas than on the labial. In most instances at least one rib is observed to run from the inside lateral edge of the outside cusp across and up the lateral edge of the middle cusp.

The bases are elongate, roughly rectangular and normally at least twice as long as wide, ovoid in cross section close to the cusps but flattening dorso-ventrally towards the distal margins as the base twists through c. 50°. In most instances the distal area of the base opposite to the principal cusp is extended lengthwise and is twisted inwards over the dorsal area of the base, while the other distal margin (in line with the principal cusp) may widen but be shorter and twist away to the ventral side. One/two major basal canal openings occur on the dorsal surface usually about half way along the length and often roughly in line with the middle cusp. At the base of the middle cusp along the labio-ventral surface up to two smaller canal openings may occur from which a groove to the ventral surface may outline a ventral node. In some specimens a small canal opening is observed on the ventral surface of the base close to the base of the principal cusp. Other minor foramina occur on the ventral, dorsal and labio-ventral surface of the base in some specimens.

Discussion: Variation within the morphology of the *Thrinacodus incurvus* ferox morphotype can be described in terms of two end members. At one extreme are finer, more delicate specimens (specimens TCD 36794, 36798, 36799 and 36800), which show a principal cusp to the right when viewed from the labio-lateral side with the crown to the bottom. Probably little significance at the moment can be put on the position of the principal cusp in relation to the delicacy or otherwise of the tooth as illustrations of

Thrinacodus ferox (*Harpago ferox*) Turner (1982 figs. 2 & 3) from Australia and from the Holy Cross Mountains of Poland, (Ginter and Ivanov 1996, fig. 2), show similar types of 'delicate' teeth with the principal cusp on either side. Derycke *et al.* (1995a plate IV) illustrated an example from the Lower Carboniferous of France. The other end member is a more robust tooth (TCD 36796, 36801, 36804). The specimens in this study show the principal cusp on the left, but Duffin (1993a, plates 1 & 2) showed examples of this end member from the early Carboniferous of Derbyshire (England) again exhibiting left- and right-handed teeth, while Derycke *et al.* (1995a, plate III) showed an example from the lowermost Carboniferous with the principal cusp to the right.

The remaining specimens exhibit intermediate morphology. An exception is TCD 36797 (Plate 5, C & D) in which, although the principal cusp is broken close to its base, it is still possible to see the typical latero-lingual curvature (to the right) and the left lateral cusp shows latero-lingual curvature to the left. The middle cusp is straight and bends back sharply at an acute angle over the length of the base with little or no curvature. This specimen is similar to that illustrated by Ginter and Ivanov (1996 figure 2 B); however, this belongs to a symmetric tooth and TCD 36797 is obviously asymmetric.

Age, Locality and Lithology:

i. Kilbride Limestone Formation, *Polygnathus mehli* conodont Biozone, Ivorian (probably Freyrian), late Tournaisian, Dinantian. Disused quarry, near Nobber, Co. Meath (N 845 848); crinoidal limestone.

ii. Lyraun Cove Shale Member, Porter's Gate Formation, *Polygnathus inornatus* conodont Biozone, Hastarian, Tournaisian, Dinantian. Small cove section, near Porter's Gate, Hook Head, Co. Wexford (S 276 100); calcareous mudstone-dolomitic limestone.

iii. Upper Ballysteen Limestone, *Polygnathus mehli* conodont Biozone, Ivorian (pre-Freyrian), late Tournaisian, Dinantian. Bore hole 3246/4 181.6-252.7m, Urlingford, Co. Kilkenny; thinly bedded crinoidal limestone.

7.2.2 *Thrinacodus incurvus* nanus morphotype

Type species: *Thrinacodus nanus* St. John & Worthen, 1875
(Figure 7.1c,d, Plate 11, 12)

1982 *Harpago ferox* Turner; Turner, 113, figs. 2-4
1983 *Harpagodens ferox* (Turner); Turner, 38
1985 *Harpagodens ferox;* Wang & Turner, 226, pl. 2 figs. 11-12

1988 *Harpagodens ferox*?: Derycke, pl. 1 figs. 1-2

1989 *Harpagodens* ferox Wang, 105, pl. 28 figs. 6&7; pl. 29 figs 2a&b; pl. 30 figs 1-2

1990 *Thrinacodus (Harpagodens) ferox*; Long, fig. 5L-M

1990 *Thrinacodus ferox*; Ginter, 76, pl. 3 figs. 2-4

1991 *Thrinacodus ferox*; Ginter, 12, pl. A figs. 6-8

1991 *Thrinacodus ferox*, Kietzke & Lucas, 18, figs. 2D-H

1991 *Thrinacodus (Harpagodens) ferox*; Turner, fig. 6, pl. 2, fig. G

1992 *Thrinacodus ferox*; Derycke, 30, pl. 1 fig. 3

1993 *Thrinacodus ferox*; Turner, fig. 8.7, F.

1993 *Thrinacodus ferox*; Duffin, 1, pl. 1 & 2

1995 *Thrinacodus ferox* Derycke *et al.*, 472, pl. IIIB, IVA

1996 *Thrinacodus ferox* Ivanov, 418, fig. 4a-e

1996 *Thrinacodus ferox* Ginter & Ivanov, 267, figs.1, 2a-d, 7

Material: Two illustrated, isolated teeth not complete. Specimen Numbers: TCD 36802 and 36808

Description: In the symmetrical type the tooth is 0.77mm in length from the base of the median cusp to the distal margin of the base and at least 0.9mm across the widest extent of the cusps.

The symmetrical type tooth TCD 36802 and slightly asymmetric type tooth TCD 36808 are smaller overall in dimension than the asymmetric associated *Thrinacodus incurvus* ferox morphotype teeth. The three enameloid cusps are roughly equal in width, curved lingually with raised ribs from the tip of each cusp, less pronounced on their labial surfaces. Cusps are slightly sigmoidal, sub-circular in cross section and a central pulp cavity is seen.

The non-enameloid base is half as wide as long with the widest extent close to the base of the cusps. There is a slight twist of the base with a flare to one side; otherwise the base tapers to the distal margin culminating in a rounded tip. A basal canal opening occurs on the dorsal surface halfway along the length in line with the median cusp. Secondary foramina occur in the same area. A prominent node occurs at the junction of the ventral and labial surfaces to one side of the mid-line, in some species associated with a basal canal opening.

Description of *Thrinacodus nanus* St. John and Worthen 1875:

The two specimens described above fall within the range of variation of *Thrinacodus nanus* St. John and Worthen 1875. These authors described *T. nanus* as follows:

"*Teeth minute. Base thick, moderately produced posteriorly, or apparently sub elliptical in outline, constricted or rounded below, and faintly excavated; coronal cusps nearly equal in size, terminating in a sharp point, with sharp lateral edges, lenticular in transverse section, more compressed in front than behind, the exterior pair diverging and recurved, central cone erect or laterally deflected, and ornamented with a very few sharp, irregular disposed costae in the outer faces. Height of medium size tooth .05 inch, and .07 inch between the tips of the exterior denticles.*

The few individuals showing the crown entire present the appearances described above. But the collections afford several imperfect teeth, apparently referable to the same species, which show the base considerably produced posteriorly flattened and slightly twisted, precisely in the same manner as in the allied forms occurring in the succeeding Burlington and Keokuk divisions. In case of this identity, the laterally elliptical outline of the base, as described above, is probably due to mechanical abrasion.

These teeth are most intimately allied to the form which occurs in the Burlington limestone, Thrinacodus incurvus, *(N. and W. sp.) from which, indeed, they are chiefly distinguishable by their exceedingly minute size. The costae seldom exceed three in the outer face of the coronal cusps, the inner face showing obscure traces of fine and more numerous striae..."* (St. John and Worthen, 1875 p.289-291)

Specimens from this study are similar but with the following additional observations: where slightly asymmetrical, the main cusp is larger and the base tapers in flaring to the distal margin with a low angle twist; canal openings may occur on either of both labial or lingual surface together with foramina/foramen on the labial surface below the enameloid of the cusps.

The specimens used by Newberry and Worthen (1866) to erect the species *Diplodus incurvus* are morphologically similar to the Irish material and to the *Thrinacodus nanus* of St. John and Worthen, but are an order of magnitude larger. This raises a general question in relation to microscopic fish teeth: are teeth that are morphologically identical except for their size conspecific? The question is discussed earlier and the tentative conclusion is that the difference in size does not rule out two teeth being conspecific. thus *Thrinacodus* [*Diplodus*] *incurvus* is regarded as a senior synonym of *Thrinacodus nanus*.

Discussion: The points discussed above in relation to *T. incurvus* ferox morphotype are pertinent to any discussion of *T. incurvus* nanus morphotype.

Ginter and Ivanov (1996) suggested that *Phoebodus gothicus* from the Famennian of the Holy Cross Mountains of Poland have strong recurved cusps and a long narrow base with a button less pronounced than in the typical specimens, and that these characters make it similar to the symmetrical teeth of *Thrinacodus* ... "*so closely that they can be mistaken at first sight, particularly when the tips of the cusps are broken.*"...They add that ..."*the base of* Thrinacodus *is slightly twisted, devoid of a button, and flattened or concave at the lingual end; the cusps are not sigmoidal, as in* P.gothicus ."... TCD 36808 shows one lateral cusp that has a tendency to be sigmoidal, however, the author believes that this specimen is a *Thrinacodus incurvus* nanus morphotype specimen on the evidence of all other features.

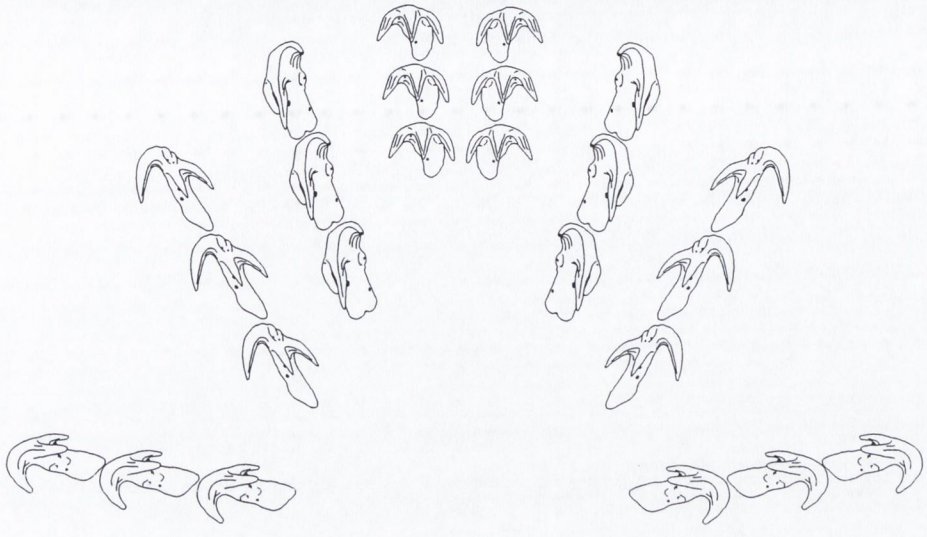
Age, Locality and Lithology:

Kilbride Limestone Formation, *Polygnathus mehli* conodont Biozone, Ivorian (probably Freyrian), late Tournaisian, Dinantian. Disused quarry, near Nobber, Co. Meath (N 845 848); crinoidal limestone.

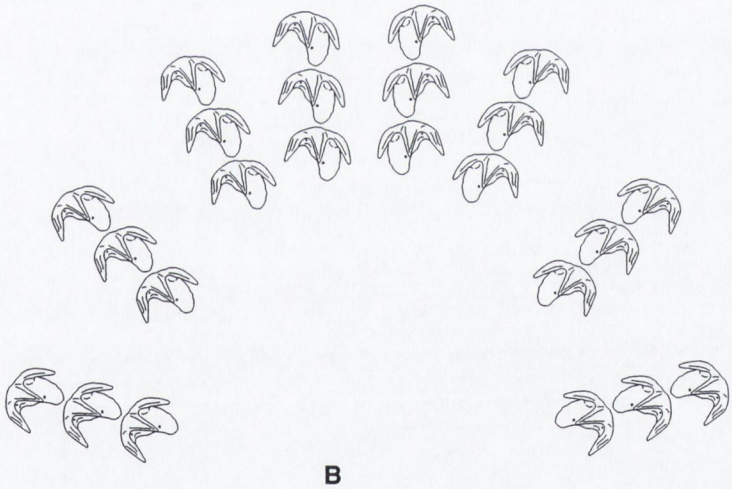
7.2.3 Some possible reconstructions of the arrangement of teeth in the jaw of *Thrinacodus incurvus*:

A relationship between the Recent *Chlamydoselachus anguineus* or frilled shark and *Thrinacodus* was first suggested by Turner (1982, p.123&124, fig. 5), who noted a similarity between the tooth arrangement in the jaws of *Phoebodus* and *Chlamydoselachus anguineus.* Ginter (1992) noted in particular a similarity to *Phoebodus bifurcatus* 'juvenile' form. However, Ginter (pers. comm. 1997) now thinks that this relationship is less likely as more becomes known about base shapes and placement of the main nutrient foramina as a result of research being carried out by Ginter and Ivanov in the area of relationships of *Phoebodus.* He has suggested that *Thrinacodus* is possibly a representative of highly specialized sharks which died out b y the mid-Carboniferous (Ginter pers. comm. 1997).

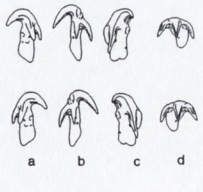
With the strange dearth of tricuspate, strongly recurved teeth with elongate bases in Recent sharks, it is still tempting to use *Chlamydoselachus* as a template for reconstructions of the tooth arrangement of *Thrinacodus.* The teeth in *Chlamydoselachus* are arranged in rows which are separated by spaces; the forked base is inserted under the labial base of the next younger (linguad) tooth. Several of these teeth (labiad) of a row are exposed on the jaw margin and used to hold prey rather than to cut it.



A



B



Key

Figure 7.2. Possible reconstructions of front part of a *Thrinacodus* jaw using A: *Thrinacodus incurvus* ferox morphotype and *Thrinacodus incurvus* nanus morphotype teeth; B: *T. incurvus* nanus morphotype only - these reconstructions show the lack of space created by the use of non-overlapping teeth. Key: a is the robust end member, b the fine end member and c the sharply recurved tooth of *T.i.* ferox morphotype), d is *T.i. nanus* morphotype tooth.

Figure 7.3. Possible reconstructions of the front part of a single *Thrinacodus* jaw; (A) using *Thrinacodus incurvus* ferrox morphotype and *T. incurvus* nanus morphotype teeth; (B) using *T. incurvus* nanus morphotype only. Key: a is the robust end member, b the fine end member and c the sharply recurved tooth of *T.i.* ferox morphotype), d is *T.i. nanus* morphotype tooth.

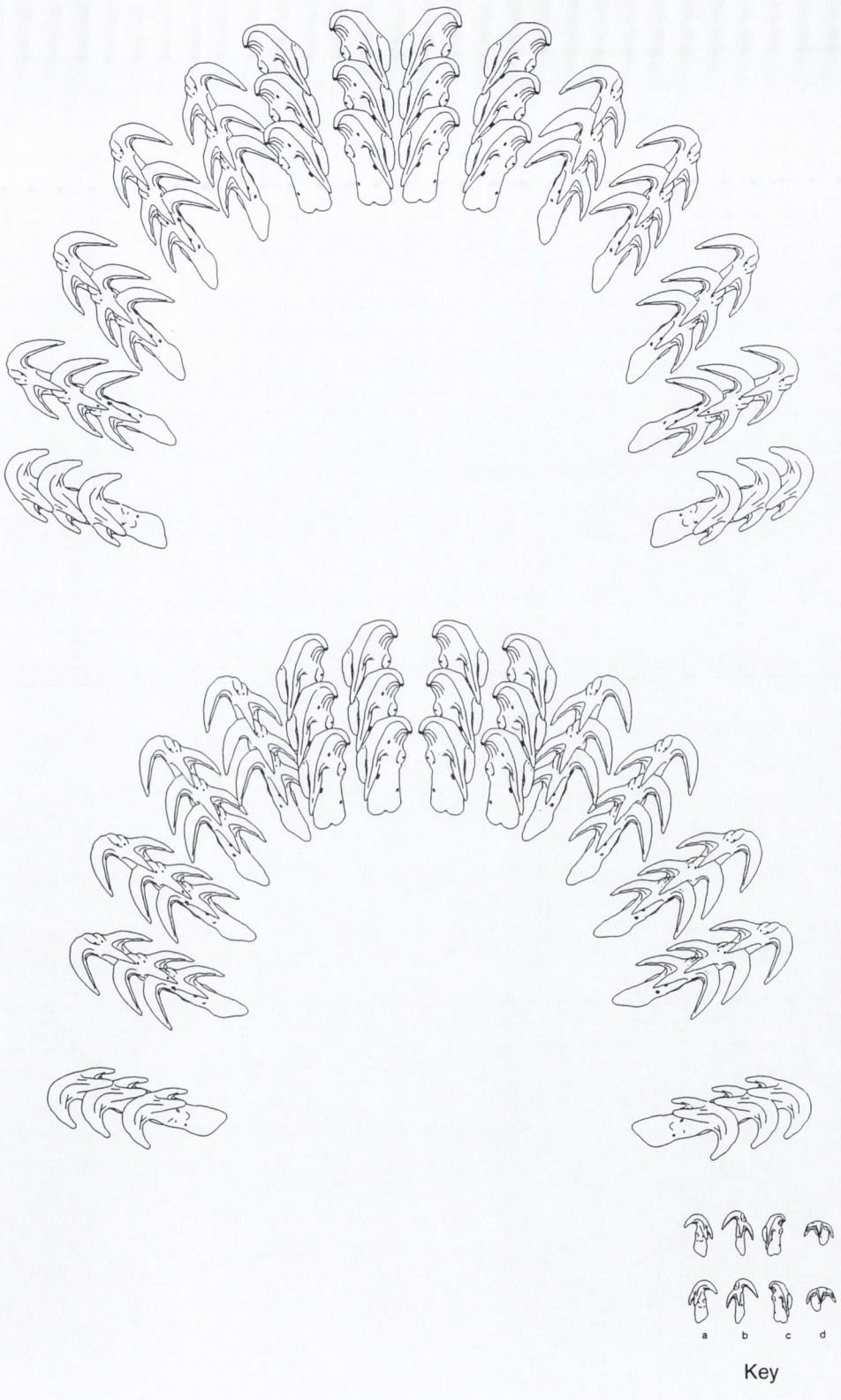


Figure 7.4. Possible reconstructions of the front part of a single *Thrinacodus* jaw, using *Thrinacodus incurvus* ferox morphotype teeth only Key: a is the robust end member, b the fine end member and c the sharply recurved tooth of *T.i.* ferox morphotype), d is *T.i. nanus* morphotype tooth.

Even taking into account the possible arrangement of the main nutrient foramina, it seems rather difficult to envisage tooth rows of *Thrinacodus* where the disproportionately long base was not inserted beneath the crown of the succeeding tooth (this assumes *Thrinacodus* had tooth rows) but the *Thrinacodus* teeth certainly do not have forked bases. Figure 7.2 shows two hypothetical examples of the arrangement of teeth in the jaw using differing morphologies highlighting the potential problems relating to lack of space for more than a few tooth rows created by non-overlapping of teeth assuming that each tooth row should contain at least seven or eight teeth. Figure 7.2a shows a central pair of *Thrinacodus incurvus* nanus morphotype teeth flanked by a pair of the strong angular, recurved end member teeth, outside of which are a pair of the delicate end member teeth and finally a pair of the more robust end member teeth - these three latter pairs are examples of *Thrinacodus* ferox morphotype described above; Figure 7.2b by contrast is made up entirely of *Thrinacodus incurvus* nanus morphotype teeth without including any of the ferox morphotype teeth.

Figure 7.3 and 7.4 show reconstructions using overlapping of the teeth. Figure 7.3 A and B show the same lay out of teeth (now overlapping) as shown in Figure 7.2, however in this instance two possibilities are show for each tooth morphology - inwardly curved principal cusps and outwardly curved cusps.

The position, number and range of morphology of teeth within the *Thrinacodus* mouth is almost entirely speculative. Arguments have been advanced above supporting the hypothesis that a single mouth contained both symmetrical and asymmetrical left- and right-handed teeth. The Irish material suggests that asymmetrical teeth were more numerous than symmetrical; if and when larger samples of *Thrinacodus* are available, it may be possible to estimate the ratio of asymmetrical to symmetrical teeth with more confidence. However, for completeness, Figures 7.2 and 7.3 show contrasting reconstructions using only *Thrinacodus incurvus* nanus morphotype teeth while Figure 7.4 shows part of a jaw made up entirely of *Thrinacodus incurvus* ferox morphotype (excluding any of the *Thrinacodus incurvus* nanus morphotype teeth) with a double pair of the strong angular, recurved teeth, flanked by four pairs of the delicate end member teeth and finally a single pair of the robust end member teeth (both incurved and outwardly curved principal cusp positions are shown) - again it is not suggested that the full complement of teeth in a row or number of rows is shown.

It seems probable on general functional morphological grounds that symmetrical teeth occurred around the mid-line and the asymmetrical teeth to the sides. There is no evidence as to whether "left-handed" asymmetrical teeth fall to the left, or to the right of the mid line. It must be stressed that all of the reconstructions are conjectural due to the lack of an articulated or partly-articulated specimen.

7.3 Lissodus Morphotypes

Class CHONDRICHTHYES Huxley, 1880

Subclass ELASMOBRANCHII Boneparte, 1838

Order EUSELACHII Hay, 1902

Superfamily HYBODONTOIDAE Zangerl, 1981

Genus *Lissodus* BROUGH 1935
Type species: *Hybodus africanus,* BROOM 1909

1985 *Lissodus* DUFFIN Without synonymy

Description of the Genus *Lissodus* Brough; (as summarized by Duffin, 1985):

Duffin (1985), in a revision of the genus, provided the following diagnosis: "*Diagnosis*: *Hybodont sharks in which some members possess a sub-terminal mouth. The teeth are small to moderately large with deep crowns. A small to well developed labial peg is present and supported by a labial root buttress in some species. The occlusal crest is strong to moderate. The crown possess a single low central cusp, usually flanked by very low lateral cusplets. Accessory cusplets are developed in some species. A longitudinal ridge may be present on the crown shoulders. The lateral margins of the crown incline steeply to an incised crown/root junction. The root is hybodontoid with simple and large vascular foramina, with anaulacorhize organization. A central longitudinal pulp cavity is situated high up inside the tooth, at the level of the crown/root junction. A single row of small specialized foramina is usually present on the upper labial root face. The root is directed lingually, but not developed into a torus. The crown/root attachment is concentrated on the lateral underside of the crown. A thick single, crystallite enameloid layer is present over the crown, and is thickest labially. There is overlap of the teeth in successive tooth files. Strong occlusal wear facets indicated a durophagous feeding habit".* (Duffin, 1985, p.142)

Discussion: Duffin (1985) suggested that *Lonchidion* is a junior synonym of *Lissodus* and that all previously erected valid species of *Lonchidion* belong to *Lissodus*. Further he suggested that ..."*it is best to distinguish* Lissodus *at generic level only*..." and if based on dental characters *Lissodus* transpires to deserve to become a genotype of a distinct family of hybodontiforms, then..." *although* Lissodus *has priority as a genus, the family name* Lonchidiidae *takes priority".*

The type species of *Lissodus* is *Hybodus africanus* Broom 1909 from the Lower Triassic of the Orange Free State of South Africa. It was re-described by Brough (1935) and assigned to the new genus *Lissodus*. Duffin (1985) described a new species from the Carboniferous (*Lissodus wirkworthensis*) and reviewed the genus, which, as now understood, comprises at least twenty-one species ranging in age from Carboniferous to Cretaceous.

The type species *Lissodus africanus*, is based on the only specimen assigned to the genus in which mineralized tissues other than teeth are known. Duffin (1985) provided an extended description of *Lissodus africanus* as follows:

Description of the teeth of the Type *Lissodus africanus* (Broom) 1909 (*Hybodus africanus*): ..." *The teeth of* Lissodus africanus *are described here on the basis of P.17531 (pl. 4, fig. 2) and P.16039 (pl. 4, fig. 1), and with reference to Brough (1932). P.17531 preserves the greater part of the ?upper dentition of the left side (text-fig. 9), plus two more anterior teeth. The latter are preserved in lateral and occluso-lateral views, and the former all in oblique basal view (text-fig. 9). P.16039 preserves three teeth from the right side of the lower dentition in lingual view.*

The teeth average 1.2mm in length. The larger and better preserved teeth are toward the centre of the tooth row exposed in P.17531. Brough (1935) cites an average length for teeth in the specimens which he examined of 0.7mm. The teeth under consideration here vary from the average 1.2mm by only 0.1mm.

The crown is smooth, showing the occasional development of very fine vertical striations. The base of the low central principal cusp is diamond-shaped in occlusal view, and expanded labially. The labial face of the crown is deeper than the lingual face. Lateral and accessory cusplets are not developed. On the labial side the crown shoulder is weak. The lower labial face of the crown is much shallower than the corresponding lingual face. The mesial and distal extremities of the crown are relatively deep, with margins which steeply undercut the crown toward the crow/root junction in labial and lingual view. The lingual crown shoulder is pronounced, giving way basally to a broad lower lingual face which deeply undercuts the crown and leads to the crown/root junction. The labial peg is moderately developed. The crown/root junction is deeply incised around the whole tooth.

The root is long and narrow, and its attachment to the crown concentrated labially. The attachment of the root to the crown undersurface is an elongate triangle in outline, an extension being developed labially toward the undersurface of the labial peg. The lingual margin of the root forms the long straight edge of the triangle. Traces of the root

*itself remain in some of the teeth in P.17531. These traces comprise lingual faces of the root in internal view in every case. From these fragments, it can be seen that the root is of hybodontiform organization, conforming to the anaulacorhizoid vascularization condition of Casier (1947). The foramina exposed appear to be irregular in virtually every case. Some foramina close to the crown/root junction may be specialized, but unfortunately no trace of the upper labial root face remains to make a further judgment on this feature. The root projects somewhat lingually from the crown undersurface. The labial and basal faces of the root were probably destroyed during the mechanical preparation of the specimen in the past. It can be seen that the undersurface of the crown is occupied by a longitudinal pulp cavity."...(*Duffin 1985)

A number of specimens in this study have been assigned to the genus *Lissodus* on the basis of the characters described above (although not all specimens exhibit all characters). The specimens have been grouped into five morphotypes which are not given specific names for the reasons discussed in Chapter 1. Since all five morphotypes are derived from the same samples (with the exception of a single specimen allocated to Morphotype 1), it is probable that they are derived from a single biological species. Similarities to species proposed in the literature on the basis of a single morphotype are noted in the descriptions.

7.3.1 *Lissodus* Morphotype 1 (Figure 7.5 and Plates 13 -19 & 29)

Diagnosis: Isolated microscopic chondrichthyan teeth. Linguo-labially compressed with enameloid crown; up to eleven non-differentiated cusps (average six to seven); prominent median crest extending from lateral edge to lateral edge widening over each cusp and contracting between, with a wider and higher median cusp which expands on the labial side to a prominent labial buttress and a minor lingual buttress. Ornamented labially and lingually by medially curving ridges; labial nodes may occur at the crown-base interface. Ventral base is elongate, usually concave with a horizontal ridge centrally; a basal canal usually appears beneath the labial buttress area; lingual surface is a convex crescent with up to seven expanded pits or furrows; labial surface short with expanded pits or furrows. (See Figure 7.5 for descriptive terminology)

Material: Fifteen figured isolated specimens, some complete. Specimen Numbers: TCD 36752-36764, 36781 & 36782.

Description: The length along the median crest ranges from 0.72mm to 1.38mm; the labio-lingual width ranges from 0.12mm to 0.34mm for the crown (base, 0.22mm to 0.56mm); the height in lingual view is 0.3mm to 0.56mm (crown only, 0.3mm to 0.56mm). The crown in some specimens is slightly asymmetric with an even number of cusps on

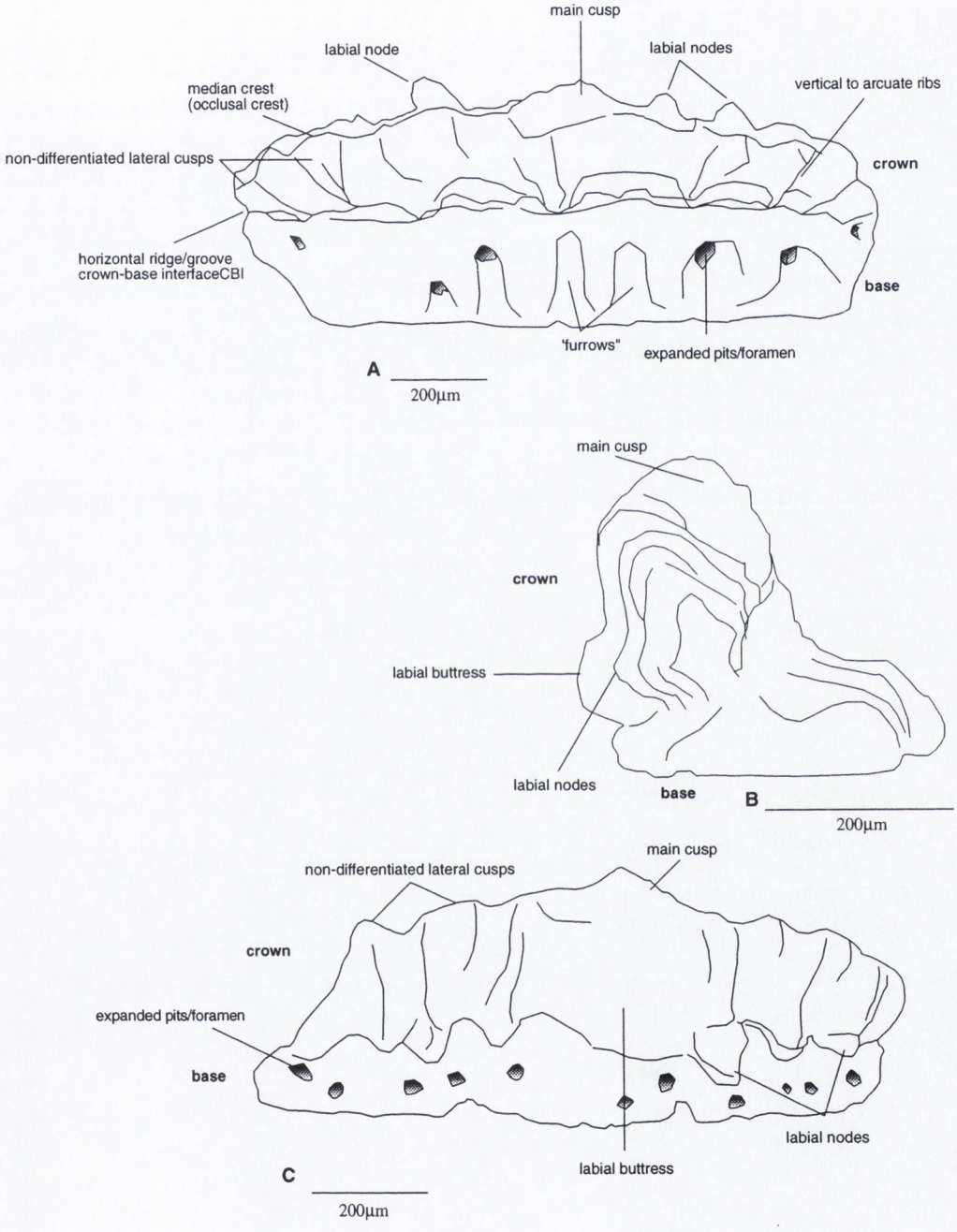


Figure 7.5. Drawing of *Lissodus* Morphotype 1 Illustrating the main morphological features. A - Lingual/semi-occlusal view; B - Lateral view; C - Labial view. Based on TCD 36758. (see plates 13-19 and 29)

one side of the main cusp and an uneven number on the other; the cusps are slightly fan shaped. The lingual crown has a main cusp with a vertical ridge bifurcating half way down, outlining a pyramidal base to the cusp; up to five non-differentiated cusps to either side, each with a ridge (not always along the mid line) from the apex, curving medio-lingually to the crown-base interface which is marked by a double horizontal ridge and groove. The lingual crown equals or slightly exceeds the length of the base; labially a buttress occurs as an extension of the main cusp which in some specimens extends into the base; vertical ridges descend from each of the other cusps culminating in a node, before curving medio-labially. The base is concave, more strongly so under the labial surface, with a horizontal ridge down the centre in many specimens; lingually the surface is long and rises sharply to the crown. It is indented with up to nine expanded pits or furrows and in some specimens longer medially than laterally. The labial side is short (where observed) and concave along the labio-ventral margin with a number of expanded pits or furrows.

Discussion: The specimens grouped here as Morphotype 1 show a variation in shape: in some specimens a very strong lingual buttress occurs; in others the lingual buttress is poorly developed. Some of the specimens are more arrow shaped in lingual/labial view than others. They have been grouped together on the similarities of the crown form and ornamentation.

Age, Locality and Lithology:

i. Kilbride Limestone Formation, *Polygnathus mehli* conodont Biozone, Ivorian (probably Freyrian), late Tournaisian, Dinantian. Disused quarry, near Nobber, Co. Meath (N 845 848); crinoidal limestone.

ii. Upper Ballysteen Limestone, *Polygnathus mehli* conodont Biozone, Ivorian (pre-Freyrian), late Tournaisian, Dinantian. Bore hole 3246/4 181.6-252.7m, Urlingford, Co. Kilkenny; thinly bedded crinoidal limestone.

7.3.2 *Lissodus* Morphotype 2 (Figure 7.6, Plate 20-all & 42 A-C)

Diagnosis: Isolated microscopic chondrichthyan teeth. Linguo-labially compressed teeth with enameloid crown, median crest from lateral edge to lateral edge, non-differentiated cusps, base exceeds horizontal length of crown. Labial crown buttress present. Base is long, may have a number of nodes on the lingual aspect, ventral surface is concave crescent shaped. (See Figure 7.6 for descriptive terminology)

Material: Two figured, isolated specimens, one complete. Specimen Numbers: TCD 36765-6.

Description: The length along the median crest ranges from 1.25mm to 1.6mm. The labio-lingual width is 0.23mm for the crown (base, from 0.32mm to 0.38mm); the height in lingual view is from 0.35mm to 0.56mm (crown only, 0.1mm to 0.32mm). The crown is slightly asymmetric sloping away from the mid point to the lateral edges. Ornamentation is sparse, though some subdued grooves appear to drop vertically from the crest outlining a median cusp. A medio-labial buttress is present. The base extends beyond the crown at both lateral margins, the lingual surface has a number of expanded pits or furrows while the linguo-ventral margin is convex; labially two hollows appear either side and below the labio-crown buttress; ventrally concave with smooth nodes at the lateral edges, wider on the lingual side.

Discussion: The specimen TCD 36765 has a shorter crown length relative to its base than TCD 36766 and also has nodes on the lingual crown surface; the slope of the median crest is steeper in TCD 36765 than in TCD 36766; the lingual base of TCD 36766 has more pronounced expanded pits or furrows. These Morphotype 2 teeth can be distinguished by their smooth, broad median crest and lack of vertical ridges descending from the crest, together with a crown that is much shorter than the base.

Age, Locality and Lithology:

Kilbride Limestone Formation, *Polygnathus mehli* conodont Biozone, Ivorian (probably Freyrian), late Tournaisian, Dinantian. Disused quarry, near Nobber, Co. Meath (N 845 848); crinoidal limestone.

7.3.3 *Lissodus* Morphotype 3 (Figure 7.7, Plates 21, 22-all & 42 D-F)

Diagnosis: Isolated microscopic chondrichthyan teeth. Enameloid crown, overall triangular shaped, asymmetric in lingual or labial view with three to five non-differentiated cusps, broad median crest from lateral edge to lateral edge. Pronounced labial buttress which continues into upper level of the base. Base triangular, central angle at labial buttress area, concave ventrally with raised margins, expanded pits and furrows occur on lingual surface with small pits on short labial surface of the base. (See Figure 7.7 for descriptive terminology)

Material: Three figured, isolated specimens. Specimen numbers: TCD 36767 - 36769.

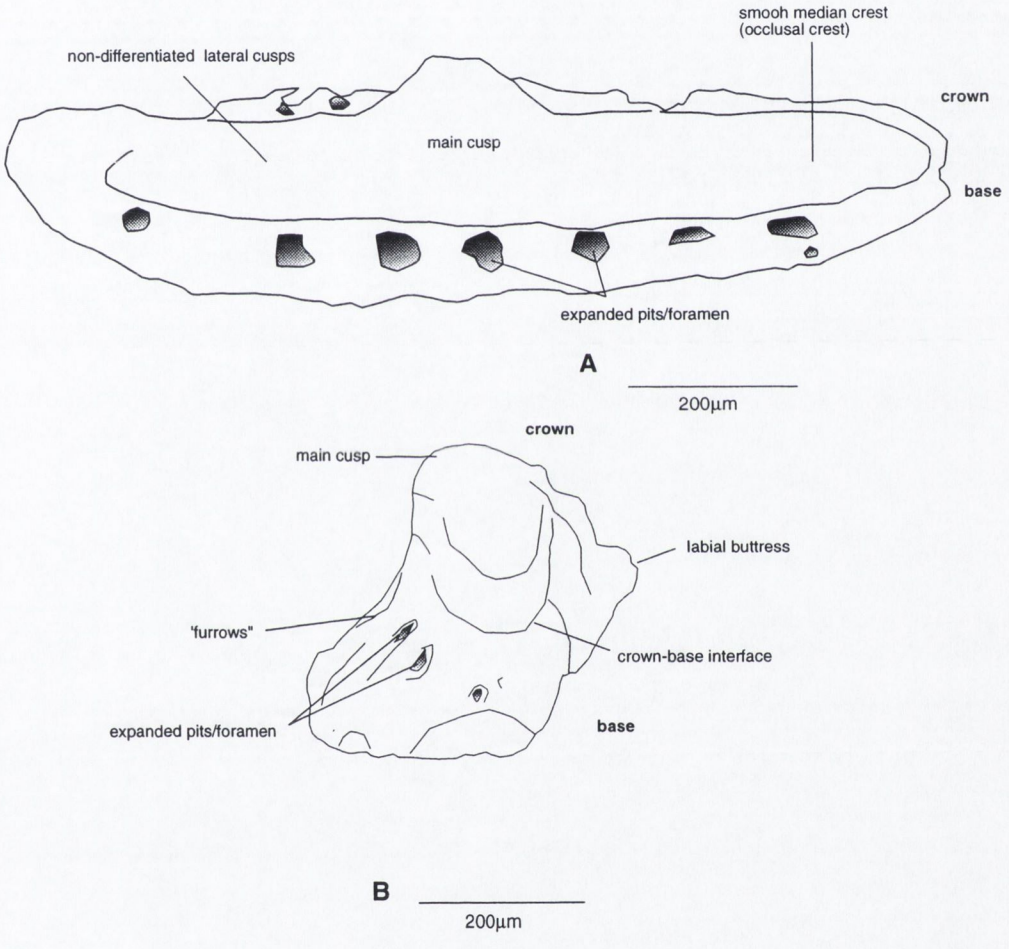


Figure 7.6. Drawing of *Lissodus* Morphotype 2 illustrating the main morphological features. A - Occlusal view, based on TCD 36765; B - Lateral view, based on TCD 36766. (see Plates 20 and 42)

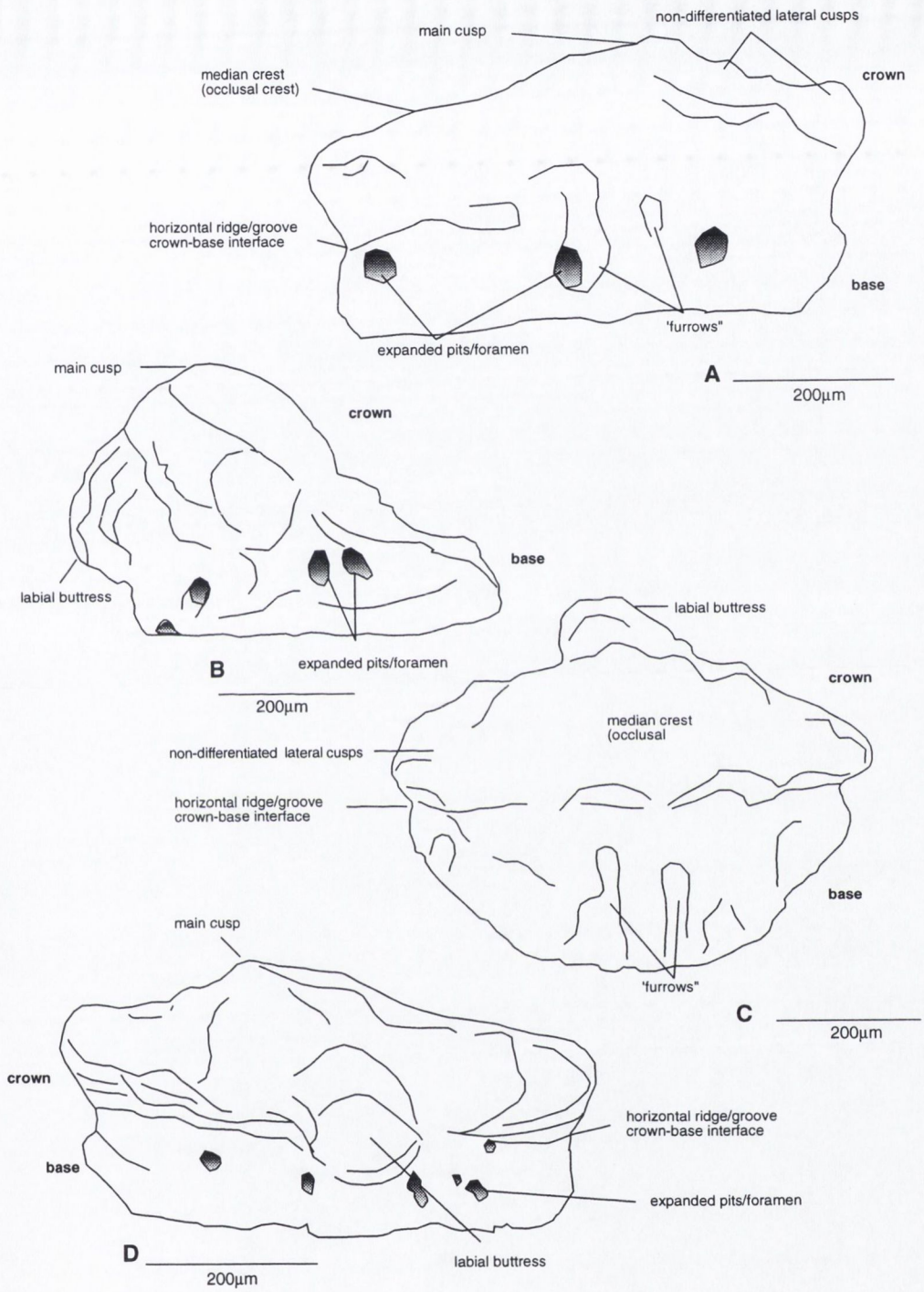


Figure 7.7. Drawing of *Lissodus* Morphotype 3 illustrating the main morphological features. A - Lingual view; B - Lateral view; C - Lingual/semi Occlusal view; D - Labial view, all based on TCD 36769. (see Plates 21, 22and 42)

Description: The length along the median crest ranges from 0.67mm to 0.77mm (crown only, 0.6mm to 0.74mm); the width of the crown labio-lingually (medially) ranges from 0.2mm to 0.38mm (base, 0.4mm to 0.58mm); height in lingual view is from 0.45mm to 0.57mm (crown only, 0.2mm to 0.27mm). Enameloid crown of three to five non-differentiated cusps with a median crest extending from lateral edge to lateral edge, asymmetric. Main cusp is off centre; higher than the remaining cusps and appears to have oblique ridges descending from the apex towards the crown-base interface on the lingual surface which is marked by a double horizontal ridge and groove structure; these non-differentiated cusps may be distinguished by slightly raised apices. Labially, a strong medio-labial buttress arises at upper crown level extending down and out to incorporate the upper level of the base. The base is triangular; lingually the base drops sharply from the crown-base interface and then fans out to the linguo-ventral margin; up to nine expanded pits and furrows occur on this surface. Labially the base is short with the medio-labial crown buttress extending into the upper level of the base; five to seven expanded pits occur on this surface. Ventrally the base is triangular with the central angle at the labial buttress where the surface is deeply concave; a number of furrows incise the ventral area.

Discussion: In specimen TCD 36767 the base exceeds the length of the crown and only three non-differentiated cusps occur, in specimen TCD 36768 crown and base are equal and three non-differentiated cusps occur; in specimen TCD 36769 the base does not exceed the length of the crown and five non-differentiated cusps occur. Despite these variations these teeth have been described together as their overall strongly triangular nature appear to separate them from the other *Lissodus* Morphotypes described.

Age, Locality and Lithology:

Kilbride Limestone Formation, *Polygnathus mehli* conodont Biozone, Ivorian (probably Freyrian), late Tournaisian, Dinantian. Disused quarry, near Nobber, Co. Meath (N 845 848); crinoidal limestone.

7.3.4 *Lissodus* Morphotype 4 (Figure 7.8, Plates 23 -25)

Diagnosis: Isolated microscopic chondrichthyan teeth. Enameloid crown, labio-lingually compressed teeth with five to seven cusps, main cusp with a strong labial buttress extending into the base; median crest from lateral edge to lateral edge forming a diamond over each pointed cusp apex; ornamented lingually with vertical ridges which curve medio-lingually towards the crown-base interface; lateral cusps also have vertical ridges many of which culminate in strong nodes. Base is sub-triangular with the central angle at the main labial buttress; ventral surface slightly concave, more so ventro-

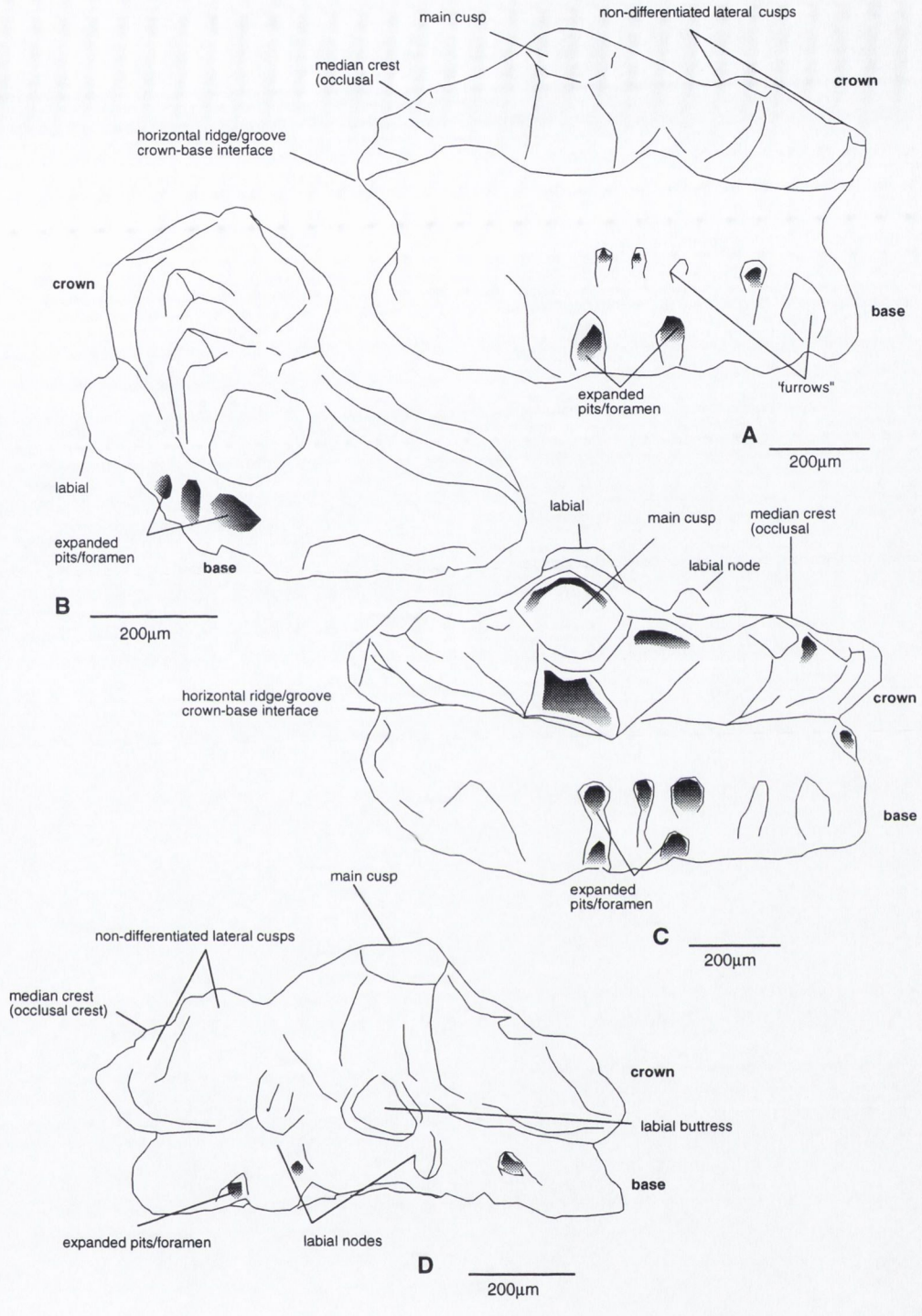


Figure 7.8. Drawing of *Lissodus* Morphoype 4 illustrating the main morphological features. A - Lingual view; B - Lateral view; C - Lingual/semi-Occlusal view; D - Labial view, all based on TCD 36772. (see Plates 23-25)

labially; lingually slightly convex with deep furrows normal to the crest; short labial base incorporating the labial crown buttress extension. (See Figure 7.8 for descriptive terminology)

Material: Five figured, isolated specimens, three of them complete. Specimen Numbers: TCD 36770 - 36774.

Description: The length along the median crest of the crown ranges from 0.71mm to 1.24mm (base only, 1.03mm to 1.13mm); the lingual height ranges from 0.45mm to 0.74mm (crown only, 0.13mm to 0.42mm). The lingual surface of the crown appears to curve labially in most instances with the main cusp set slightly off-centre; the main cusp has a vertical ridge from the pointed apex bifurcating into two sharp ridges forming a gentle lingual buttress; the lateral cusps on the lingual surface generally have pointed crests from which strong vertical ridges descend and curve medio-lingually; the linguo-lateral edges tend to curve labially. Labially, the main cusp extends into a laterally compressed buttress which overhangs the base and extends into it, the lateral cusps tend to curve labially and are ornamented by vertical ridges which culminate in nodes at the crown-base interface. The lingual crown-base interface is marked by a horizontal ridge and groove, with only a groove visible on the labial side. The base on the lingual surface drops sharply from the crown-base interface, fans out to a platform and then drops again to the ventral margin, this surface has up to seven expanded pits and furrows; the labial surface is short, one-third the length of the lingual surface and dominated by the medio-labial extension of the labial crown buttress with four to five expanded pits on the surface. Ventrally the base is sub-triangular; the area under the lingual base appears as a sloping platform; there is a deep cavity under the labial buttress - these two areas appear to be separated by a horizontal ridge; pits occur on the surface.

Discussion: Morphotype 4, although similar to Morphotype 1, is more triangular than elongate and in most instances the prominent labial buttress that initiates at the mid to lower crown level extends into the upper level of the labial base; also a number of minor buttress or large nodes occur along the labial surface.

Age, Locality and Lithology:

Kilbride Limestone Formation, *Polygnathus mehli* conodont Biozone, Ivorian (probably Freyrian), late Tournaisian, Dinantian. Disused quarry, near Nobber, Co. Meath (N 845 848); crinoidal limestone.

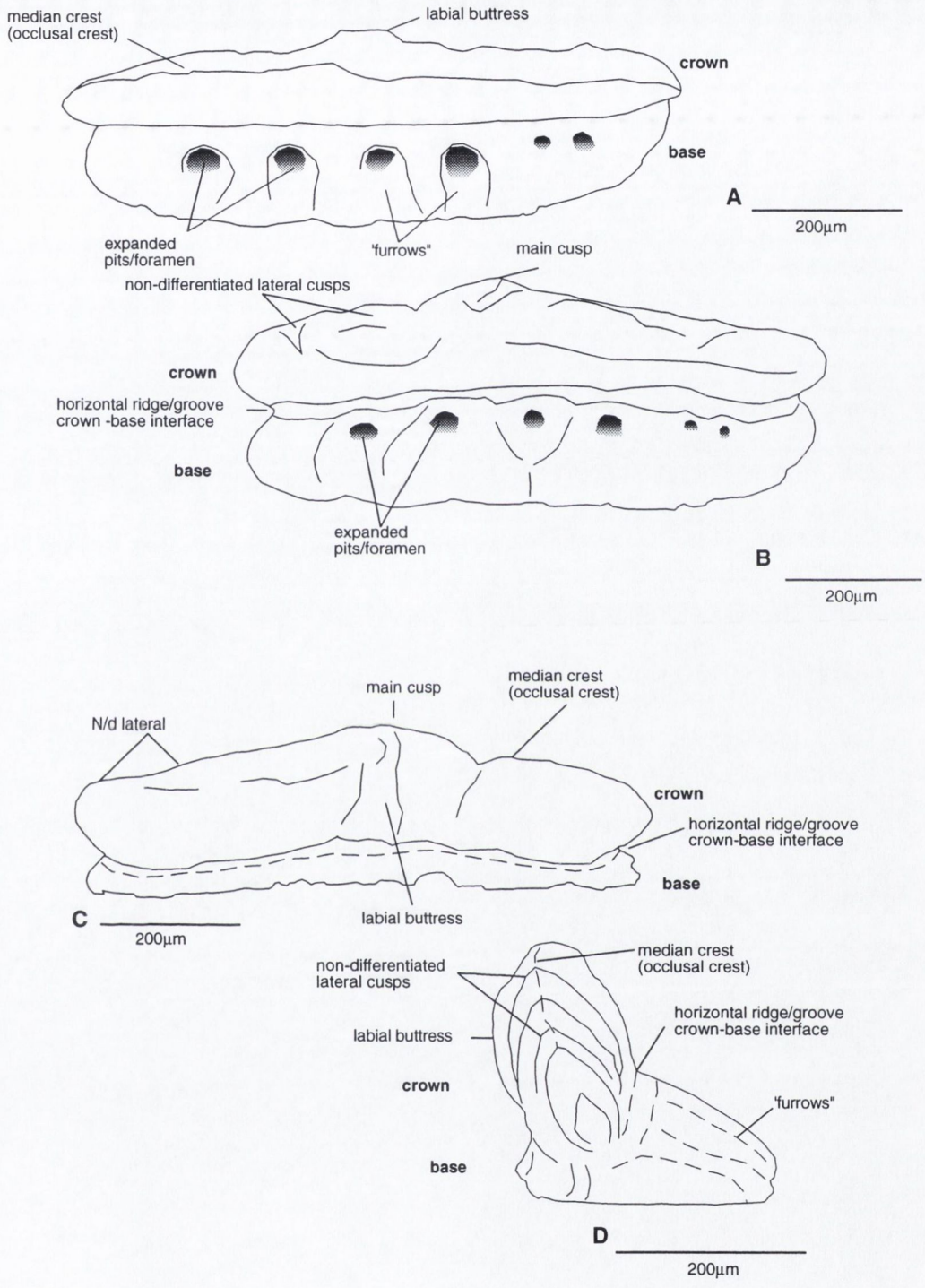


Figure 7.9. Drawing of *Lissodus* Morphotype 5 illustrating the main morphological features. A - Lingual/semi-Occlusal; B - Lingual view; C - Labial view; D - Lateral view, all based on TCD 36778. (see Plates 26-28 and 30-32)

7.3.5 *Lissodus* Morphotype 5 (Figure 7.9, Plates 26-28 & 30-32)

Diagnosis: Isolated microscopic chondrichthyan teeth. Enameloid crown; labio-lingually compressed with four to eight non-differentiated cusps, asymmetric, blade like. Narrow median crest extends from lateral edge to lateral edge lying more to the dorso-lingual; main cusp off centre, higher than the lateral cusps with a subdued vertical ridge descending from the apex lingually, labially ridge bifurcates before the crown-base interface (may bifurcate a second time) delineating a labial buttress; lateral non-differentiated cusps are outlined in most instances by shallow grooves on both aspects, though some evidence of ridging may also occur. Base outline elongate, ventrally slightly concave with furrows radiating towards the centre; lingually base is long and sloping with at least seven deep furrows and foramina, labially short, punctuated by foramen. (See Figure 7.9 for descriptive terminology)

Material: Twelve figured, isolated specimens (some complete). Specimen Numbers: TCD 36775-36780; 36783-36788.

Description: The length along the median crest ranges from 0.7mm to 1.33mm (in most cases the length of the base is very slightly less than or equal to that of the crown); labio-lingually the width of the crown ranges from 0.12mm to 0.24mm (base, 0.22mm to 0.39mm); the lingual height ranges from 0.24mm to 0.46mm (crown, 0.1mm to 0.32mm). The median crest is very narrow along the narrow blade-like crown. Cusps on both aspects are differentiated only by shallow oblique grooves from this crest towards the crown-base interface. Hence in lateral view the crown is lenticular in outline. Very subdued ridging occurs in some specimens. Lingually the crown-base interface is arcuate. The main cusp is higher than the lateral cusps and forms a labial buttress (lateral compressed) outlined in most instances by a vertical descending ridge that bifurcates at least once; subdued ridges may occur on the remaining labial cusps in some specimens. The lingual base is long, sloping and slightly convex; embayments may be seen at both lateral edges, though the crown is usually less than or equal to the length of the base. Up to seven deep furrows ending in foramina incise the lingual base from the linguo-ventral margin towards the arcuate crown-base interface. Labially, the base is one-third to one-quarter the length of the lingual surface, with a slightly convex labio-ventral margin, a few expanded pits occur; the ventral surface is concave especially along the labio-ventral margin from which a number of short furrows run in toward the central area while the linguo-ventral area is flatter.

Discussion: Morphotypes 1 and 5 are similar in the blade-like nature of their crowns, the presence in some specimens of small labial nodes at the crown-base interface and common occurrence of a minor lingual buttress. However, Morphotype 5 tends to be

smooth crowned, i.e. without vertical ridges, which contrasts with the strongly ridged Morphotype 1.

Age, Locality and Lithology:

Kilbride Limestone Formation, *Polygnathus mehli* conodont Biozone, Ivorian (probably Freyrian), late Tournaisian, Dinantian. Disused quarry, near Nobber, Co. Meath (N 845 848); crinoidal limestone.

7.3.5 Discussion of *Lissodus* Morphotypes 1-5 and other Carboniferous *Lissodus* teeth: Figure 7.10 outlines some characteristics seen within the five tooth morphotypes isolated during this study and also includes equivalent characteristics from two previously described Carboniferous *Lissodus* species (*L. wirkworthensis* and *L. pectinatus*). Duffin (1985, table 1, page 146) also outlined characteristics of tooth types but indicated only one Carboniferous species (although another species is cited in his text) and nineteen other species ranging from the Permian to the Cretaceous.

However, it is not suggested here that the five morphotypes described above are different species since it is possible that they could have been housed within a single jaw. Duffin (1985, fig. 12, page 122) reconstructed a dentition of the Triassic *Lissodus nodosus* (Seilacher) and showed the possible variation of teeth within a jaw (Figure 7.11 A). The more elongate and perhaps larger teeth with bifurcating ridges from the median ridge were placed in lateral tooth rows and the more triangular based, less-ornamented and strongly buttressed (labially) teeth in the mesial position. Duffin suggested that *.."variations in the tooth form must be of functional significance."*... He envisaged the labial buttress (peg of Duffin) of the mesial teeth holding adjacent tooth files "*in functional and rigid juxtaposition*" but having a reduced root; the lateral teeth having less a important labial buttress relying on an increase in the robustness of the base (root of Duffin) to "*accommodate higher occlusal loads, in conjunction with a system of nodes which may have anchored successive teeth by overlapping the extremely convex lingual root face of the preceding tooth*".

Although *Lissodus nodosus,* whose dentition Duffin (1985) reconstructed is from the Middle to Upper Triassic, the tooth variation found in the Carboniferous *Lissodus* morphotypes 1-5 in this study follows a similar pattern. This suggests that Carboniferous *Lissodus* also bore teeth of differing morphology within a single jaw. The simplest explanation of the material from the Kilbride locality is that *Lissodus* morphotypes 1-5 belonged to a single species (Figure 7.11 B). Because all of the teeth are different in some respects to those of *Lissodus wirksworthensis* (Duffin, 1985) (most of which have symmetrical crowns with accessory cusps on the crest of the labial buttress) and to those referred to *Lissodus pectinatus* by Lebedev (1996) (which have strong lingual nodes), they may belong to a closely related species, which will not be

formally named until there is additional evidence that they are indeed derived from a single species.

Length of Tooth	Overall Shape	Median Crest	Crown Ridges	Cusps	Labial Buttress	Lingual Buttress	Base	Base characters	TYPE
0.7mm-1.38mm	elongate slight asymmetry	narrow sharp	vertical lingual & labial	av. 6-7 to 11 (non-diff.) labial nodes at CBI	prominent may run into base	minor	elongate lenticular	lingual long labial short ventro-labial concave	**Lissodus Morphotype 1**
1.25mm-1.6mm	elongate slight asymmetry	broad smooth	none	non-diff.	present	none	elongate (lenticular) has lingual nodes	lingual long labial short ventral concave	**Lissodus Morphotype 2**
0.6mm-0.77mm	triangular asymmetric	broad	oblique/vertical lingually	av. 3-5 (non-diff.)	pronounced runs into base	none	triangular	lingual long labial short-buttress extn ventral deeply concave	**Lissodus Morphotype 3**
0.7mm-1.24mm	elongate slight asymmetry	narrow	vertical lingual & labial	av. 5-7 (non-diff.) labial nodes at CBI	pronounced runs into base	minor	sub-triangular	lingual long labial short-buttress extn deep cavity under buttress	**Lissodus Morphotype 4**
0.7mm-1.33mm	elongate asymmetric	narrow sharp	very slight if present both lingual & labial	av. 4-8 where distinguishable labial nodes at CBI	present	residual	elongate (lenticular)	lingual long Labial short ventral-concave esp. under buttress	**Lissodus Morphotype 5**
1mm-2mm	elongate symmetric	moderate	vertical labial	up to 12 accessory lingually	moderate to well developed runs into base	none	elongate	lingual long labial short-buttress extn very slightly concave	**L.wirksworthensis**
2mm-4mm	elongate	moderate	vertical labial	lingual nodes at CBI	pronounced	none	elongate	lingual long labial short ventral smooth-concave	**L. pectinatus**

Figure 7.10. Comparison of the different Carboniferous *Lissodus* teeth.

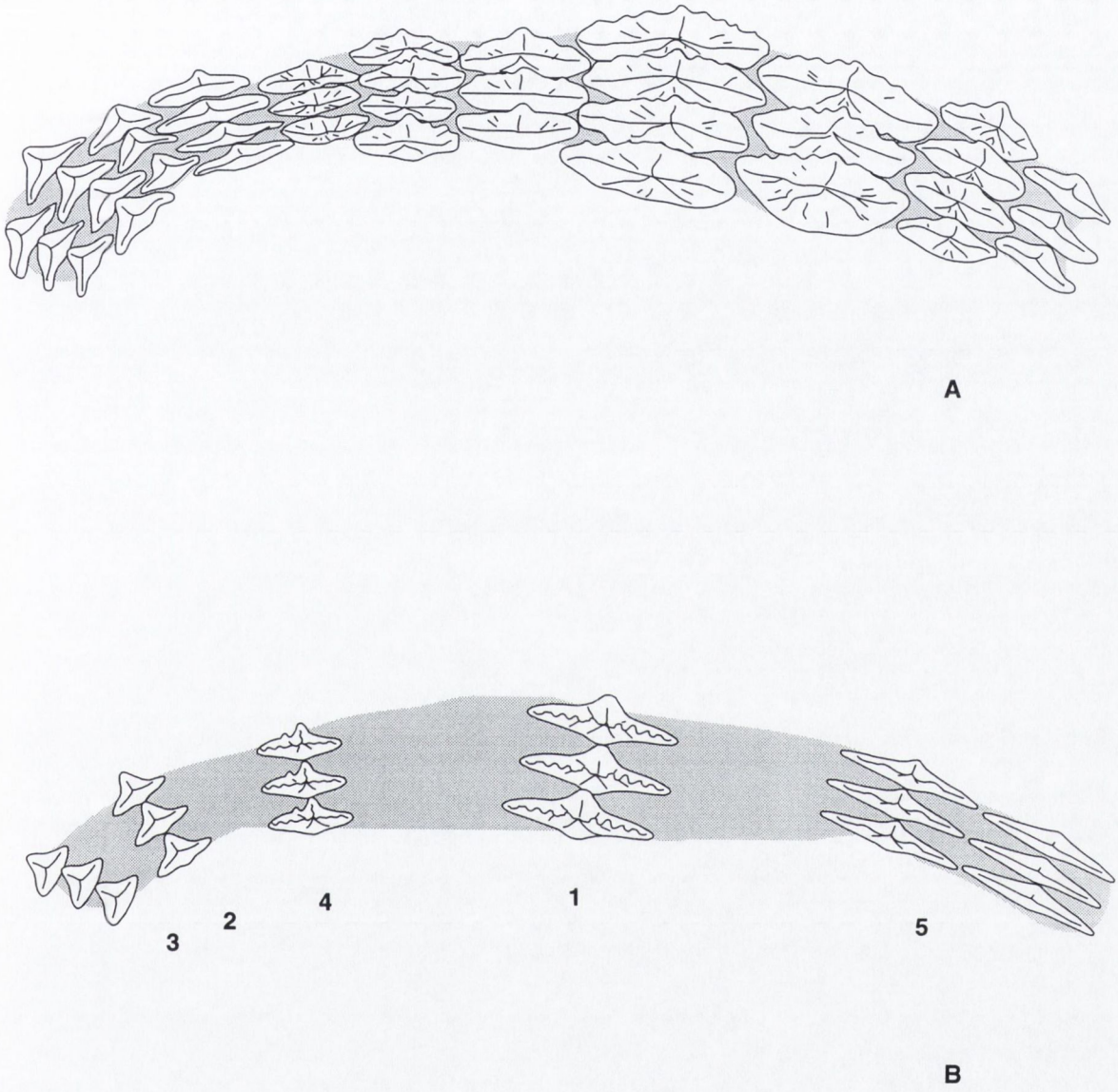


Figure 7.11. A. Reconstruction of the dentition of *Lissodus nodosus* (Seilacher) (After Duffin 1985). B. *Lissodus* Morphotypes 1-5 interpreted as constituents of a single dentition jaw using the reconstruction shown in Figure 7.11A as a template.

7.4 cf. Denaea

Class CHONDRICHTHYES Huxley, 1880

Subclass ELASMOBRANCHII Bonaparte, 1838

Order SYMMORIIDA Zangerl, 1981

Family SYMMORIIDAE Dean, 1909

Discussion: One of the distinguishing feature of this family is that all the constituent genera have been found so far to be naked, or nearly naked. Taxonomic distinctions are based on features such as isolated spines, denticles and the exceptional preservation of other probably calcified cartilaginous tissues. In the absence of articulated or partly articulated material, the taxonomy of genera and species has commonly been based solely on isolated teeth. Genera within the family include *Denaea*, *Symmorium*, *Cobelodus*, *Stethacanthus*, *Cladoselache,* and others, all of which have typical cladodont teeth.

Genus *Denaea* Pruvost, 1922

Type species: *Denaea fournieri* Pruvost, 1922, Lower Viséan Marbre Noir de Denée, Belgium

Discussion: Two species have been assigned to *Denaea*: the type *Denaea fournieri* Provost; and *Denaea meccaensis* Williams. Pruvost's original diagnosis of *D. fournieri* on which the concept of the genus was based is as follows:

"Dents*: nombreuses, très petites, formèes de cinque denticules insérés sur une seule base, le médian étant plus élevé que les quatre autres, les latéraux externes un pu plus longs ques les latéraux internes. Ces dents rappellent de façon frappante, mais en miniature, celles des* Cladodus."(Fournier and Pruvost, 1928) (Teeth: numerous, very small, with five denticles inserted on a single base, the middle denticle being higher than the other four, the external laterals a little longer than the internal laterals. The teeth resemble in a striking way, but in miniature, those of *Cladodus.* Eng. tranl).

Williams (1985) described *Denaea meccaensis* and amended the generic diagnosis of *Denaea* as follows:

..."*A very small, cladodont shark bearing numerous 3 to 7 cusped teeth of approximately 0.5mm to slightly over 1mm in height. Tooth bases expanded labio-lingually, irregularly*

hexagonal, lacking articular prominences and bearing arcuate excavations on the basal surface."...

In the type specimen of *D. fournieri*, from the Marbre Noir de Denée, Belgium, which I have looked at, the teeth are embedded in limestone and features of the base, referred to in Williams diagnosis, are not visible. The diagnosis of *Denaea* formulated by Williams is clearly based largely on *Denaea meccaensis,* which Williams (1995) described as follows:

..."*The normal dentition teeth of* Denaea *are rather typically cladodont, with a large central cusp and 1 to 3 pairs of lateral cusps. The most common tooth type bears three pairs of lateral denticles with the second pair being the largest. Although the teeth used in making the illustrations were partially imperfectly replaced by pyrite, it appears that all cusps bore vertical striations. Very few teeth were seen in side view, but at least one shows that the main cusp was sigmoid in shape and that the base was gently arched. Unlike the base of the teeth of most cladodont sharks, which are usually elliptical or trapezoidal in outline, the base of the teeth in* Denaea *approach the shape of an irregular hexagon. In addition, the teeth as preserved lack either apical or basal buttons, prominences, or ridges that are often present in typical cladodont teeth. ".. ..."In spite of the apparent absence of articular bosses, the tooth bases do, however, show paired arcuate excavations on the latero-lingual margins of the basal surfaces. "... ..."A prominent nutrient foramen is situated on the basal surface just below the central cusp, and another is present on the apical surface between the main cusp and the lingual border."* *Denaea meccaensis* is also under review as part of the revision of *Denaea fournieri* (Ivanov, 1999 pers. comm.).

Identification of the Irish Material as the genus *Denaea*: In the literature, *Denaea* has been distinguished from *Symmorium* by reference to descriptions of teeth identified as *Symmorium reniforme* (Mapes and Hansen, 1984; Williams, 1985; Duffin *et al.* 1996) based on the misapprehension that there is a symmetrically arranged double projection and labial sulcus along the labial border of the base and the articular facets on the supper surface of the lingual root. This interpretation of the morphology which has been well documented (Mapes and Hansen, 1984; Williams, 1985; Duffin *et al.* 1996) and held to be true until very recently. It was based on a misinterpretation of figure captions, b y others, of figures contained in Williams (1985). However, the teeth of the holotype of *Symmorium reniforme* Cope 1893 in the Field Museum of Natural History, Chicago have neither two buttons nor two distinct labio-basal projections; rather there is a long low, crescentic ridge close to the lingual rim of the base and an opposing shallow curved basal cavity (Ginter, 1998). A further complication is that the specimens identified as *Symmorium reniforme* by Mapes and Duffin appear to be identical to teeth described b y Leidy (1859) as *Cladodus occidentalis*. The latter taxon is probably also a senior

synonym of *Cladodus mortifer* Newberry and Worthen (1866). Glickman (1964) assigned *Cladodus occidentalis* to the genus *Ctenacanthus*, a taxonomic decision which should be reviewed (Ginter, 1998). As can be seen from the discussion above, the taxonomy of the genera contained within the family Symmoriidae is confused. A first step towards clarification of the distinctions between the different genera would be achieved by a detailed investigation of the morphology of the teeth in the type species of *Denaea*, *Denaea fournieri*. Since it is unlikely that it will be possible to prepare the holotype, an approach which might be successful would be to dissolve limestone from the type locality in the hopes of finding isolated teeth. A revision of *Denaea* is currently being undertaken by Ivanov (pers. comm. 1999).

Seven specimens are tentatively assigned to *Denaea* in this study on the basis that their morphology conforms to that of *Denaea fournieri* in those features of the latter taxon which can be seen. They do not belong to *Stethacanthus* as there is no prominent labio-ventral projection (rectangular in shape) under the central cusp and a corresponding rectangular groove on the upper surface of the base; the outline of the base is pentagonal to hexagonal rather than oval and the lateral cusps are not equal in height (Williams, 1985).

cf. *Denaea*

(Figure 7.12, Plates 33-39)

Diagnosis of material isolated during this study: Isolated microscopic chondrichthyan teeth. Multicuspid enamel crown with five to seven cusps - a central principal cusp (pc) with a pair of short secondary cusps (2y) either side; a pair of lateral tertiary cusps (3y) longer and broader than the 2y; a pair of secondary auxiliary cusps (2yaux) may occur between the pc and the 2y; all cusps tend to show lingual curvature, and rise linearly from the labial surface of a lingually expanded pentagonal to hexagonal base. Base may or may not extend beyond the 3y with the lingual margin punctuated by a large basal canal; ventrally concave with raised margins and an undulating labio-ventral surface slightly arching under both 2y cusps. No obvious apical button present on dorsal surface of base.

Material: Seven figured isolated specimens (two more or less complete, with secondary cusp broken; three with base and lower quarter of cusps intact). Specimen Numbers: TCD 36744-36750. A single cusp (TCD 36984) and damaged tooth (TCD 36984) not illustrated.

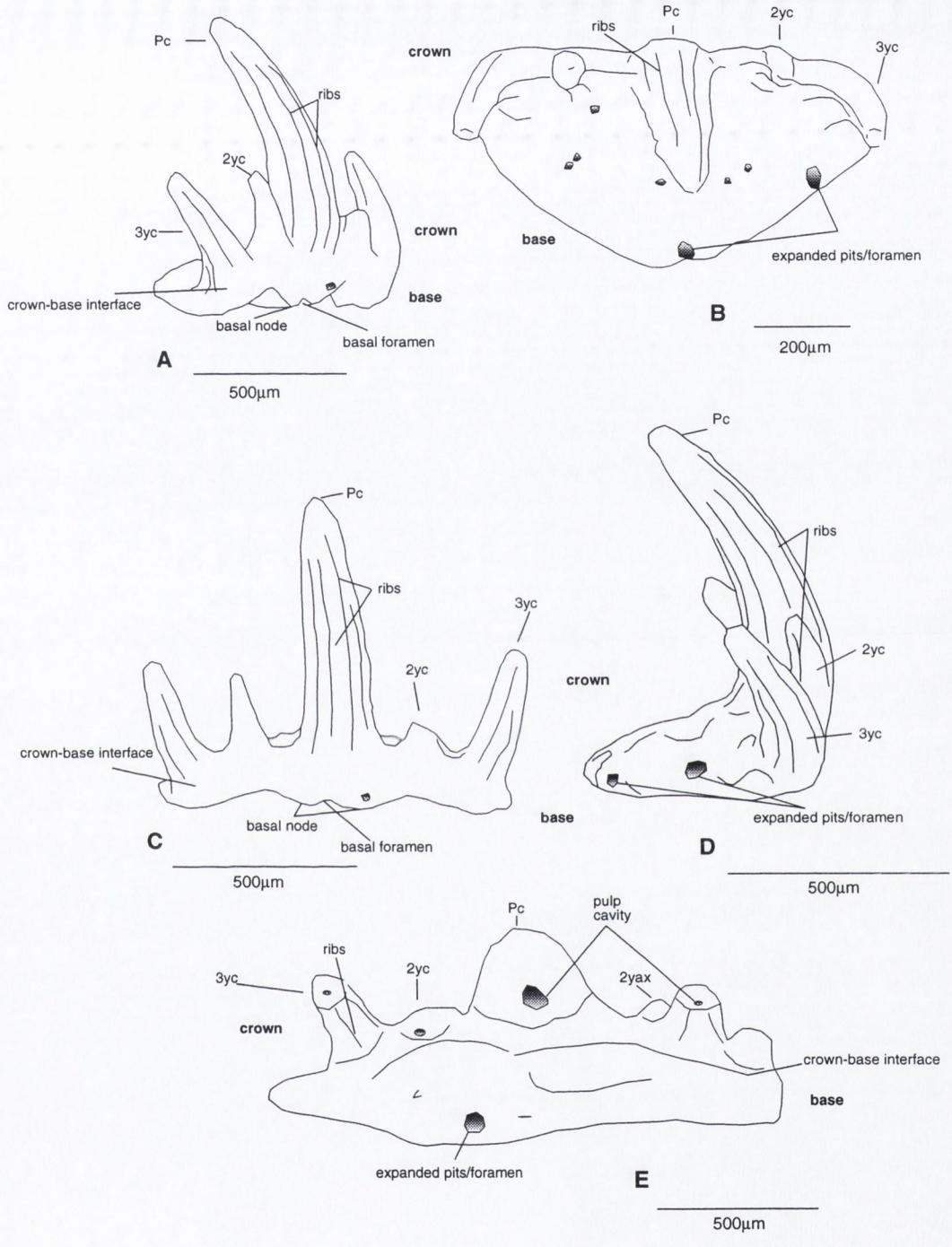


Figure 7.12. Denaea Type Teeth. A - Oblique Labial view; B - Occlusal view; C - Labial view; D - Lateral view, A-D based on TCD 36746. E - Lingual view, based on TCD 36748. (see Plates 33-39)

Description: Length across the extent of the preserved cusps ranges from 1.13mm to 1.6mm; the labio-lingual width ranges from 0.48mm to 0.94mm; the height from the ventral surface to the tip of the principal cusp ranges from 0.65mm to 0.81mm.

The principal cusp (pc) is long and narrow with a strong lingual curvature; up to six closely spaced ridges extend from the base to the tip lingually with a strong ridge delineating the lateral edges; the labial surface shows up to six ridges stopping short of the tip which may be less pronounced than the lingual ridges. Where the cusps are broken a small central lumen can be seen. The secondary cusps (2y) initiate either side of the pc at a level very slightly higher than the base of the latter and may be one-third to one-quarter the height of the pc; they are curved lingually but at a broader angle than the pc with a small central lumen; closely spaced ridges occur on all surfaces. The tertiary (3y) cusps initiate below the base of the 2y cusps at the lateral edges and may be up to one-third longer than them but less than half the length of the pc; they are curved latero-lingually with raised ridges on all surfaces, more subdued labially. The secondary auxiliary cusps (2yaux) occur between the pc and 2y cusps and are attached to the latter, they initiate above the base of the pc; however, where they occur they are not complete and appear to curve medio-lingually.

In most instances the lateral ridges of each cusp type tend to join across the inter-cusp area. In lateral view the cusps generally are slightly off-set rather than being aligned.

The base is pentagonal to hexagonal with the central angle medio-lingually (which may form the sixth 'side'). The linguo-dorsal surface of the base slopes gently to the margin from the cusp bases and may have a very slightly raised central crest rather than a pronounced apical button. The base is punctuated on the lower linguo-dorsal margin by a large central basal canal that extends in towards the centre; some minor expanded pits may occur on this surface in the crest area The base may extend beyond the labio-lateral edge of the cusps (in lateral view the base is wedge-shaped). Labially the base is short and the labio-ventral margin undulates with an arch occurring in the area beneath the 2y cusps. This surface has a foramen under the principal cusp and may have two further foramina (one to each side). The ventral surface is slightly concave to concave, with raised margins. Two concave areas which die out towards the centre of the ventral surface occur under the 2y cusps (where the labio-ventral margin is arched) and may be punctuated by a small foramen; scattered expanded pits occur on this ventral surface.

Discussion: Superficially these teeth bear a greater similarity to those described as *Denaea meccaensis* than to the description of the teeth of the type specimen *Denaea fournieri*. However, comparison between these two species by Williams (1985) is based on both meckel's cartilage and the palatoquadrate rather than on the types of dentition. The presence of 'cladodont' type teeth is also not specific as they are now

known to occur in a considerable number of shark genera of the Palaeozoic. Zangerl (1990) has suggested that *Denaea meccaensis* Williams 1985 matches his description of the cladodont teeth of *Stethacanthulus* Zangerl 1990 (both Pennsylvanian) and are .."indistinguishable".. in terms of dentition. Both forms appear to have a basal canal opening on the dorso-lingual surface just behind the principal cusp.

Lebedev (1996) described ? *Denaea* sp. from the Upper Viséan of Central Russia in which the overall morphology is similar to that of *Denaea meccaensis* Williams 1985. However, there are a symmetric pair of large vascular openings on the oral side of the lingual projection (presumably lingual base) and two more at the base of the intermediate cusps lingually, as well as labio-lingual ridge on the ventral side of the base separating two depressed areas.

The Irish material appears very similar to specimens illustrated from the Late Carboniferous (Westphalian/Stephanian) of Brazil (Duffin *et al.* 1996) and to specimens yet to be formally described (Ginter, pers. comm.1997), though those from the Ural Mountains of Russia (Late Carboniferous to Lower Permian) have been briefly discussed in a paper outlining the relationships of the genus *Phoebodus* (Ginter and Ivanov, 1996). The slightly younger Brazilian material has a central cusp flanked by three pairs of lateral cusps on at least one side (specimens are not intact) whereas the Irish material predominantly has a central cusp flanked by two pairs of lateral cusps (occasional auxiliary cusps appear). The Brazilian and the Irish specimens show on the linguo-dorsal margin a single large central basal canal that extends in towards the centre. The Irish specimens show an undulating labio-ventral margin with an arch occurring in the area beneath the 2y cusps (the pair of cusps closest to the central cusp) and a foramen punctuating this surface below the central cusp on the labio-ventral margin.

Age, Locality and Lithology:

Kilbride Limestone Formation, *Polygnathus mehli* conodont Biozone, Ivorian (probably Freyrian), late Tournaisian, Dinantian. Disused quarry, near Nobber, Co. Meath (N 845 848); crinoidal limestone.

7.5 Protacrodus

Class CHONDRICHTHYES Huxley, 1880

Subclass ELASMOBRANCHII 1838

Order EUSELACHII Hay, 1902

Superfamily PROTACRODONTOIDEA Zangerl, 1981

Description of the teeth of taxa assigned to the Superfamily Protacrodontidea ZANGERL 1981: ..."*The palatoquadrate is cleaver-shaped, and the lower jaw is an angular piece of about the same height fore and aft. The teeth are located in tooth wells above and below, hence do not form a tooth pavement. The teeth are orodontid having a main cone flanked by a number of smaller conule; all are strongly ridged.*"...(Zangerl, 1981, p.61)

However, Zangerl did not create any Families within the Superfamily quoting only the genera *Protacrodus* Jaekel, 1921 (teeth and scales) and *Holmesella* Funnell, 1931 (scales and possible mucous denticles) under the Superfamily heading.

Family PROTACRODONTIDEA Zangerl, 1981

Derycke *et al.* (1995a) notes the following: ..."*The name* Protacrodontoidea *was created by Zangerl (1981: 61). According to the ICZN articles 36a (Ride et al. 1985:76) this name is also established with the same author and date for any other taxon based upon the name-bearing type at other ranks in the family group with appropriate change of suffix. So* Protacrodontidae *Wang and Turner, 1985 is a junior synonym of* Protacrodontidae *Zangerl, 1981.*"...

Genus *Protacrodus* Jaekel, 1921

Type *Protacrodus vetustus* Jaekel 1921

Discussion: Gross (1938, 1973) described teeth of cladodont type with a crown of short, rounded conical and striated cusps set on a high base with lingual foramina and assigned them to *Protacrodus* .

Turner (1982) described three types of teeth of *Protacrodus*, *Protacrodus* A-C from north Queensland, Australia. Type A is 0.8mm long, 0.5mm wide and 0.5mm in height, tricuspate with a large central cusp and a smaller cusp to either side separated from the central cusp by a furrow, each cusp is strongly ridged; the base has an arched crown-base interface, the upper basal surface lingually has a large canal opening below the central cusp and four smaller ones, two each side of the large one, ventrally concave. Type B is longer, up to 1.92mm; wider, up to 0.92mm; and slightly higher, up to 0.72mm (another isolated specimen is larger still). The crown in this type is long with a continuous ridge of cusps, a relatively large central mound and two to four laterally decreasing mounds on each side; all have no raised ridges. The lingual base has a

shallow platform with numerous (13) canal openings and further small foramina. Type C are similar to Type A but are smaller and have labio-lingually compressed cusps possibly with sigmoidal ridges.

Derycke *et al.* (1995a) described a *Protacrodus* sp. which she considered to be similar to the type species from the Devonian/Carboniferous boundary in France. In the Devonian/Carboniferous boundary material, the teeth are labio-lingually compressed with cusps joined by a crest over the central conical cusp and two to three smaller cusps to each side, all of which are strongly ridged. There are numerous foramina on the lateral faces; a second type of *Protacrodus* was also described with wide cusps, minor ridging, a sharp crest and lingually extended base; a broken boss occurs under the central cusp with large foramina in the surrounding depression.

Ivanov (1996) described a new species of *Protacrodus* (*Protacrodus aequalis*) and suggested that this new species was the same as *Protacrodus "C"* of Turner (1982), differing from the type species by having ..."*a pyramidal crown with fused basal parts of the cups and a short and wide base. Also the cusps of* P. vetustus *are rounded in cross-section.*"...

From the descriptions above, the range of variation in teeth assigned to *Protacrodus* spp. is large. The taxon as understood by the authors cited above includes specimens with three cusps of more or less equal size; three cusps of obviously unequal size; and a continuous ridge of cusps. The Irish material falls within this range of variation.

General Description of the Irish Material: Labio-lingually compressed teeth with short, rounded conical cusps, ornamented with strong descending ridges; base shows numerous foramina on an extended lingual and labial surfaces. This is similar to the descriptions by the authors cited above.

7.5.1 *Protacrodus* Morphotype 1: (Figure 7.13; Plate 40, Figures A-B)

Diagnosis: Isolated microscopic chondrichthyan tooth. Asymmetric enamel like crown with prominent median crest offset towards lingual side extending to each lateral margin; linguo-labially compressed; crown can be divided into five pyramidal cusps with bifurcating vertical ridges. Long convex lingual base with a number of basal pits extending beyond crown at lateral margins; short labial base; convex ventral base with horizontal ridge. (See Figure 7.13 for descriptive terminology).

Material: A single figured specimen. Specimen number TCD 36789.

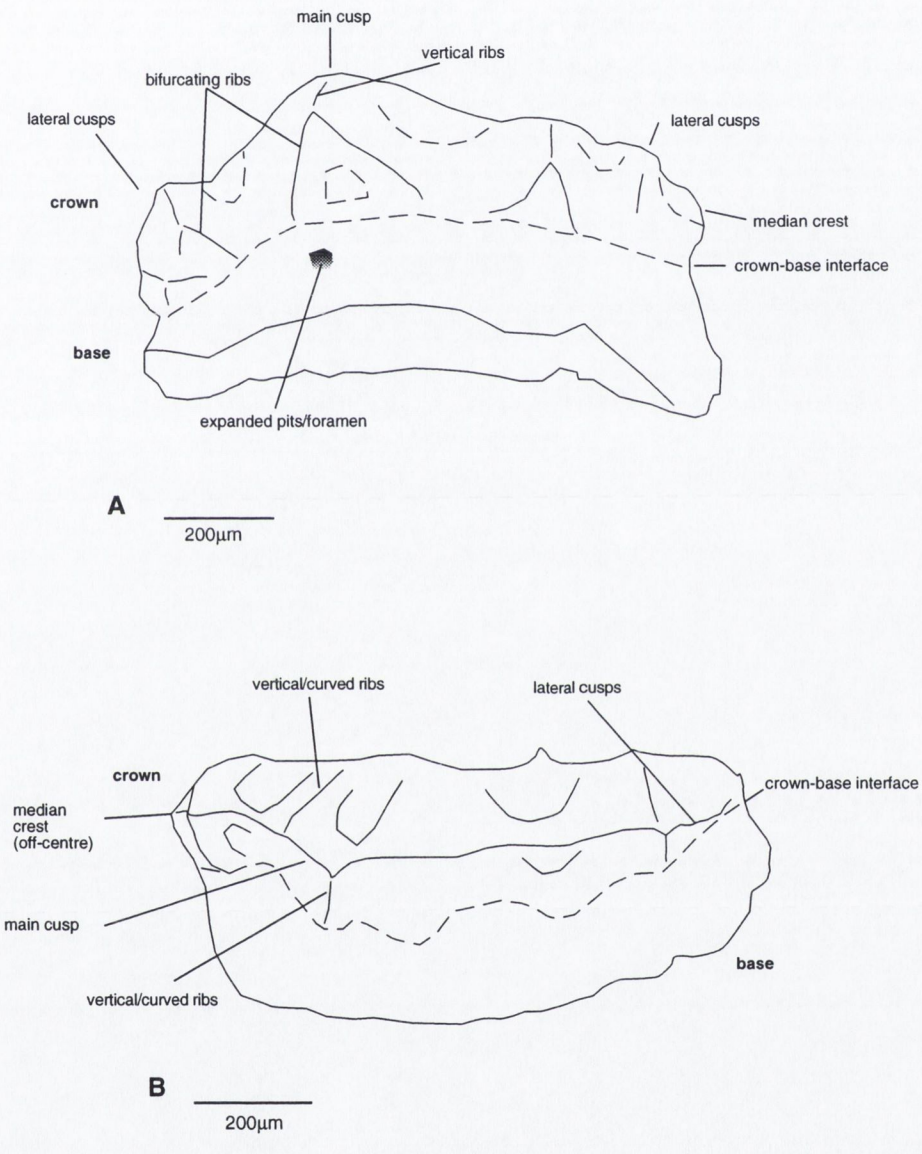


Figure 7.13. Protacrodus Morphotype 1. A - Labial view; B - Occlusal/lingual views, based on TCD 36789 (see Plate 40).

Description: Length along median crest in dorsal view is 1.0mm (crown, 0.94mm); linguo-labial width 0.5mm (crown only, 0.34mm); the height in lingual view is 0.54mm (crown, is 0.24mm). Viewed from the lingual side the main cusp is to the left of the mid line with a short ridge normal to the median crest bifurcating and then extending down to the crown-base interface. To right of the mid line, two lateral cusps, each with a strong central ridge normal to the crest, curve slightly to the centre at the crown-base interface, bifurcating just above it; a small right linguo-lateral cusp appears also to have a vertical ridge to the crown-base interface; to the left of the mid line a single cusp with a central ridge curving towards the centre at the crown-base interface is not entire - a further lateral cusp may have been present. On the labial side each cusp has a vertical ridge from the apex descending towards the crown-base interface. The lingual base is long, sloping and convex, with five expanded pits or furrows. Labially, the base is a third as high as the lingual side with a few small pits on the surface. The ventral base is convex with a subdued horizontal ridge and possibly transverse furrows.

Discussion: This specimen shows some similarity to *Protacrodus vetustus* Jaekel 1921. However, the cusps are not divided as deeply as in *P. vetustus* (Zangerl, 1981, Derycke *et al.* 1995a, fig. 4) and are more asymmetrical. As only one specimen has been isolated it is not thought prudent to describe it as a new species.

Age, Locality and Lithology:

Kilbride Limestone Formation, *Polygnathus mehli* conodont Biozone, Ivorian (probably Freyrian), late Tournaisian, Dinantian. Disused quarry, near Nobber, Co. Meath (N 845 848); crinoidal limestone.

7.5.2 *Protacrodus* Morphotype 2 (Figure 7.13; Plate 40, Figures C-E)

Diagnosis: Isolated microscopic tricuspate chondrichthyan tooth. Enamel like crown with three separate linguo-labially flattened cusps. They curve lingually towards their apex and rise from the labio-dorsal surface; ridges diverge from the apex on both aspects. Lenticular shaped base with expanded pits and furrows on both long lingual and short labial aspects; ventrally concave in the labio-ventral area to convex at the linguo-ventral margin; expanded pits occur in the central concave area. (See Figure 7.13 for descriptive terminology).

Material: A single figured specimen. Specimen number TCD 36790.

Description: Length along median crest is 0.74mm (crown 0.68mm); the width of the crown in linguo-labial view is 0.02mm, and with the base 0.21mm; height in lingual view is 0.52mm (crown 0.28mm). The three differentiated cusps rise vertically from the labial side of the base, turn towards the right labial margin and then curl over near the median crest to the lingual side. On the lingual side the main cusp rises vertically and turns gently to the left as it curls over the lingual surface. A series of ridges extend from the tip with at least two with deep furrows in between them on the lingual surface either side of the mid line. The right linguo-lateral cusp rises vertically from the base, curling in over the lingual surface. Two strong lateral ridges extend from the crest tip to either side; two more extend from the tip down the lingual surface either side of the mid line. The left linguo-lateral cusp rises obliquely to the left from the base, curling over the lingual surface at the tip; two strong ridges extend linguo-laterally with two further ridges on the lingual surface either side of the mid line. On the labial side the main cusp has four ridges from the crest slightly oblique from the tip to the crown-base interface, two of which form a central node where the crown tip turns over to the lingual side. The right labio-lateral cusp is straight initially, then turns to the right; two strong, off-centre ridges curve towards the main cusp with another to the left; the left labio-lateral cusp has four ridges from the tip to the base of the cusp. The cusps appear to be joined halfway along their length before separating towards their tips. The whole crown curves out from the crown-base interface and then back towards the lingual side at crest level.

The lingual base is four times wider than the labio-lingual cusp width; a large central pit occurs with furrows either side; the labial base is less than one-third the height of the lingual, with the ventral margin crescent shaped and turning away and out to the lateral margins expanding towards the lingual base. A number of expanded pits or furrows occur on the labial side. The ventral base is lenticular with the labial side concave and the lingual convex; the central area is concave with a number of expanded pits.

Discussion: This specimen is similar to *Protacrodus aequalis* Ivanov 1996 (Lower Tournaisian of the South Urals) but differs in that the base of the Irish specimen is obviously lenticular rather than triangular or round as described by Ivanov. As no dimensions are given in relation to the diagnosis of *P. aequalis* this makes comparison with the Irish material difficult; although illustrations are shown with scale bars it is still not possible to get accurate measurements due to the unknown orientation of the specimens on a stub and working distance used in taking the Scanning Electron Microscope photographs. Ivanov (1996) in his remarks suggested that the teeth from the ..."Famennian of the Kuznetsk Basin, Tom and Yaya Rivers and Australia (Turner 1982)"... are all the same species, referring in the Australian case to *Protacrodus* Type C of Turner (1982); however, the latter shows labio-lingually flattened cusps placed on the labial side of a lozenge or D-shaped base.

As *Protacrodus* Morphotype 2 is based on only one specimen it is deemed prudent to describe it as a new species.

Age, Locality and Lithology:

Kilbride Limestone Formation, *Polygnathus mehli* conodont Biozone, Ivorian (probably Freyrian), late Tournaisian, Dinantian. Disused quarry, near Nobber, Co. Meath (N 845 848); crinoidal limestone.

7.5.3 *Protacrodus* Morphotype 3 (Figure 7.13; Plate 41)

Diagnosis: Isolated, microscopic, chondrichthyan tooth. Enamel-like crown with seven to eight semi-differentiated cusps; narrow median crest extending from each lateral margin over the apices of each pointed cusp and into the inter-cusp area; linguo-labially compressed; in dorsal view concave labially and convex lingually; ornamented with initially vertical ridges that bifurcate repeatedly to the crown-base interface. Lingually the base is convex, sloping, with up to five deep expanded pits or furrows; labially it is short and concave with up to eight deep expanded pits or furrows; ventrally it is concave with a deep arcuate groove under the labial crown area. (See Figure 7.13 for descriptive terminology).

Material: A single figured specimen, TCD 36791.

Description: Length along median the crest is 0.84mm (crown length 0.81mm); the crown width in linguo-labial view is 0.23mm (width including the base 0.29mm); height in lingual view is 0.32mm (crown 0.16mm). On the lingual side the crown is convex with the main cusp off centre to the left, rising to a point and facing obliquely to left of vertical. A vertical ridge extends from the apex, bifurcating one-quarter way down and the left ridge then runs obliquely to the crown-base interface; the right bifurcates again forming two diverging ridges to the crown-base interface. The main cusp is nearly three times as high as the remaining cusps. To the left of the main cusp are three further pointed cusps (the one closest to the main cusp is shorter with a single vertical ridge to the crown-base interface) with bifurcating ridges to the crown-base interface. To the right of the main cusp in lingual view are three (possibly four) pointed cusps (the one closest to the main cusp is shorter); the remaining cusps have a single vertical ridge to the crown-base interface which curves out in an arc to the right linguo-lateral margin. All the cusps on the lingual side are separated by deep vertical grooves. On the labial side the main cusp has two diverging ridges from the apex to the crown-base interface with a ridge outside each of these starting half way down; the first cusp to the right has a short vertical ridge while the remaining cusps to the right of the main cusp have strong ridges from the apex which start vertically and then curve left towards the crown-base interface. To left of the main cusp on the labial side, the first cusp is shorter with a single vertical ridge; the next

cusp has diverging ridges while the remaining cusps on the labial surface are conjoined close to their apices with vertical ridges; otherwise each cusp is separated by deep vertical grooves on the concave labial surface.

The lingual base is convex (strongly so at the lateral margins) with up to five deep expanded pits or furrows; the labial base is concave and roughly one-third the length of the lingual, punctuated by up to eight deep expanded pits or furrows running to a concave ventro-labial margin. The ventral base is concave with a deep arcuate groove under the labial crown area with a tendency to twist to the left linguo-lateral edge (twisted up and inwards) whilst the right latero-labial edge twists in and down.

Discussion: This specimen differs from the Morphotypes 1 and 2 in that the cusp ridges have a tendency to bifurcate similar to those shown in illustrations of the type *P. vetustus* (late Devonian). However, although it shows up to eight furrows it does not show the numerous expanded pits illustrated by Zangerl (1981) in *P. vetustus* and is considerably shorter in length (0.84mm long compared to c.5.0mm). The Irish material does however, appear similar to the united pair described from the Devonian/Carboniferous boundary in France by Derycke *et al.* (1995a, fig. 4d-e). As the Irish material is described here on the basis of a single specimen, no specific name has been assigned.

Age, Locality and Lithology:

Upper Ballysteen Limestone, *Polygnathus mehli* conodont Biozone, Ivorian (pre-Freyrian), late Tournaisian, Dinantian. Bore hole 3246/4 Urlingford, Co. Kilkenny; thinly bedded crinoidal limestone.

7.6 Tricuspid Tooth

Class CHONDRICHTHYES Huxley, 1880

Order, Family, Genus Incertae sedis

Tricuspid tooth (Figure 7.14, Plate 42, Figures G-I)

Material: A single specimen. Specimen number TCD 36809.

Description: An isolated chondrichthyan tooth. Length in occlusal view is 0.84mm (crown 0.57mm); the width is 0.90mm (crown 0.60mm) labio-lingually. Tricuspate with the three cusps rising in an arc along the labial aspect of the dorsal surface. The main cusp is higher than the laterals and has a vertical ridge from the apex down the lingual surface where it joins the convex horizontal ridge marking the crown-base interface.

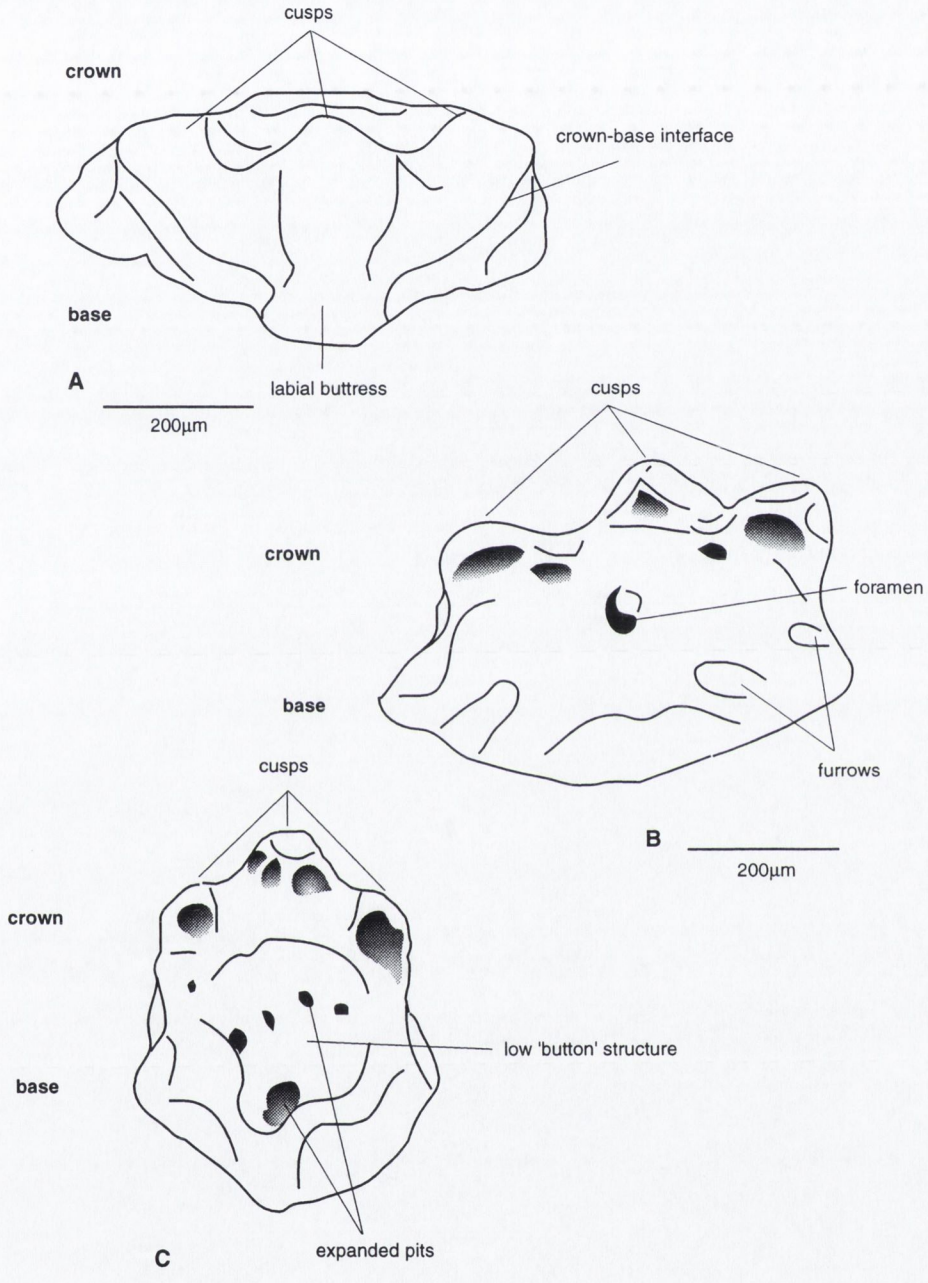


Figure 7.14. Tricuspid tooth. A -Dorsal view; B - Oblique Lingual; C - Lingual view. Based on TCD 36809 (see Plate 42).

Ridges extend from the apex of the lateral cusps to the crown-base interface. The left linguo-lateral cusp is oval and short whilst the right is sub-triangular. In labial view the main cusp forms a smooth labial buttress extending down to and including the base. The labial surface is convex with the labial buttress at the centre. The lingual base is convex, long, sloping and 'v' shaped; a very low button structure forms the centre of the base area with up to five expanded pits surrounding it. The labial base as preserved (incomplete) is very short with a small foramen on either side of the main cusp labial buttress. The buttress extends into and incorporates the labial base. The ventral base is lenticular, the linguo-ventral margin is 'v' shaped and forms a platform while the remaining area is concave with four furrows from the margin running towards the crown area. A deep expanded foramen occurs ventrally under the labial buttress.

Discussion: This tooth has not been identified below the level of Class. (Duffin *et al.* 1996) figured a similar tricuspid tooth from the Upper Carboniferous of Brazil. It differs from the Irish specimen in being smaller overall and in having an outgrowth of the labial base. However, the tooth described above does have a central labial buttress of the crown which extends into the short labial base. Duffin *et al.* (1996) suggested that the Brazilian specimen may be a very worn '*Cladodus*' type tooth, possibly resembling *Cladodus tumidus* Newberry (1889, plate 27, fig. 8). The Irish specimen shows less resemblance to this species.

Age, Locality and Lithology:

Kilbride Limestone Formation, *Polygnathus mehli* conodont Biozone, Ivorian (probably Freyrian), late Tournaisian, Dinantian. Disused quarry, near Nobber, Co. Meath (N 845 848); crinoidal limestone.

7.7 Chondrichthyan Pavement Dentition (CPD)

Class CHONDRICHTHYES Huxley, 1880

Order, Family, Genus Incertae sedis

Discussion: The following teeth have been segregated into types based on their overall gross morphology and have been named herein collectively as Chondrichthyan Pavement Dentition (CPD) as they cannot be assigned with any confidence to a specific order, family, genus or species.

CPD type teeth described below are elongate, labio-lingually compressed with crowns not divided specifically into cusps in most instances; however, medially the crown is

higher than laterally creating an asymmetric outline. Ornamentation of the crown is minor to slight; the crown rises from the labial side of the base; in some types the base extends lingually with extended pits or furrows and foramina on this surface; usually the labial base is short while the ventral base is concave. In some instances the teeth may belong to a known genus but are too worn to be identified with confidence.

7.7.1 Discussion of the affinities of the Chondrichthyan Pavement Dentition Teeth: It is possible that some of the CPD types described above could be assigned to "*Orodus*"; however, this is not anyway certain and they may in fact belong to other types.

De Koninck (1878) erected the family Orodontidae and included within it the genus *Orodus* proposed by Agassiz (1838). Zangerl (1981) has placed the family Orodontidae in an order Orodontida. The genus *Orodus* was based on a few isolated teeth from the Carboniferous limestone of Bristol. Thirty or more species have since been described based on isolated teeth (Zangerl, 1981). Zangerl has pointed out that *Orodus* has a pavement dentition of a large number of teeth and in common with other genera exhibiting pavement dentition ..."*there is a great variety of tooth shapes within a single dentition, and no doubt a good deal of variation in different individuals of the sample species, not to mention different ontogenetic stages.*"... Most of the teeth assigned to *Orodus* in the literature are considerably larger than the Irish material described here: some teeth are as much as 110mm maximum dimension.

To complicate matters, many teeth formerly assigned to *Orodus* have now been placed in different genera and even orders. An example derived from a synonymy list published recently (Lebedev, 1996, p. 394-396) concerns the Russian Lower Carboniferous teeth first described as *Orodus tumidus* Trautschold 1874. According to Lebedev, this species has been variously described as *O. excentricus* Trautschold 1874, *O. sublaevis* Woodward 1889, *Helodus aversus* Trautschold 1874, *H. gibberulus* Trautschold 1874, *H. contractus* Trautschold 1874, *H. angustus* Trautschold 1874, *Psammodus porosus* Trautschold 1874, *P. inflexus* Semenov and Moller 1864, and *P. linearis* Trautschold 1874. These genera have been assigned by Zangerl (1981) to different orders: *Orodus* to the Orodontida; *Helodus* to the Holocephali; and *Psammodus* Agassiz 1838 in part to *Chomatodus* Agassiz 1838 and thus to the order Petalodontida. It now seems certain that orodontid type teeth, which for many years were assumed to all belong to relatives of the genus *Orodus* (Carboniferous), also occur in other groups of chondrichthyans such as the casaeodontoid sharks belonging to the order Eugeneodontida.

For this reason the specimens described below, in which each morphotype is represented by fewer than four specimens, are not assigned to particular orders, genera or species.

7.7.2 CPD Morphotype 1 (Figure 7.15; Plate 43)

Diagnosis: Isolated, microscopic, chondrichthyan tooth. Crown enamel-like, elongate, divided very broadly into five non-differentiated cusps with a larger main cusp; the two cusps either side graduating to the lateral edges; broad subdued median crest. Base extends beyond crown on the lingual, labial and lateral surfaces, with up to nine expanded pits or furrows on both arcuate lingual surface and on the shorter labial surface; ventral surface strongly concave, (See Figure 7.15 for descriptive terminology).

Material: Three figured isolated teeth. Specimen Numbers: TCD 36731-36733.

Description: The average overall length along the median crest is 1.2mm (without the base 1.16mm); average linguo-labial width is 0.55mm (without the base 0.33mm); average height in lingual view is 0.49mm (without the base 0.28mm). In lingual view one to three subdued ridges extend from the apex of the main cusp which is 'off-centre' towards the crown-base interface; the cusps closest to the main cusp also have broad ridges from their apices extending to the crown-base interface and culminating in small nodes; these cusps themselves are defined by embayments of the crown between the ridges that are normal to the crest; the lateral cusps slope away from the main cusp at c.10°. In labial view the main cusp, secondary cusps and lateral cusps are defined by oblique furrows and poorly defined ridges from their apices to the crown-base interface. The slope of the lateral edges is c.50°. The base extends beyond the labial, lingual and lateral side of the crown. The lingual side of the base is arcuate; in some instances the

base shows an embayment at each lateral margin. Up to nine extended pits or furrows extend from the linguo-ventral margin towards the crown. Foramina may be present at the end of these furrows. The labial side of the base may be slightly less than half as deep as the lingual, and follows the line of the crown surface punctuated again by up to nine fossae. The ventral surface of the base is concave overall with a ridge running horizontally; the labio-ventral area is marked by a deep groove increasing the cavity at this point; several furrows extend from this margin inwards towards the centre of the base. Lateral buttresses are embayed and die away before the end of the base on the lingual side.

Discussion: Of the specimens, TCD 36733 is the shortest and widest and has a lower number of expanded pits or furrows on the base.

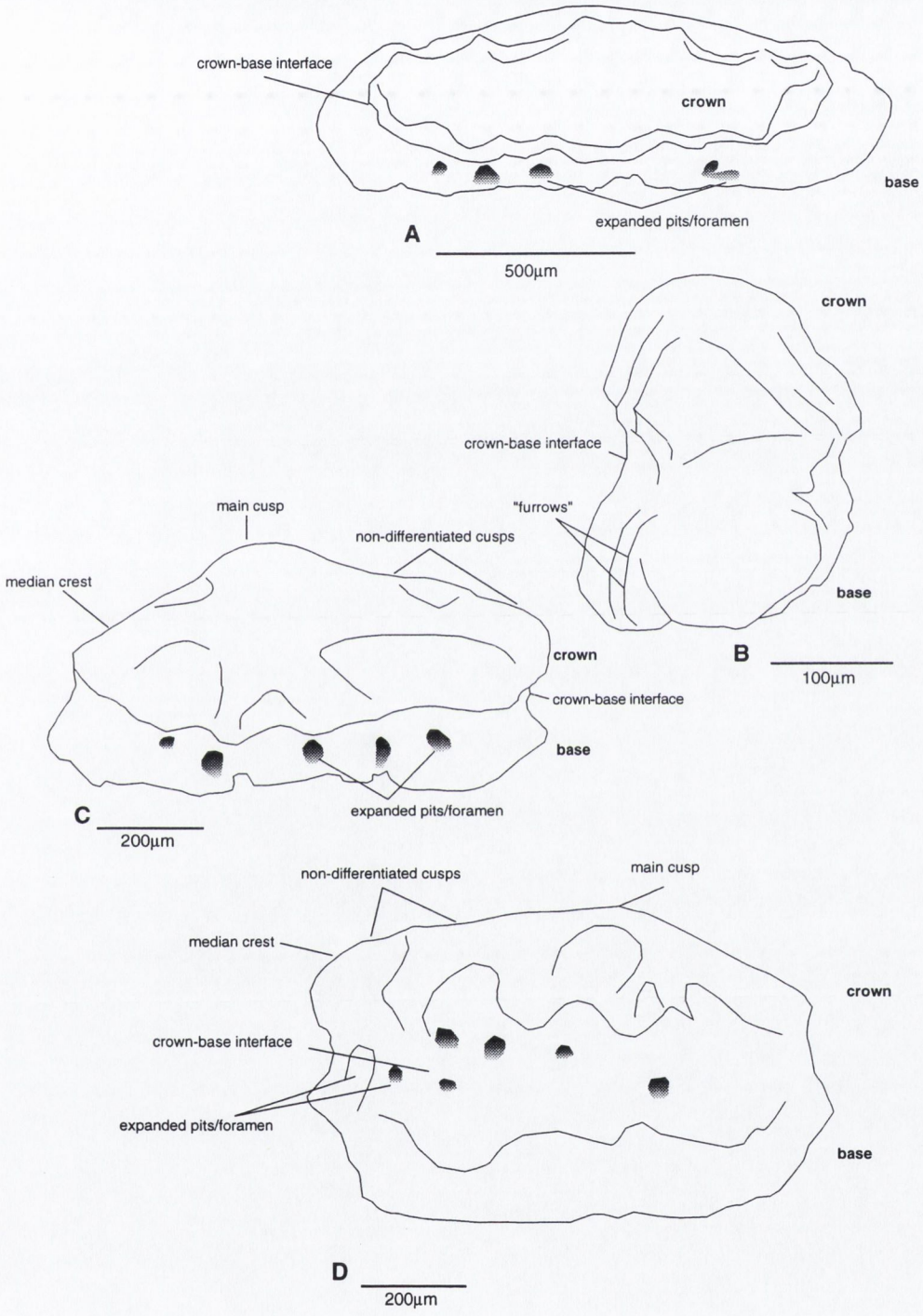


Figure 7.15. Chondrichthyan Pavement Dentition (CPD). A - Occlusal view; B- Lateral view; C - Labial View; D - Lingual view. A & B based on TCD 36731, C & D based on TCD 36733 (see Plate 43).

Age, Locality and Lithology:

Kilbride Limestone Formation, *Polygnathus mehli* conodont Biozone, Ivorian (probably Freyrian), late Tournaisian, Dinantian. Disused quarry, near Nobber, Co. Meath (N 845 848); crinoidal limestone.

7.7.3 CPD Morphotype 2 (Figure 7.15; Plate 44)

Diagnosis: Isolated, microscopic, chondrichthyan tooth. Crown enamel-like, cusps elongate non-differentiated; narrow median crest extending from left linguo-dorsal edge to apex of a pointed crest lingually, dying out to right of this apex and reappearing again along the right lateral crest more on the lingual surface. Base no longer than crown; up to eight large expanded pits on lingual and labial aspects; ventral surface concave with expanded pits. (See Figure 7.15 for descriptive terminology)

Material: A single, incomplete specimen. Specimen number TCD 36734.

Description: The overall length along the median crest is 1.35mm; the linguo-labial width is 0.55mm; the height in lingual view is 0.68mm (without the base 0.35mm). On the lingual side the area to the left of the apex is absent; this apex is to left of the midline with the left lateral edge sloping sharply away at c.60° and c.10° to the right, curling up at the right lateral margin. The lingual surface of the crown is convex around the apex so that the lingual crown overhangs the base. The crown-base interface follows this sigmoidal pattern; on either side of the apex an oblique groove fans outward towards the crest. On the labial side the area to the right of the apex slopes under itself at an angle oblique to the median crest. The area immediately to the left of the apex swells outwards at lower crown level to form a labial buttress; the surface then curves back in towards the central crest line and back out again to form a strong buttress at the left lateral margin. The lingual base is generally not longer than the crown except at the right lateral margin where the base exceeds the crown. The crown-base interface is marked by a 'U' shaped groove. Eight large expanded pits or furrows occur along the base; no crown-base interface is distinguishable on the labial side but up to eight median expanded pits or furrows occur along the labial base. The ventral surface on the lingual side is concave with a horizontal ridge along the middle, and from this the labio-ventral side falls sharply away to form a cavity under the crown. Along the remaining labio-ventral area up to twelve expanded pits or furrows occur; some under the apex involve the labio-ventral margin. The deep labio-ventral cavity continues along the left lateral margin; however, as no labio-ventral base is present in the specimen, the cavity is probably exaggerated.

Discussion: This tooth shows some similarity to those described and illustrated by Derycke (pers. comm.) as *Orodus* sp. although the Irish specimen is slightly smaller.

Age, Locality and Lithology:

Kilbride Limestone Formation, *Polygnathus mehli* conodont Biozone, Ivorian (probably Freyrian), late Tournaisian, Dinantian. Disused quarry, near Nobber, Co. Meath (N 845 848); crinoidal limestone.

7.7.4 CPD Morphotype 3 (Figure 7.15; Plate 45)

Diagnosis: Isolated, microscopic, chondrichthyan tooth. Crown enamel-like, elongate to slightly arcuate, labio-lingually compressed; non-differentiated cusps; wide median crest running from apex of crown sloping to preserved lateral edge. Base generally slightly longer than crown and short where preserved, up to five very deep furrows or expanded pits oblique to the median crest; ventral surface sub-triangular, with a sloping platform towards the labio-ventral margin. (See Figure 7.15 for descriptive terminology)

Material: Three figured, incomplete, isolated teeth. Specimen Numbers: TCD 36735-36737.

Description: Overall length (specimens incomplete) ranges from 1.67mm to 1.97mm along the median crest; the average linguo-labial width ranges from 0.9mm to 1.33mm (crown only from 0.67mm to 0.77mm); the average height in lingual view is 0.83mm to 1.13mm (crown only 0.57mm to 0.7mm). The wide median crest extends from the preserved lateral edge, sloping up and widening towards the apex. The crown-base interface is difficult to discern other than by a subdued horizontal groove but the crown is convex normal to the long axis and extends over, but does not exceed the base on the lingual side. On the labial side in the area of the probable main cusp, the crown swells out labially to form a slight labial buttress. The labial base is very short where it is preserved. The lingual side of the base is short, with up to five deep furrows extending from above the linguo-ventral margin obliquely towards the apex of the crown. On the ventral aspect of the base the main linguo-ventral platform slopes sharply away towards the labio-ventral margin. There is a deep furrow under the labial buttress area oblique to the long axis, with up to three further furrows oblique to the long axis towards the lateral margins. At the lateral edge a furrow runs sub-parallel to the main axis. The base is sub-triangular in overall shape.

Discussion: It is interesting to note that all three specimens appear to have fractured in the same area, interpreted as the apex. It is further interesting that they do not all

come from the same locality. Also, TCD 36736 and 36737 are 'left' and 'right' specimens but do not appear to be counterparts,

Age, Locality and Lithology:

i. Kilbride Limestone Formation, *Polygnathus mehli* conodont Biozone, Ivorian (probably Freyrian), late Tournaisian, Dinantian. Disused quarry, near Nobber, Co. Meath (N 845 848); crinoidal limestone.

ii. Lyraun Cove Shale Member, Porter's Gate Formation, *Polygnathus inornatus* conodont Biozone, Hastarian, Tournaisian, Dinantian. Small cove section, near Porter's Gate, Hook Head, Co. Wexford (S 276 100); calcareous mudstone-dolomitic limestone.

7.7.5 CPD Morphotype 4 (Figure 7.15; Plates 46 & 47)

Diagnosis: Isolated, microscopic, chondrichthyan tooth. Enamel-like crown with narrow median crest from lateral edge to lateral edge; asymmetric with non-differentiated cusps with an off-centre apex; crown exceeds the horizontal length of the base and is, labio-lingually compressed. The base is long, convex and sloping on the lingual surface, while the labial base is lobed and one to two-thirds the length of the lingual; the ventral surface is concave and double horse-shoe shaped with raised margins when viewed with the labial aspect to the north. (See Figure 7.15 for descriptive terminology)

Material: Three isolated specimens. Specimen Numbers: TCD 36738-36740.

Description: The length along the median crest ranges from 0.67mm to 1.03mm (the base from 0.57mm to 0.83mm); the width in linguo-labial view from 0.03mm to 0.17mm (the base from 0.4mm to 0.73mm); and the height in lingual view from 0.35mm to 0.57mm (the crown from 0.23mm to 0.30mm). The apex of the crown may be either to right of left of midline sloping to the lateral edges at c. 15° or c. 20° (creating an overall asymmetric outline) with a narrow median crest which varies in width along its length from left lateral edge to right lateral edge where the crown slightly exceeds the base. Some subdued ridges occur on the crown; they are normal to the crest and die away before reaching the poorly defined crown-base interface. In labial view the crown tends to curve very gently over to the labial side. There is little ornamentation other than three subdued ridges normal to the crown, which outline minor labial buttresses at lower crown level. The buttresses tend to overhang the base at both lateral margins. The crown-base interface, where seen, is marked by a horizontal ridge and groove. The lingual side of the base is long and sloping, convex, interrupted by five to nine furrows which in some cases culminate in foramina. The labial base is one to two-thirds the length of the lingual,

with the labial crown buttresses involving the base delineated by grooves creating a tri-lobed effect. The ventral surface is concave, double horse-shoe shaped with raised margins; the secondary horse-shoe initiates as a raised ridge at the labio-ventral margins. Shallow furrows radiate inwards from the main horse-shoe margins, with further furrows to the centre of the base.

Discussion: At least one specimen, TCD 36740 (preserved as vivianite), appears quadra-lobate in labial view rather then tri-lobate but is very similar in other aspects - including the double horse-shoe shaped ventral surface of the base - to the other specimens included in Morphotype 4.

Age, Locality and Lithology:

i. Kilbride Limestone Formation, *Polygnathus mehli* conodont Biozone, Ivorian (probably Freyrian), late Tournaisian, Dinantian. Disused quarry, near Nobber, Co. Meath (N 845 848); crinoidal limestone.

ii. Upper Ballysteen Limestone, *Polygnathus mehli* conodont Biozone, Ivorian (pre-Freyrian), late Tournaisian, Dinantian. Bore hole 3246/4 Urlingford, Co. Kilkenny; thinly bedded crinoidal limestone.

7.7.6 CPD Morphotype 5 (Figure 7.15; Plate 48)

Diagnosis: Isolated, microscopic, chondrichthyan, fused adjacent teeth. Crown enamel-like, elongate to slightly arcuate, labio-lingually compressed; non-differentiated cusps; wide median crest running from the apex of crown sloping to extant lateral edge. Base generally slightly longer than crown and short where preserved. (See Figure 7.15 for descriptive terminology)

Material: One isolated specimen. Specimen number TCD 36741.

Description: The overall length of the two teeth is 1.03mm (excluding the base, 0.83mm); the width of each tooth crown is 0.03mm in linguo-labial view (with the base 0.73mm); the average height is 0.35mm (crown average is 0.27mm) in lingual view. Each tooth has a broad median crest with three non-differentiated cusps although each has a higher main cusp set slightly off-mid line, slightly differentiated by grooves. The crowns do not exceed the base laterally and show some subdued ridges normal to the crown; two from the main cusp appear to bifurcate and outline a minor buttress on the lingual and labial surface. The lingual base is long and sloping where visible with approximately five pits/foramina below the crown-base interface marked only by a shallow horizontal groove. The labial base is not visible where conjoined and non-

existent on the other tooth. The ventral base is a sloping platform with a subdued horizontal ridge off centre.

Discussion: United pairs of teeth are uncommon from this study, however, a second pair of fused adjacent teeth occurs in the same residue which seem more related to CPD Type 1.

Age, Locality and Lithology:

Kilbride Limestone Formation, *Polygnathus mehli* conodont Biozone, Ivorian (probably Freyrian), late Tournaisian, Dinantian. Disused quarry, near Nobber, Co. Meath (N 845 848); crinoidal limestone.

7.7.7 CPD Morphotype 6 (Figure 7.15; Plate 49)

Diagnosis: Isolated, microscopic, chondrichthyan tooth. Crown enamel-like, elongate to slightly arcuate, labio-lingually compressed, triangular shaped; a broad median crest extends from one lateral edge to the other over a high round-pointed cusp. The base is generally slightly longer than the crown with expanded pits/furrows normal to the crown on the lingual and labial surfaces; the ventral base is arcuate. (See Figure 7.15 for descriptive terminology)

Material: One isolated specimen, Specimen number: TCD 36742.

Description: Length along median crown crest is 1mm (1.03mm with the base); the linguo-labial width is 0.84mm (crown alone 0.36mm); the height in lingual view is 1.03mm. The triangular cusp is straight along the lingual area with the central angle of the triangle at the centre of a labial buttress. The broad median crest extends from each lateral edge on the lingual side over the centre of the main round-pointed cusp. The median crest slopes to the left linguo-lateral edge at c. 48° and to the right linguo-lateral edge at c. 38°. The lingual crown overhangs the base and turns under to a horizontal furrow at the crown-base interface. The crown forms a shallow node along each linguo-lateral edge. The labial surface of the crown forms the top angle of a triangle. The lingual base is convex with the linguo-ventral margin concave. Seven to eight expanded pits or furrows extend from the lingual margin normal to the crown towards the crown-base interface. The labial base is short with an arcuate labio-ventral margin. Up to four foramina occur under the buttress area. The ventral base is arcuate with slightly raised edges.

Discussion: This specimen differs from the other CPD morphotypes isolated during this study in that the crown is triangular-shaped in dorsal view and in outline when

viewed from the lingual or labial sides. The crown-base interface is arched as is the ventral surface of the base. As this is an isolated specimen it is not possible to decide to which order it belongs. It has tentatively been classified as a type of chondrichthyan pavement dentition.

Age, Locality and Lithology:

Kilbride Limestone Formation, *Polygnathus mehli* conodont Biozone, Ivorian (probably Freyrian), late Tournaisian, Dinantian. Disused quarry, near Nobber, Co. Meath (N 845 848); crinoidal limestone.

7.7.8 CPD Morphotype 7 (Figure 7.15; Plate 49)

Diagnosis: Isolated, microscopic, chondrichthyan tooth. Enamel-like crown with median crest from lateral edge to lateral edge (tending to be more on the lingual surface) bifurcating over each cusp apex, nearly symmetric with up to five differentiated cusps; subdued labial buttress; crown does not exceed horizontal length of the base and is labio-lingually compressed. Base sub-triangular in ventral view, lingual and labial aspects show up to six expanded pits or furrows. (See Figure 7.15 for descriptive terminology).

Material: An isolated specimen. Specimen number: TCD 36743.

Description: In dorsal view along the median crest the length of the crown is 0.74mm (with base 0.88mm); in linguo-labial view the width of the crown is 0.22mm (0.4mm with base); overall height in lingual view is 0.46mm (crown only 0.26mm). The crown is nearly symmetric with a large main cusp. Two secondary cusps about half as high as the main cusp occur one on each side of the main cusp, with small tertiary undifferentiated lateral cusps. The median crest extends from the lateral edges, bifurcating and rejoining around each cusp. On the lingual side the main and secondary cusps bend over at their crests to the lingual side; the main cusp has a vertical ridge from the apex to the crown-base interface culminating in a lingual node; the secondary cusps have very wide ridges from median crest to crown edge. All the ridges end in a horizontal ridge along the crown-base interface. On the labial side a ridge, normal to the median crest, occurs on the main cusp forming a buttress, with subdued ridges on the secondary cusps, all ending in nodes at the crown-base interface. The lingual base has six expanded pits or furrows on a base that slopes away from the lateral cusps extending out and beyond the crown. The labial base is short with a few expanded pits or furrows. The ventral aspect is concave and sub-triangular, the deepest area is under the labial buttress.

Discussion: This specimen differs from the other CPD morphotypes by having five partially-differentiated cusps with a lingually extended base arched under the linguo-ventral margin. A tooth resembling the Irish specimen but with much more rounded cusps than those described here (which are pyramidal) was described by Derycke (1994 pers. comm.) and attributed to *Orodus* sp.

Age, Locality and Lithology:

Kilbride Limestone Formation, *Polygnathus mehli* conodont Biozone, Ivorian (probably Freyrian), late Tournaisian, Dinantian. Disused quarry, near Nobber, Co. Meath (N 845 848); crinoidal limestone.

7.8 Sarcopterygian

Class Sarcopterygii Romer 1955

Discussion: Sarcopterygians (extinct and extant) are normally characterised by the gross morphology seen in macro-vertebrate specimens, in particular by their so called 'lobed fins'. Although true enamel was once thought to be restricted to the scarcopterygians, it is now believed that actinopterygian ganoine and collar enamel is similar to true enamel. Scarcopterygians however do have enamel on the entire tooth and this (so far) appears to be an attribute unique to the Class (Janvier, 1996)

The Onychodontiformes (also known as struniforms) of the Devonian have simple teeth of non-folded dentine apart from the base, with scales showing ridges or horseshoe shaped tubercles of dentine. According to Janvier (1996) ..."*occurrences from the Carboniferous are now discounted...*". Scales of the Actinista (or coelacanths) of the later Devonian and early Carboniferous show either horseshoe shaped tubercles similar to the Onychondontiformes or thin dentinous ridges. The Dipnoans (lungfish) have large tooth plates and body scales of rounded form with a cosmine covering which became reduced from the late Devonian onwards.

Although the material described below can only be classified to the Class Sarcopterygii, the most likely candidate for the material are the Rhizodontiforms. The Rhizodontiforms are poorly known due to their thin skull dermal bones which can be easily disarticulated. However, they are common in upper Devonian and Carboniferous rocks world-wide. For many years these were always described as large fish (i.e. jaws greater than one metre in length) but Andrews (1985) described a 'small-form' from Foulden, Scotland. Teeth are folded; scales are large, rounded and ornamented with thin ridges, whilst the underside has a small node.

7.8.1 Sarcopterygian - isolated teeth (Figure, 7.16, Plate 70 & 71 A-B)

Diagnosis: Isolated microscopic (though mainly greater than 2mm in overall dimension) possible rhizodont (sarcopterygian) teeth. Conical to sigmoidal; tooth may be labio-lingually compressed towards base with folding close to base, external surface enamel-like; marked longitudinal striations on the labial surface with vestige of the same ornament labially. Ovoid to circular central lumen.

Material: Four, figured isolated teeth. Specimen Numbers: K28717-K28720 inclusive loaned for the project and to be reposited with the Ulster Museum on completion. Other non-illustrated specimens (K28779).

Description: No teeth are complete. The more complete range from 1.36mm (long) and 0.43mm (wide) to 3.29mm (long) and 1.86mm (wide). Most teeth are either conical throughout or conical to sigmoidal. Longitudinal striations are prominent on the lingual side of the teeth (the concave side) running parallel or sub-parallel to each other. In some instances they converge towards the tip area. Subdued to vestigial longitudinal striations occur on the labial surface which appears 'shiney' . In the larger teeth, where some of the basal area can be seen, the striations are involved in an external folding of the dentine. Teeth appear to be slightly labio-lingually compressed along their length. This is more pronounced at the basal area. The become more circular towards their tips giving an overall oval cross-section. A central lumen which follows the tooth curvature is ovoid in outline and decreases in diameter from base to tip with a rounded termination.

Age, Locality and Lithology:

Mormeal Member, Altagoan Formation, PU miospore Biozone, ?Ivorian ?Freyrian, Tournaisian, Dinantian. Faulted river section, Moyola River, near Draperstown, Co. Derry (H 792 974); channel fill within sabhka/tidal flat, calcarenite with evaporite.

7.8.2 Sarcopterygian - Isolated dentary fragment (Figure 7.17)

Diagnosis: Isolated dentary fragment possibly of a rhizodont. Anterior and posterior sections absent. Houses seven preserved curved teeth.

Material: A single specimen K28723 lent for the project which will be deposited with the Ulster Museum on completion.

Description: Labial side of dentary with anterior and posterior absent; no sigmoidal tusk, extant fragments imbedded in matrix. Overall length of the dentary as preserved is

c. 30mm with a maximum exposed width of 25mm; up to five extant teeth and teeth fragments with a maximum exposed tooth length of 19mm and width of 6mm. Vestigial longitudinal striations visible on the labial surface which (prior to consolidation of the specimen) appeared shiney. Teeth appear to be conical with a lingual curvature and no acrodin tip (an actinopterygian feature).

Discussion: Damaged and re-assembled prior to this study. The nature of the matrix is such that little or no hand-working could be carried out on this specimen other than to gently uncover the seven teeth and part of the dentary bone (although much of this was carried out by the author, further preparation was undertaken in Cambridge). Because of the fragile nature of the specimen which is a result of the microfractures induced by compaction the surface of the whole rock sample bearing the dentary was consolidated using acetone soluble glue .

Age, Locality and Lithology:

Mormeal Member, Altagoan Formation, PU miospore Biozone, ?Ivorian ?Freyrian, Tournaisian, Dinantian. Faulted river section, Moyola River, near Draperstown, Co. Derry (H 792 974); channel fill within sabhka/tidal flat, calcarenite with evaporite.

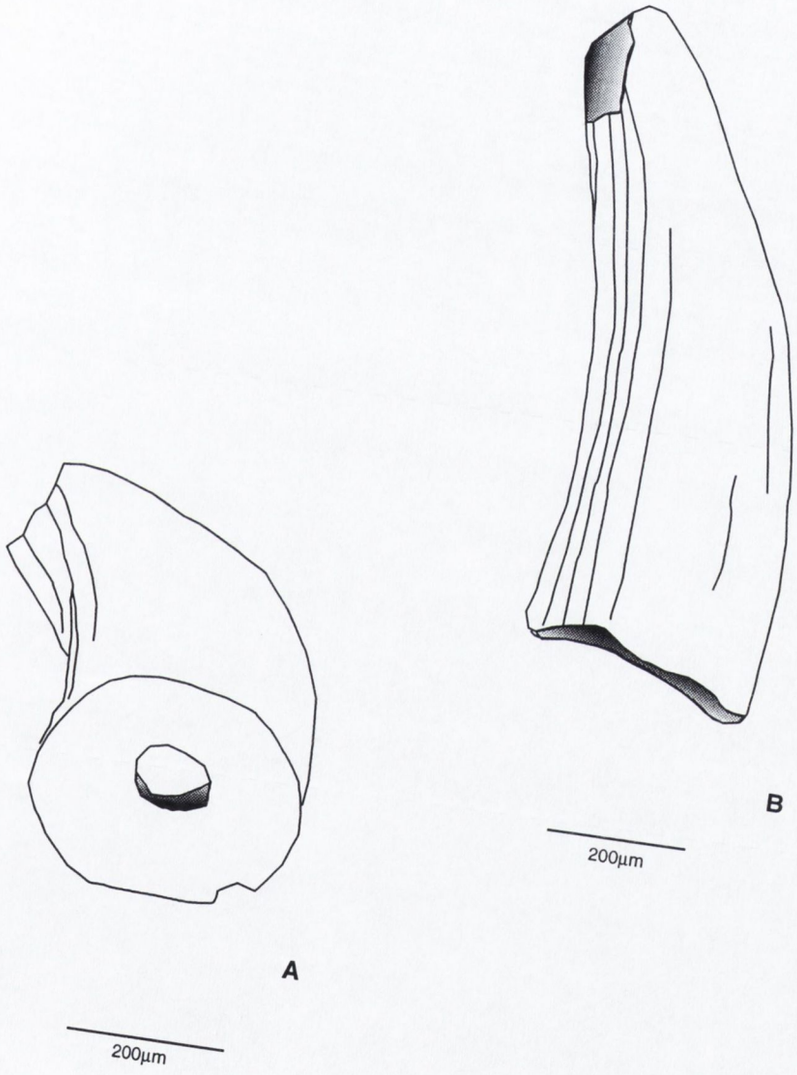


Figure 7.16. Probable sacropterygian teeth. A. Basal view showing lumen (ovoid). B. Lateral view with striations on lingual aspect. Based on K28719 (see plates 70 & 71).

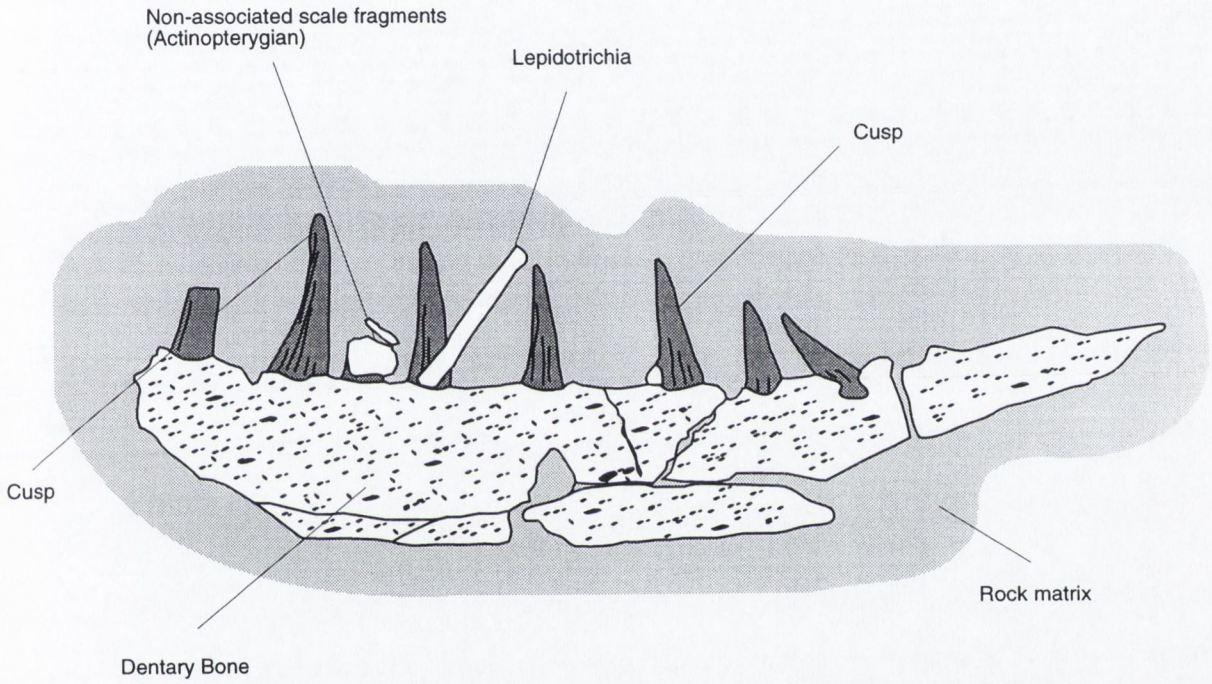


Figure 7.17. Part of Dentary of probable rhizondont (sarcopterygian). Based on specimen K28723. (Camera Lucida drawing)

7.9 SCALES AND DENTICLES AND ACTINOPTERYGIAN CONICAL TEETH:

Discussion: Many specimens of scales and denticles were recovered. A representative range of these are described and illustrated below. Numerous conical teeth derived from actinopterygians were also recovered but these have not been described in this thesis. Representative material includes the following specimens: K28779; TCD 35866-67, 35872-73, 35879, 36936-40, 36942-43, 36946, 36948, 36955, 36960, 36962, 36986 & 36997.

In most instances it has not been possible to identify the scales and denticles to the level of family or genus. They have been grouped into categories which cannot in most cases be identified to below the level of class; however, they are described and illustrated because they provide evidence of the diversity of the Carboniferous fish faunas. At present they are of little use as biostratigraphical tools in the Irish Carboniferous as considerably more investigation of their taxonomy has to be carried out; this will require information about their locations (i.e. head, body, fin, tail, etc.). Time constraints did not allow this work to be completed for this thesis.

No two scales or denticles are exactly alike but they fit into quite distinctive patterns and thus have been described on that basis. Identification of the scales/denticles is left in open nomenclature until articulated material is found.

7.9.1 Chondrichthyan denticles/scales

Denticles Morphotype 1 (Plate 55, Figures A-B)

Material: One, figured isolated specimen. Specimen Number: TCD 36810.

Description: The overall length of the base is 1mm; its width 0.42mm and its height 0.5mm. The lenticular base is strongly convex at its ventral surface, with three unequal lobes rising from it, posteriorly-directed, differentiated by inter-lobe grooves; the lateral lobes curve towards the mid-line enclosing the central lobe.

Age, Locality and Lithology:

Kilbride Limestone Formation, *Polygnathus mehli* conodont Biozone, Ivorian (probably Freyrian), late Tournaisian, Dinantian. Disused quarry, near Nobber, Co. Meath (N 845 848); crinoidal limestone.

Denticles Morphotype 2 (Plate 55, Figures C-E)

Material: One figured, isolated specimen. Specimen number: TCD 36811.

Description: 0.54mm long, 0.4mm wide and 0.34mm high. The base is half-circular in outline (the cusp rising from the straighter side) ventrally dominated by a large cavity in the centre of a shallow concave surface; the semi-circular surface of the base is long sloping and punctuated by up to four furrows running towards the cusp; two expanded pits occur on the short posterior surface of the base. Rising from the straight side is an asymmetric button-like cusp, which is narrow at the lateral margins and expands anteriorly into four lobes separated by grooves. The latter extend from the cusp-base junction towards the mid line where the cusp rises into a rounded apex. Posteriorly five subdued nodes occur along the cusp-base junction.

Age, Locality and Lithology:

Kilbride Limestone Formation, *Polygnathus mehli* conodont Biozone, Ivorian (probably Freyrian), late Tournaisian, Dinantian. Disused quarry, near Nobber, Co. Meath (N 845 848); crinoidal limestone.

Denticles Morphotype 3 (Plate 55, Figure G)

Material: One figured, isolated specimen. Specimen number: TCD 36812.

Description: An asymmetric, oval 'frilled node' with a length of 0.96mm and a width of 0.72mm. The ventral surface is concave with a flat rim around the whole; the lower one-third of the dorsal surface is punctuated all round by at least twenty furrows from the dorso-central margin which die out gradually. Each of the furrows contains a foramen which does not appear to punctuate the inner surface.

Age, Locality and Lithology:

Kilbride Limestone Formation, *Polygnathus mehli* conodont Biozone, Ivorian (probably Freyrian), late Tournaisian, Dinantian. Disused quarry, near Nobber, Co. Meath (N 845 848); crinoidal limestone.

Denticles Morphotype 4 (Plate 55, Figures H-I)

Material: One figured, isolated specimen. Specimen number: TCD 36818. Non-figured specimens TCD 36987 and 36993.

Description: The length is 0.96mm; width 0.87mm; and the height 1.03mm. The base is roughly square in outline and about one-eighth the height of the whole. It is pierced by a number of expanded pits on the lateral edge facing the cusp; the ventral surface of the base is badly abraded but appears convex. Rising from one side are two overlapping odontode-like structures that curve over the opposing side of the base, creating a conical shape.

Age, Locality and Lithology:

Kilbride Limestone Formation, *Polygnathus mehli* conodont Biozone, Ivorian (probably Freyrian), late Tournaisian, Dinantian. Disused quarry, near Nobber, Co. Meath (N 845 848); crinoidal limestone.

Denticles Morphotype 5 (Plate 55, Figures J-L)

Material: One figured, isolated specimen. Specimen number: TCD 36820.

Description: 0.57mm long (base), 0.48mm wide (base), height of cusp 0.45mm (including base 0.60mm). Oval base with a cusp extending from one long side which curves up and in, over the rest of the base. The opposite long side is indented. The lateral edges of the base excluding the cusp area are pierced by expanded pits. The ventral base area is flat but where the indentation occurs on the dorsal surface this continues into and includes the ventral surface.

Discussion: This may be a worn and fractured 'cladodont type tooth' rather than a denticle.

Age, Locality and Lithology:

Kilbride Limestone Formation, *Polygnathus mehli* conodont Biozone, Ivorian (probably Freyrian), late Tournaisian, Dinantian. Disused quarry, near Nobber, Co. Meath (N 845 848); crinoidal limestone.

7.9.2 Chondrichthyan composite scales/denticles:

Morphotype 1 (Plate 56, Figures A-B)

Material: One figured, isolated specimen. Specimen number: TCD 36823.

Description: Length 1.48mm, height 1mm. Long narrow scale with a sub-triangular base and a concave ventral surface. The cusp is posteriorly orientated, fan-shaped, with up to nine ridged odontodes descending from the apex; a secondary row of ridged odontodes, which are badly abraded, lie behind the main row, with evidence of a possible third behind.

Discussion: This is possibly similar to a ctenacanth type scale but has no neck between base and cusp as described by Reif (1978).

Age, Locality and Lithology:

Kilbride Limestone Formation, *Polygnathus mehli* conodont Biozone, Ivorian (probably Freyrian), late Tournaisian, Dinantian. Disused quarry, near Nobber, Co. Meath (N 845 848); crinoidal limestone.

Morphotype 2 (Plate 56, Figure C-E)

Material: Two figured, isolated specimens. Specimen numbers: TCD 36826 & TCD 36828.

Description: Long, triangular shaped denticle, 0.84mm long and 0.57mm wide, with greater than eleven overlapping, pointed, posteriorly-directed odontodes; odontodes are small at the low angled end, broadening and lengthening towards the posterior; odontodes lie in pairs along the cusp. Base is absent in both specimens.

Age, Locality and Lithology:

i. Kilbride Limestone Formation, *Polygnathus mehli* conodont Biozone, Ivorian (probably Freyrian), late Tournaisian, Dinantian. Disused quarry, near Nobber, Co. Meath (N 845 848); crinoidal limestone.

ii. Upper Ballysteen Limestone, *Polygnathus mehli* conodont Biozone, Ivorian (pre-Freyrian), late Tournaisian, Dinantian. Bore hole 3246/4 Urlingford, Co. Kilkenny; thinly bedded crinoidal limestone.

7.9.3 Chondrichthyan - 'Ctenacanth-type' scales

Morphotype 1 (Plate 57)

Material: Three figured, isolated specimens. Specimen numbers: TCD 36822, 36824 & 36825). Non-figured specimens TCD 35878, 36993-4.

Description: The overall length varies from 0.57mm to 1.03mm, averaging 0.9mm (base) in width. Very narrow, posteriorly-directed cusps are separated from the base by an obvious neck; in TCD 36825 there are up to ten overlapping odontodes each ornamented by a vertical ridge of a diamond shaped cusp; in both TCD 36825 and TCD 36822 the cusp forms a very thin fan shaped crown with three to eleven sharp ridges from the base petering out before the apex. The cusp rises from a horse-shoe shaped concave base.

Age, Locality and Lithology:

i. Kilbride Limestone Formation, *Polygnathus mehli* conodont Biozone, Ivorian (probably Freyrian), late Tournaisian, Dinantian. Disused quarry, near Nobber, Co. Meath (N 845 848); crinoidal limestone.

ii. Upper Ballysteen Limestone, *Polygnathus mehli* conodont Biozone, Ivorian (pre-Freyrian), late Tournaisian, Dinantian. Bore hole 3246/4 Urlingford, Co. Kilkenny; thinly bedded crinoidal limestone.

7.9.4 Chondrichthyan - mucous membrane denticles

Morphotype 1 (Plate 59)

Material: Two figured, isolated, incomplete specimens. Specimen numbers: TCD 36829 & TCD 36832. Non-figured specimens TCD 36982, 36993-4.

Description: Average length 1.48mm; width 0.89mm and average height 1.48mm. Two to three main cusps in a line curving to one lateral edge posteriorly, with a further smaller cusp set anteriorly; cusps tend to overlap each other but do not line up exactly. They are ornamented with cristae all around. Ventral surface of the base, which is abraded, is marginally concave.

Age, Locality and Lithology:

Kilbride Limestone Formation, *Polygnathus mehli* conodont Biozone, Ivorian (probably Freyrian), late Tournaisian, Dinantian. Disused quarry, near Nobber, Co. Meath (N 845 848); crinoidal limestone.

Morphotype 2 (Plate 60)

Material: Two figured, isolated, incomplete specimens. Specimen numbers: TCD 36830 and TCD 36831.

Description: The average length is 0.78mm; average width 0.47mm; and the height ranges from 0.42mm to 0.81mm. Three to four overlapping odontodes curve in a line towards one lateral edge posteriorly. The odontodes or cusps, increase in size towards the posterior. They are crudely aligned but in detail are offset from each other to a greater or lesser degree; the overall style of the odontodes or cusps is that of longitudinally flattened cones. A small outward protruding node on each side close to the junction of the base and the odontode appears more pronounced on the small odontodes or cusps. The overall shape of the base as preserved is lenticular; the ventral surface of the base is slightly concave with raised margins.

Age, Locality and Lithology:

Kilbride Limestone Formation, *Polygnathus mehli* conodont Biozone, Ivorian (probably Freyrian), late Tournaisian, Dinantian. Disused quarry, near Nobber, Co. Meath (N 845 848); crinoidal limestone.

7.9.5 Chondrichthyan body scales (Plate 61, Figures A-D)

Material: One figured, isolated specimen. Specimen number: TCD 36837.

Description: Length 0.82mm, width in dorsal view 0.43mm and height, 0.28mm. Overall shape is triangular with the cusps rising from the long side opposite the top angle. The cusps occur as four non-differentiated cusp-like structures overlapping each other (flower like) and fan out towards the apex. Each is ornamented by up to three strong ridges and inter-ridge furrows and all curve over towards the side containing the top angle; a fifth cusp structure occurs centrally in front of the fan along the long side. The base is short in all dimensions sloping down and out from the cusp area forming a triangle with a number of foramina; along the junction of the cusp and base a number of vertical furrows also occur. The ventral surface is slightly concave with two expanded pits or foramen.

Age, Locality and Lithology:

Kilbride Limestone Formation, *Polygnathus mehli* conodont Biozone, Ivorian (probably Freyrian), late Tournaisian, Dinantian. Disused quarry, near Nobber, Co. Meath (N 845 848); crinoidal limestone.

7.9.6 Chondrichthyan - possible *Thrinacodus* denticle

(Plate 61, Figures E-F)

Material: One figured, isolated specimen. Specimen number: TCD 36845. Non-figured specimens TCD 36994.

Description: The height is 0.75mm; the width of the base is 0.45mm; and the average width of the cusp is 0.12mm. A single narrow, conical cusp rises from the centre of a lenticular shaped base; the cusp rises vertically initially and then curves along the top two-thirds, becoming strongly posteriorly-directed at the apex. The base slopes out to the dorso-ventral margins and is indented along this margin on the antero-ventral margin more or less at mid-line. The suggestion that this type of denticle belongs to a *Thrinacodus* is based on Turner (1982) who described similar denticles.

Age, Locality and Lithology:

Kilbride Limestone Formation, *Polygnathus mehli* conodont Biozone, Ivorian (probably Freyrian), late Tournaisian, Dinantian. Disused quarry, near Nobber, Co. Meath (N 845 848); crinoidal limestone.

7.9.7 Hybodont, Neoselachian, Placoid - type scales

Class CHONDRICHTHYES Huxley, 1880

Subclass ELASMOBRANCHII Bonaparte, 1838

Order EUSELACHII, Hay, 1902

Superfamily HYBODONTOIDAE Zangerl 1981

Morphotype 1 - heart shaped denticles (Plate 62)

Material: Eight figured, isolated specimens. Specimen numbers: TCD 36838 - 35844 & 36815. Non-figured specimens TCD 35870, 35876, 36973.

Description: Although they vary in size, these scales are generally small (average 0.35mm long and 0.27mm wide) and heart shaped, with a base at the broad end of the heart. The single element cusp of the scale is heart-shaped with a wide longitudinal groove with the lateral margins curving dorsally; the cusp curves posteriorly at a variable angle to the base. The base is triangular to sub-rectangular in outline and

extends beneath the ventral surface of the cusp, narrowing and forming a ridge that extends longitudinally along the centre of the cusp and dies out before the tip. The base is ventrally concave where preserved, with a flat platform around the edges.

Age, Locality and Lithology:

Kilbride Limestone Formation, *Polygnathus mehli* conodont Biozone, Ivorian (probably Freyrian), late Tournaisian, Dinantian. Disused quarry, near Nobber, Co. Meath (N 845 848); crinoidal limestone.

Morphotype 2- Hybodont - raised button-like denticles

(Plate 63, Figures A-D & Plate 69, Figure E)

Material: Seven figured, isolated specimens. Specimen numbers: TCD 36846, 36813, 36817 and K28716. Non-figured specimens TCD 36940, 36993.

Description: The base is triangular to sub-rectangular in outline, long and sloping in on all sides to the junction with the cusp; numerous furrows extend vertically towards this junction. The cusp rises as a single rounded node which may have a sloping dorsal surface; the cusp is indented deeply all around by eight to sixteen furrows (one-third the height of the cusp) outlining node-like structures; otherwise the cusp lacks ornament.

Discussion: Although these scales/denticles have a well developed neck they do not have the thin cusps associated with ctenacanth scales; the cusps are more rounded than the thorn-like denticles attributed to hybodont scales (Reif, 1978). They have here been assigned to the hybodonts.

Age, Locality and Lithology:

i. Kilbride Limestone Formation, *Polygnathus mehli* conodont Biozone, Ivorian (probably Freyrian), late Tournaisian, Dinantian. Disused quarry, near Nobber, Co. Meath (N 845 848); crinoidal limestone.

ii. Mormeal Member, Altagoan Formation, PU miospore Biozone, ?Ivorian ?Freyrian, Tournaisian, Dinantian. Faulted river section, Moyola River, near Draperstown, Co. Derry (H 792 974); channel fill within sabhka/tidal flat, calcarenite with evaporite.

Morphotype 3 - Hybodont thorn-like

(Plate 63, Figures E-H & Plate 68, Figures C-G)

Material: Four figured, isolated specimens. Specimen numbers: TCD 36814 & TCD 36816, K28711 & K28712. Non-figured specimens K28777, TCD 35878, 36941, 36993-4.

Description: The length ranges from 0.34mm to 1.15mm; the width from 0.27mm to 0.63mm; and the height from 0.12mm to 0.63mm. The thorn-like cusps with three to five conjoined odontodes rising from the centre of an ovoid base, probably posteriorly-directed and curving over at their apices in that direction. In some specimens there is a slight neck between base and cusp. The base in both specimens is abraded but at least four expanded pits and furrows are visible; the ventral surface appears marginally concave.

Discussion: For the same reasons as discussed in the case of Morphotype 2, even though the junction of the base and cusp is necked, Morphotype 3 is assigned to the hybodonts rather than ctenacanths.

Age, Locality and Lithology:

i. Kilbride Limestone Formation, *Polygnathus mehli* conodont Biozone, Ivorian (probably Freyrian), late Tournaisian, Dinantian. Disused quarry, near Nobber, Co. Meath (N 845 848); crinoidal limestone.

ii. Mormeal Member, Altagoan Formation, PU miospore Biozone, ?Ivorian ?Freyrian, Tournaisian, Dinantian. Faulted river section, Moyola River, near Draperstown, Co. Derry (H 792 974); channel fill within sabhka/tidal flat, calcarenite with evaporite.

Morphotype 4 - Hybodont thorn-like (Plate 63, Figures I-J)

Material: One figured, isolated specimen. Specimen number: TCD 36819. Non-figured specimens TCD 35870, 36993-4.

Description: Length 0.36mm with a width of 0.36mm. Square base in dorsal view with posteriorly-directed single pointed cusp. The cusp and base are indented up to two-thirds of the height by six to seven vertical grooves which outline ridges that die out before the apex.

Age, Locality and Lithology:

Kilbride Limestone Formation, *Polygnathus mehli* conodont Biozone, Ivorian (probably Freyrian), late Tournaisian, Dinantian. Disused quarry, near Nobber, Co. Meath (N 845 848); crinoidal limestone.

7.9.8 Acanthodii - Acanthodian scales

Class ACANTHODII Owen, 1846

Order Incertae sedis

(Plates 64 & 65)

Material: Ten figured, isolated specimens, together with numerous other non-figured specimens. Specimen numbers: TCD 36847-36851, TCD 36853-35857. Non-figured specimens, specimen numbers: TCD: 35870, 36936, 36938-9, 36943, 36947, 36953-4, 36959-60, 36970.

Description: Typically these scales are c. 0.4mm long and wide, although they may be slightly less wide than long in some specimens. The height varies from c.0.2mm to 0.4mm; the rhomboidal crown is generally flat to marginally concave and separated from the base by a well defined neck; the upper surface of the base may exceed the overall extent of the crown; the remaining base is cone-like with a rounded blunt end and is normally asymmetric. In some specimens a protuberance occurs above the lower base level at one corner.

Age, Locality and Lithology:

i. Kilbride Limestone Formation, *Polygnathus mehli* conodont Biozone, Ivorian (probably Freyrian), late Tournaisian, Dinantian. Disused quarry, near Nobber, Co. Meath (N 845 848); crinoidal limestone.

ii. Lyraun Cove Shale Member, Porter's Gate Formation, *Polygnathus inornatus* conodont Biozone, Hastarian, Tournaisian, Dinantian. Small cove section, near Porter's Gate, Hook Head, Co. Wexford (S 276 100); calcareous mudstone-dolomitic limestone.

iii. Upper Ballysteen Limestone, *Polygnathus mehli* conodont Biozone, Ivorian (pre-Freyrian), late Tournaisian, Dinantian. Bore hole 3246/4 Urlingford, Co. Kilkenny; thinly bedded crinoidal limestone.

7.9.9 Osteichthyan - Actinopterygian scales

Class OSTEICHTHYES Huxley, 1880

Subclass ACTINOPTERYGII Klein, 1885

(Plates 50, 51, 66, 67, 68 Figures A-B & Plate 69, Figures A-C)

Material: Twenty-seven figured isolated specimens together with numerous other non-figured specimens Numbers: TCD 36859 - 36861; TCD 36865; TCD 36867-36872; TCD 36874 - 36877; K28701-K28710; K28713-K28714. Non-figured specimens, specimen numbers: K28772-6; TCD 35864, 35869, 35870, 35874-6, 36936-9, 36941-3, 36946, 36948, 36953-4, 36958-9, 36963.

Description: These scales are typically rhomboidal although they show great variation end in some specimens are rectangular. Not all the specimens show the peg and socket articulation associated with advanced actinopterygians (Derycke *et al.,* 1995) There is considerable variation in size from 0.57mm to 1.93mm along the long axis, and 0.27mm to 0.76mm along the short axis.

Age, Locality and Lithology:

i. Kilbride Limestone Formation, *Polygnathus mehli* conodont Biozone, Ivorian (probable Freyrian), late Tournaisian, Dinantian. Disused quarry, near Nobber, Co. Meath (N 845 848); crinoidal limestone.

ii. Lyraun Cove Shale Member, Porter's Gate Formation, *Polygnathus inornatus* conodont Biozone, Hastarian, Tournaisian, Dinantian. Small cove section, near Porter's Gate, Hook Head, Co. Wexford (S 276 100); calcareous mudstone-dolomitic limestone.

iii. Upper Ballysteen Limestone, *Polygnathus mehli* conodont Biozone, Ivorian (pre-Freyrian), late Tournaisian, Dinantian. Bore hole 3246/4 Urlingford, Co. Kilkenny; thinly bedded crinoidal limestone.

iv. Mormeal Member, Altagoan Formation, PU miospore Biozone, ?Ivorian ?Freyrian, Tournaisian/Viséan, Dinantian. Faulted river section, Moyola River, near Draperstown, Co. Derry (H 792 974); channel fill within sabhka/tidal flat, calcarenite with evaporite.

7.9.10 Actinopterygian flat scales (Plate 58)

Material: Four figured isolated specimens. Specimen numbers: TCD 36833-3683.

Description: The length ranges from 0.63mm to 1.27mm and the width ranges from 0.36mm to 0.81mm. The scales are square to rectangular bases from one corner of which rise diamond, to elongated diamond-shaped cusps lying on and parallel to the base. The ventral base is very slightly concave; the lateral edges are punctuated by many foramina. The scales are almost smooth with up to five subdued ridges. These arise from the anterior margin extending out along each dorso-lateral edge dying out before the pointed apex of the cusp.

Age, Locality and Lithology:

Kilbride Limestone Formation, *Polygnathus mehli* conodont Biozone, Ivorian (probably Freyrian), late Tournaisian, Dinantian. Disused quarry, near Nobber, Co. Meath (N 845 848); crinoidal limestone.

7.9.11 Osteichthyan - Actinopterygian tooth plate

Class OSTEICHTHYES Huxley, 1880

Subclass ACTINOPTERYGII Klein, 1885

(Plate 52)

Material: One figured isolated, specimen. Specimen number: TCD 36883

Description: Part of tooth plate or jaw; semi-circular in shape housing one preserved tooth (minus the acrodin tip) and the sockets of seven more large teeth; secondary cusps radiate around the jaw material.

Discussion: Though not figured the most numerous microvertebrate remains from the above Porter's Gate Formation, Ballysteen Limestone Formation and the Kilbride Formation are actinopterygian conical straight to curved teeth each with a distinctive acrodin tip (many of the tips became disarticulated during either initial or later preparation). TCD 36883 is the only specimen recovered showing the tooth plate which these conical teeth were attached.

Age, Locality and Lithology:

Kilbride Limestone Formation, *Polygnathus mehli* conodont Biozone, Ivorian (probably Freyrian), late Tournaisian, Dinantian. Disused quarry, near Nobber, Co. Meath (N 845 848); crinoidal limestone.

7.9.12 Unknown Affinity - possible Gill Rakers or Spines (Plate 53)

Material: Four figured isolated specimens, some incomplete. Specimen numbers: TCD 36878-36881.

Description: Specimen TCD 36878 is complete with a blade length of 0.30mm (including the base overall length is 0.69mm); the width of the blade is 0.06mm; height of the blade is 1.36mm (with the base the overall height is 1.73mm), the other specimens are incomplete. The blade is long with six to seven ridges rising centrally and normal to the short robust base. It curves gently and tapers slightly to the apex, projecting more on the concave curved edge, while the other edge is convex and set in line with the margin of the base. A deep groove runs the length of the blade between opposing sides (on either side). The base to either side of the blade is rounded and node-like with a slight arc between the ventral surface. Where the specimens are incomplete the junction of the preserved blade and non-preserved base is horseshoe-shaped, broadest at the toe of the horseshoe and narrowest at the heel.

Age, Locality and Lithology:

Kilbride Limestone Formation, *Polygnathus mehli* conodont Biozone, Ivorian (probably Freyrian), late Tournaisian, Dinantian. Disused quarry, near Nobber, Co. Meath (N 845 848); crinoidal limestone.

7.9.13 The following are figured and described as examples of some other rare and unusual microvertebrate remains recovered from acid insoluble residues described in this work.

Un-classified denticles (vertebrate?)

1. 'Handle-bar moustache' (Plate 54, Figure A)

Material: One figured, isolated specimen. Specimen number: TCD 36882.

Description: Bilaterally symmetrical element with short, crescent-shaped base (length 0.36mm, 0.12mm wide) and two cusps. These arise from the centre and lie sub-parallel to the length of the base extending beyond it (overall extent of the two cusps is 0.63mm, width 0.06mm, and maximum height of the cusps including the base 0.27mm). Each cusp terminates in a blunt point and in lateral view the upper surface of the two cusps is slightly concave.

Discussion: The overall impression of this denticle is that of either a handle-bar moustache or the shape made by the horns of a steer.

Age, Locality and Lithology:

Kilbride Limestone Formation, *Polygnathus mehli* conodont Biozone, Ivorian (probably Freyrian), late Tournaisian, Dinantian. Disused quarry, near Nobber, Co. Meath (N 845 848); crinoidal limestone.

2. Possible Chondrichthyan denticle (Plate 54, Figures B-C)

Material: One figured, isolated specimen. Specimen number: TCD 36827

Description: Part of an incomplete denticle, square in outline with more than seventeen conical 'odontodes' (not all intact) rising from a flat to concave base. These cone are each isolated from each other but all lie roughly parallel to the base curving up initially and then turning rapidly towards the horizontal.

Age, Locality and Lithology:

Kilbride Limestone Formation, *Polygnathus mehli* conodont Biozone, Ivorian (probably Freyrian), late Tournaisian, Dinantian. Disused quarry, near Nobber, Co. Meath (N 845 848); crinoidal limestone.

3. Possible Chondrichthyan denticle (Plate 54, Figures D-F)

Material: One figured, isolated specimen. Specimen number TCD 36821. Non-figured specimens, specimen numbers: K28777; TCD 36987.

Description: Roughly triangular in outline in dorsal view with up to fourteen conical 'odontodes' of unequal height rising from the base set at an outward angle to the edges of the base. The larger and higher cones are positioned at each corner and ate the middle line of the longest and shortest side. Four shorter and smaller cones are distributed along the intermediate length side; and five smaller shorter cones are placed

centrally. The base extends in dorsal view beyond platform which bears the cones forming a flat to sloping margin which appears to show a number of expanded pits or indentations above the dorso-ventral margin. The ventral area is strongly convex.

Age, Locality and Lithology:

Upper Ballysteen Limestone, *Polygnathus mehli* conodont Biozone, Ivorian (pre-Freyrian), late Tournaisian, Dinantian. Bore hole 3246/4 Urlingford, Co. Kilkenny; thinly bedded crinoidal limestone.

CHAPTER 8: INCERTAE SEDIS (PROBABLE NON-VERTEBRATE ELEMENTS)

8.1 Bar-like microscopic elements:

Distinctive, bar-like, phosphatic elements were found in the three, fully marine Tournaisian faunas investigated in this study. They are reported to be common in other acid-insoluble residues from Tournaisian to Viséan limestones in Ireland and Britain (Sevastopulo, pers. comm. 1999) and have been recorded from residues of Carboniferous age in France (Derycke, pers. comm. 1994), and Australia (Turner, pers. comm. 1999). Similar bar-like elements have been reported from samples of Ordovician, Silurian and Devonian age (Walliser, 1964; Bischoff, 1973). These last authors have suggested that the bar-like elements were hard tissues of conodont animals, a conclusion which is rejected in this study.

Derycke (pers. comm. 1994) described some of microscopic bar-like elements (similar to the more complex bars elements described below) assigning them to the fish Superfamily Caseodontoidea *Incertae sedis.* Her description (translated from the French original) is as follows:

.."*The teeth are pavement type grinders, a little like the case of Ptychodontidae. Their special feature apart from their length is the appearance of ridges with transverse crenulations, generally oblique in relation to the edges....*" Derycke suggested that these 'bars' should be assigned to the Superfamily Caseodontoidea (Order Eugeneodontida) on the basis of the crenulated ridges. The Superfamily Caseodontoidea was erected by Zangerl (1981) who described the teeth thus: ..."*the symphysial teeth are transversely crested, or tumid...*" Zangerl erected the new genus *Casaeodus,* the nominate genus of the Superfamily, with the following diagnosis of the teeth: ..."*symphysial teeth roof-shaped in labial or lingual aspect, never fused at the base; lateral teeth forming a pavement consisting of diagonal rows of elongated, relatively low-crowned teeth. All teeth are spaced by strong buttress projections on the labial faces of the teeth.*".. The teeth of *Casaeodus eatoni,* the type species of *Caseodus*, was described as being ..."*very strongly crenulated both on lingual and labial faces*"...

However, the bar types described here do not exhibit a tendency for the dentition teeth to become tumid or bulbous, nor do they exhibit a strong buttress projection on the labial face of the bar. Therefore, assignation to the Superfamily Caseodontoidea is not supported. In addition, limited evidence from ultrastructure suggests that the Irish specimens are not derived from vertebrates.

Several different morphotypes are described below; since they all occur in the Kilbride fauna, it is possible that they represent the hard tissues of a single species of organism. The different morphotypes share the following features: each consist of a bar which is nearly straight in dorsal view (the elements are orientated as though they were fish teeth, although this affinity is still uncertain - see below) and slightly arched or straight in lingual or labial view. The convex surface of the arched forms and the homologous surface of non-arched forms bear denticle-like nodes which are narrowest along the length of the bar and widest transverse to the bar.

Walliser (1964) found many specimens of what he described as "Stäbchen" (literal translation is a small rod) - spike bearing bars from Silurian strata. He observed that the spikes on the bars were similar in shape to the basal cavities of some simple cone conodont elements. He claimed a direct relationship between the bars and simple conodont elements because he found a broken bar fragment with two simple cone elements attached to it, interpreting the spike-bearing bars as a common basal filling of several 'specimens' of simple-cone type conodonts.

Bischoff (1973) in a controversial paper entitled "*On the nature of the conodont Animal*" found that "conodont supporting elements" were ...*"a significant component of heavy acid residues of many Lower Palaeozoic samples*".... The 170 samples to which he referred were from limestones of Ordovician, Silurian and Devonian age of the Baltic area, Western Germany, and New South Wales, Australia. It is important to note however, that he found only one case where he identified conodont elements attached to the "conodont supporting elements". Bischoff concluded that the "conodont supporting elements" could occur as single bars, plate-like, or more complex structures.

The single "bars" he described and illustrated (Bischoff, 1973, plate 1, figs. 1-20, 22-23, 26-29) occur as either "sharp-edged" elements or exhibit broken remains of "sheet like" extensions (Bischoff, 1973, plate 1, figs. 16, 20, 22-23, 26, 28-29, and, in addition, figs. 15, 17, 24-25, 27 as observed by this author).

The straight edged bars described by Bischoff are either straight or gently arched, with the outer side bearing spikes whose number vary with the length of the bar. Spikes are similar in terms of shape and direction of curvature on any one bar; height may decrease in one direction or both; spacing between spikes in some case decreases systematically in one direction. Spikes may be smooth cones, or hooked, or triangular, with lateral edges or grooves, and gently curved or inclined in one direction, more or less perpendicular to the long axis of the bar.

It is not clear how Bischoff envisaged the relationship between the basal cavity of a simple-cone type conodont element and a 'bar spike'. It appears that the outline in

lateral view of the spikes and central basal cavity are congruent but he did not discuss how they might have been attached or grown. Neither did he comment on why one bar specimen had a simple-cone type conodont element found attached to the spike.

According to Bischoff ..."bars are only fragments of larger units"... This was because many of the bars had broken fragments of sheet-like extensions along their edges which could easily be removed from the plate-like structures with a needle. He accounted for the bars with smooth edges along the long axis to fast physical or chemical weathering (sic) leaving behind the ..."more solid "bars""... He further concluded that the plate-like structures are in fact the "tests" of certain conulariids. Because he believed that the simple cone type conodont elements were attached to the spikes he concluded that conodonts should be assigned to the Conulata. More recent studies of the affinity of conodonts have demonstrated convincingly that they are chordates and thus Bischoff's conclusion is clearly incorrect. Bischoff's illustrations suggest that these "plate-like" structures may have been indeed parts of conulariid integument, but they did not bear simple-cone type conodont elements.

The work of Bischoff has been discussed here because certain figures in his paper (Bischoff, 1973 plate I, figs. 1-14, 18-19) bear a strong resemblance to Bar Morphotype F and G recovered from marine Lower Carboniferous samples which are described later in this Chapter. The question thus arises as to whether Bishoff's material contained fragments of conulariids (the plate-like material) and bar-like elements with different affinities.

In this regard, the study by Jerre (1993) on conulariid microfossils from the Silurian is of interest. Jerre illustrated two new species, *Conularia sarae* and *Conularia wimani* (Jerre, 1993, plates I & 3) representatives of which are similar to the Bar Morphotypes F and G described in this study. Plate 1 of Jerre's paper shows in particular the crenulated surfaces of the cusp ridges (terminology of this study) or rod-crests (terminology of Jerre) found in most of the Bar Morphotypes described in this work. Bar Morphotype A (right-handed) and Bar Morphotype D (left-handed) of this study are also similar in some respects to the specimen illustrated by Jerre (1993, plate 1, figure 6). This specimen consists of a number of rods still joined by the inter-rod sheets. In contrast, the types described in this work are discrete individuals. This could, however, be a consequence of incomplete preservation of the Irish material, although the clean edges of the bars is perhaps suggestive that this is not the case. Bar Morphotype C of this work is similar to *Conularia* sp. a. (Jerre, 1993 text-fig. 4 a-c) especially in the subdued transverse crenulations on the cusp ridges (rod/rod-crest of Jerre). In the case of *Conularia* sp. a, Jerre stated that: ..."*The margins of the rods are smooth and no pieces of the interrod areas have been found. This could indicate that there were no mineralized interrod areas present. One would expect to find fractures along the rod*

margins if such mineralized areas had been broken away."... This situation is what is found in all of the Irish Bar-type elements.

The Bar Morphotypes B and E of this work are of a more complex and robust nature, and comprise left and right-handed forms which, although showing some similarities to the other types described are distinctive on account of their strong basal hooks and lateral base extensions, and the lack of crenulated cusp ridges.

In summary the possible affinities of the 'bars' is as follows:

1. all the different types most probably are closely related;
2. they are not conodont support structures, even though some of the elements described by Bischoff (1973) and Walliser (1964) probably should be assigned to the same group of organisms as the Irish material;
3. they may be fish remains, but if so represent non-described taxa (probably to the level of family, or higher);
4. they may be fish remains, but elements as yet unrecognized due to the paucity of articulated material;
5. they may be part of conulariids; however, the apparent integrity of the individual elements and the lack of ragged edges which might be expected if they represented the most heavily mineralized 'struts' of the conulariid integument suggest that the elements described in this study may have lacked the inter-rod areas previously described in conulariid species.

Although some preliminary thin sections have been made, they reveal no recognizable vertebrate ultrastructure. The bars appear to have been constructed of dense, cryptically layered phosphate rather a more massive layered structure. A critical feature to be investigated in further assessment of the affinities of 'bars' will be their ultrastructure as revealed by improved thin sections and by Scanning Electron Microscopy.

8.2 Bar Morphotype A (Figure 8.1, Plates 73-76)

Diagnosis Right-handed, curved, linguo-labially compressed with five, or more than five crenulated cusp ridges decreasing in height to left. Lingual base hook absent to shallow and lateral base extension short or long. (see Figure 8.1 for terminology)

Material: Ten isolated, figured specimens, a few of which appear complete. Specimen numbers: TCD 36694-36703. TCD 36980.

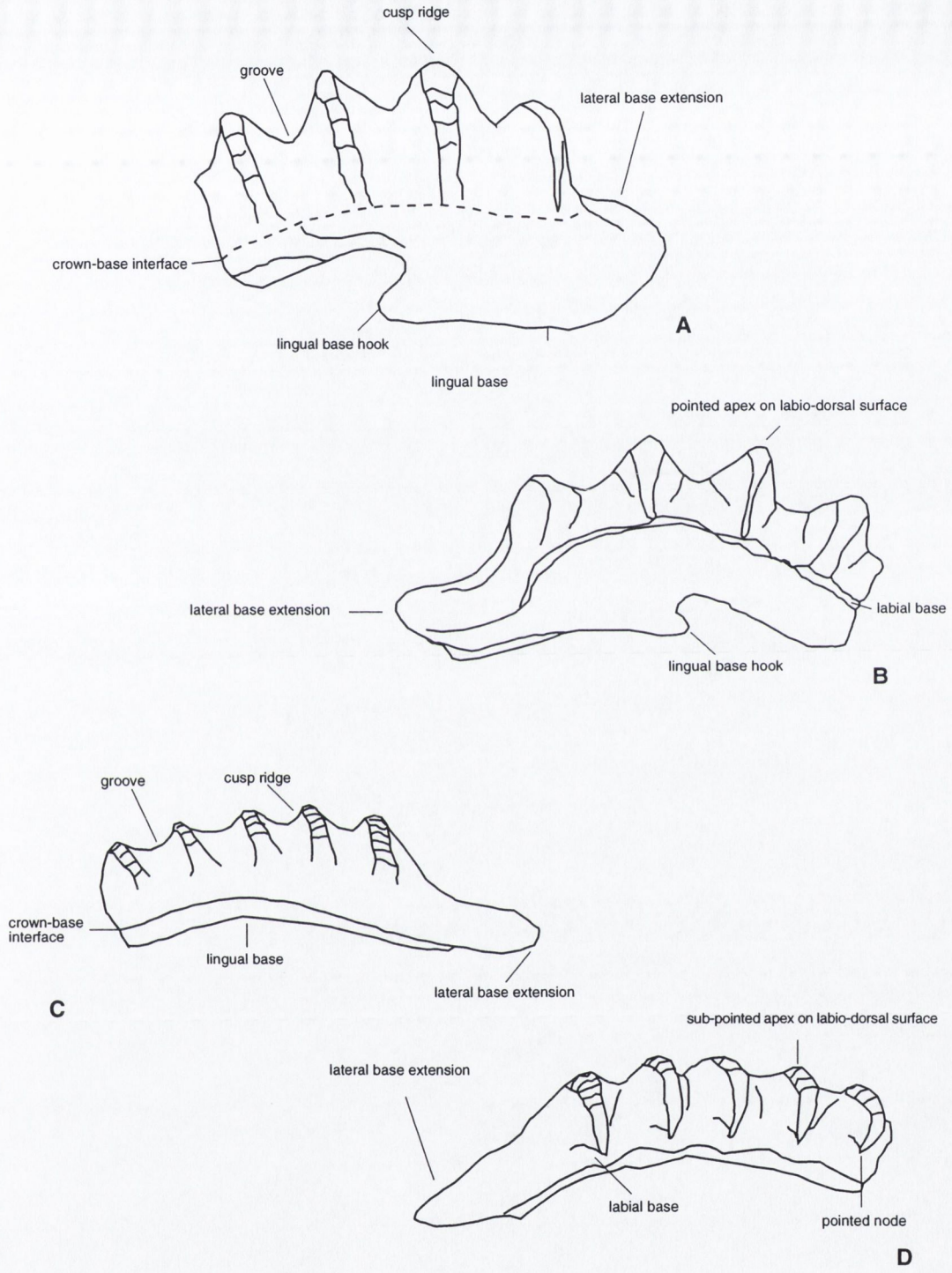


Figure 8.1. Bar-like microscopic elements - terminology used in the descriptions: Bar Morphotype A - A lingual view, B labial view, based on TCD 36704; Bar Morphotype B - C lingual view, D labial view, based on TCD 36699.

Description: Three to six times longer than wide, asymmetric, higher at right linguo-lateral area, labio-lingually compressed. Arcuate (lingually convex). The length ranges from 0.57mm to 1.27mm, with the width (labio-lingually) from 0.12mm to 0.27mm, and height from 0.15mm to 0.42mm. On the crown, the cusp ridges are parallel to each other but oblique to the lateral edges and decrease in height to the left. The cusp ridges, which show transverse crenulations, extend from a horizontal groove on the lingual side (marking the crown-base interface) to the labial side, with pointed to rounded apices on the labio-dorsal surface, culminating in pointed nodes on the labial side. The cusp ridges of the crown are separated by inter-ridge grooves which vary in depth along the dorsal surface and in some instances are so weak that two or three cusp ridges are more or less joined.

The lingual base is generally sloping, short on the left lingual side and arcuate from the left linguo-lateral margin towards the right linguo-lateral margin as the base gets longer. It extends beyond the right lateral margin forming a short to long lateral base extension, and may or may not have a shallow central basal hook. The labial base is arcuate along the labio-ventral margin, with the crown in some cases overhanging the base. The ventral base is concave and arcuate under the labial region. It forms a flat platform in the lingual area and into the lateral base extension or may be a flat to slightly concave platform with or without a horizontal ridge broadening out in the region of the lateral base extension.

Age, Locality and Lithology:

i. Kilbride Limestone Formation, *Polygnathus mehli* conodont Biozone, Ivorian (probably Freyrian), late Tournaisian, Dinantian. Disused quarry, near Nobber, Co. Meath (N 845 848); crinoidal limestone.

ii. Upper Ballysteen Limestone, *Polygnathus mehli* conodont Biozone, Ivorian (pre-Freyrian), late Tournaisian, Dinantian. Bore hole 3246/4 Urlingford, Co. Kilkenny; thinly bedded crinoidal limestone.

8.3 Bar Morphotype B (Figure 8.1, Plates 77 & 78)

Diagnosis Right-handed, curved, linguo-labially compressed with four, or more than four crenulated cusp ridges decreasing in height to the left. Strong lingual base hook and long lateral base extension. (see Figure 8.1 for terminology)

Material: Four isolated, figured specimens. Specimen Numbers: TCD 36704-36707.

Description: Three to seven times longer than wide, asymmetric, higher at right linguo-lateral area, labio-lingually compressed. Arcuate (lingually convex). The length ranges from 0.72mm to 1.54mm; the width (labio-lingually) from 0.15mm to 0.24mm; and the height from 0.3mm to 0.43mm. It should be noted that few specimens appear complete. On the crown the cusp ridges are parallel to each other but oblique to the lateral edges (though the cusp ridge closest to the right linguo-lateral edge may be parallel to this edge) and decrease in height to the left. The cusp ridges, which show transverse crenulations, extend from a horizontal groove on the lingual side (marking the crown-base interface) to the labial side with pointed to rounded apices on the labio-dorsal surface culminating in pointed nodes on the labial side crown-base interface. The cusp ridges of the crown are separated by inter-ridge grooves which vary in depth along the dorsal surface and in some instances are so weak that two or three cusp ridges are more or less joined.

The lingual base is generally sloping, short on the left lingual side and arcuate from the left linguo-lateral margin towards the right linguo-lateral margin as the base gets longer. It extends beyond the right lateral margin, curving away to a point and back towards the labial margin forming a long lateral base extension. A lingual basal book to the left occurs beneath the horizontal groove. The labial base is short where it occurs and is arcuate. The ventral base is generally concave under the labial surface and then mirrors the lingual surface ending in a flattened platform extending into the lateral base extension, the lateral margin of which is concave.

Age, Locality and Lithology:

Kilbride Limestone Formation, *Polygnathus mehli* conodont Biozone, Ivorian (probably Freyrian), late Tournaisian, Dinantian. Disused quarry, near Nobber, Co. Meath (N 845 848); crinoidal limestone.

8.4 Bar Morphotype C (Plate 79)

Diagnosis Straight narrow bar with six or greater than six cusp ridges on the crown; base slightly longer on lingual aspect than labial. (see Figure 8.1 for terminology)

Material: One isolated, figured specimen. Specimen number: TCD 36708.

Description: Straight narrow bar, four times longer than wide. Six cusp ridges rise from the lingual side; the right linguo-lateral cusp ridge is angled to the right lateral margin. The other finer, longer, cusp ridges are parallel to each other and lie oblique to the lateral edges with pointed apices on the labio-dorsal surface. Shallow transverse crenulations occur on the cusp ridges. A horizontal ridge forms the lingual crown-base interface; on

the labial side the cusp ridges have vertical ribs that culminate in pointed nodes at a double horizontal ridge and groove structure which overhangs the base area.

The lingual base slopes down and inwards towards a central vertical horizontal ridge; the right linguo-lateral area extends beyond the right lateral cusp ridge. The labial base is short where it occurs. The ventral base is a narrow raised platform with a centrally raised circular area (more on the labial than lingual side) containing a large lumen.

Age, Locality and Lithology:

Kilbride Limestone Formation, *Polygnathus mehli* conodont Biozone, Ivorian (probably Freyrian), late Tournaisian, Dinantian. Disused quarry, near Nobber, Co. Meath (N 845 848); crinoidal limestone.

8.5 Bar Morphotype D (Plates 80-85)

Diagnosis Left-handed, curved, linguo-labially compressed with five or more than five crenulated cusp ridges which decrease in height to the right. Lingual base hook absent to shallow and lateral base extension short to long. (see Figure 8.1 for terminology)

Material: Ten isolated, figured specimens. Specimen numbers: TCD 36709-36718. Non figured specimen, specimen number TCD 36980.

Description: Three to six times longer than wide, asymmetric, higher at left linguo-lateral area, labio-lingually compressed. Arcuate (lingually convex). The length ranges from 0.57mm to 1.42mm, the width (labio-lingually) from 0.12mm to 0.21mm, and the height from 0.15mm to 0.39mm. On the crown the cusp ridges are parallel to each other but oblique to the lateral edges and decrease in height to the right. The cusp ridges, which show transverse crenulations, extend from a horizontal groove on the lingual side (marking the crown-base interface) to the labial side with pointed to rounded apices on the labio-dorsal surface, culminating in pointed nodes on the labial side. The cusp ridges of the crown are separated by inter-ridge grooves which vary in depth along the dorsal surface and in some instances are so weak that two or three cusp ridges are more or less conjoined.

The lingual base is generally sloping, short on the right lingual side and arcuate from the right linguo-lateral margin towards the left linguo-lateral margin as the base gets longer. It may extend beyond the left lateral margin forming a short to long lateral base extension, and may or may not have a shallow central basal hook. The labial base is arcuate along the labio-ventral margin, with the crown in some examples overhanging the base. The

ventral base is concave and arcuate under the labial region forming a flat platform in the lingual area and into the lateral base extension. It may be a flat to slightly concave platform with or without a horizontal ridge broadening out in the region of the lateral base extension.

Age, Locality and Lithology:

i. Kilbride Limestone Formation, *Polygnathus mehli* conodont Biozone, Ivorian (probably Freyrian), late Tournaisian, Dinantian. Disused quarry, near Nobber, Co. Meath (N 845 848); crinoidal limestone.

ii. Upper Ballysteen Limestone, *Polygnathus mehli* conodont Biozone, Ivorian (pre-Freyrian), late Tournaisian, Dinantian. Bore hole 3246/4 Urlingford, Co. Kilkenny; thinly bedded crinoidal limestone.

8.6 Bar Morphotype E (Plate 86)

Diagnosis Left-handed, curved, linguo-labially compressed with four, or more than four crenulated cusp ridges, decreasing in height to the right. Strong lingual base hook and long lateral base extension. (see Figure 8.1 for terminology)

Material: One isolated, figured specimen. Specimen number: TCD 36719. Non-figured specimens, specimen numbers TCD 35877, 36981.

Description: Four times longer than wide, asymmetric, higher at left linguo-lateral area, labio-lingually compressed. Arcuate (lingually convex). The length is 0.96mm, with a width(labio-lingually) of 0.21mm, and height of 0.35mm. On the crown the cusp ridges are parallel to each other but oblique to the lateral edges' decreasing in height to the right. The cusp ridges, which show transverse crenulations, extend from a horizontal groove on the lingual side (marking the crown-base interface) to the labial side with pointed to rounded apices on the labio-dorsal surface culminating in pointed nodes on the labial side. The cusp ridges of the crown are separated by inter-ridge grooves which vary in depth along the dorsal surface; in some examples they appear to join two or three cusp ridges.

The lingual base is generally sloping, short on the right lingual side and arcuate from the right linguo-lateral margin towards the left linguo-lateral margin. The base gets longer and extends beyond the right lateral margin, curving away to a point and back towards the labial margin, forming a long lateral base extension. A lingual basal hook to the right occurs beneath the horizontal groove. The labial base is short, where it occurs, and arcuate. The ventral base is generally concave under the labial surface and then mirrors

the lingual surface ending in a flattened platform extending into the lateral base extension, the lateral margin of which is concave.

Age, Locality and Lithology:

Kilbride Limestone Formation, *Polygnathus mehli* conodont Biozone, Ivorian (probably Freyrian), late Tournaisian, Dinantian. Disused quarry, near Nobber, Co. Meath (N 845 848); crinoidal limestone.

8.7. Bar Morphotype F (Plates 87-90)

Diagnosis Straight narrow bar with three or more than three long cusp ridges on crown; the short base is slightly longer on the lingual aspect compared to the labial aspect and may be slightly curved. (see Figure 8.1 for terminology)

Material: Seven isolated specimens, a few of which appear complete. Specimen Numbers: TCD 36720 -36726. Non-figured specimens, specimen numbers: TCD 35865, 35871, 35877, 36937, 36939, 36941-2, 36949, 36980-1.

Description: Straight narrow bar, three to six times longer than wide. The length ranges from 0.5mm to 1.18mm, the width (labio-lingually) from 0.12mm to 0.27mm and the height from 0.15mm to 0.34mm. Long laterally compressed cusp ridges rise from the crown-base interface on the lingual side curving toward their apices as rounded points on the labio-dorsal surface, culminating in most instances in pointed nodes on the labial side.

The base is narrow and rectangular with a lingually sloping dorsal surface. The ventral surface is a flat platform. or may be concave along the labial side with a minor horizontal keel.

Age, Locality and Lithology:

i. Kilbride Limestone Formation, *Polygnathus mehli* conodont Biozone, Ivorian (probably Freyrian), late Tournaisian, Dinantian. Disused quarry, near Nobber, Co. Meath (N 845 848); crinoidal limestone.

ii. Lyraun Cove Shale Member, Porter's Gate Formation, *Polygnathus inornatus* conodont Biozone, Hastarian, Tournaisian, Dinantian. Small cove section, near Porter's Gate, Hook Head, Co. Wexford (S 276 100); calcareous mudstone-dolomitic limestone.

iii. Upper Ballysteen Limestone, *Polygnathus mehli* conodont Biozone, Ivorian (pre-Freyrian), late Tournaisian, Dinantian. Bore hole 3246/4 Urlingford, Co. Kilkenny; thinly bedded crinoidal limestone.

8.8. Bar Morphotype G (Plates 91 & 92)

Diagnosis Straight narrow bar with six or more than six short cusp ridges on crown; some cusp ridges may show transverse crenulations. Short base slightly longer on the lingual aspect compared to the labial and may be slightly curved. (see Figure 8.1 for terminology)

Material: Four isolated specimens, a few of which appear complete. Specimen numbers: TCD 36727-36730. TCD 35865, 35871, 35877, 36936-7, 36939, 36941-2, 36949, 36960-1, 36980-1.

Description: Three to six times longer than wide, straight narrow bar. The length ranges from 1.06mm to 1.48mm, the width (labio-lingually) from 0.20mm to 0.24mm, and height from 0.23mm to 0.26mm. Short laterally compressed cusp ridges rise from the crown-base interface on the lingual side curving toward their apices as rounded points on the labio-dorsal surface culminating in most instances in pointed nodes on the labial side. Each cusp ridge is separated by an inter-ridge groove.

The base is a platform with a central horizontal groove, the linguo-ventral and labio-ventral margins appear as horizontal ridges creating a laterally concave impression.

Age, Locality and Lithology:

i. Kilbride Limestone Formation, *Polygnathus mehli* conodont Biozone, Ivorian (probably Freyrian), late Tournaisian, Dinantian. Disused quarry, near Nobber, Co. Meath (N 845 848); crinoidal limestone.

ii. Lyraun Cove Shale Member, Porter's Gate Formation, *Polygnathus inornatus* conodont Biozone, Hastarian, Tournaisian, Dinantian. Small cove section, near Porter's Gate, Hook Head, Co. Wexford (S 276 100); calcareous mudstone-dolomitic limestone.

iii. Upper Ballysteen Limestone, *Polygnathus mehli* conodont Biozone, Ivorian (pre-Freyrian), late Tournaisian, Dinantian. Bore hole 3246/4 Urlingford, Co. Kilkenny; thinly bedded crinoidal limestone.

CHAPTER 9: TAPHONOMIC PROCESSES

9.1 INTRODUCTION

Efremov (1940) first coined the term *Taphonomy* which can be defined as the changes that occur to any organism from its death to its later discovery as a fossil; this also covers any trace relating to the organism.

Taphonomy has been taken into account in this study, to try to establish: whether the fish microvertebrates are autochthonous or allochthonous (where mobile organisms, such as fish, are the objects of study, the terms autochthonous and allochthonous refer to whether or not the rocks containing the fossils represent the bottom sediments of the environment in which the fish lived); whether the relative abundances of recovered fish microvertebrates might reflect the composition of the original fish population; and whether fish were 'rare' or 'common' in the Irish Lower Carboniferous compared to non-vertebrate organisms.

Problems in evaluating the taphonomy of fish microvertebrate assemblages are considerable because of the lack of actualistic studies and because the detailed anatomy of most of the Carboniferous fish that yielded the microvertebrates is not known.

Taphonomic processes actually bias the fossil record, since they actively affect the composition of fossil assemblages. Almost all of them are likely to be time averaged, raising the possibility that they contain fish which lived in different environments. The relative abundances of microvertebrates of different size and morphology reflects their hydrodynamic properties, as well as their original frequency in the living population. An additional source of bias is the possible selective destruction of the smaller delicate skeletal remains.

Within individual assemblages there is likely to have been post-mortem bias and the possible selective destruction of individuals or skeletal elements in the death assemblage (Kidwell and Behrensmeyer, 1988).

However, bones, teeth and scales (both macroscopic and microscopic) being primarily phosphatic probably have at least as high a preservation potential as invertebrates with shells, tests, etc. made of calcium carbonate.

9.2. TAPHONOMIC PROCESSES

9.2.1 MODERN FISH - DEATH, DECAY AND BURIAL

The material described in this thesis, with one exception, consists of disarticulated microvertebrate material. The exception is an assemblage of teeth, tentatively identified as petalodonts, from limestone and shale of deep water origin at Ballybunion, Co. Kerry (see Chapter 12, section 2.2).

Studies on the taphonomy of Recent fish have ranged from cases where large numbers of fish are preserved intact to cases more relevant to the present study where soft tissues have decayed and hard tissues have become dispersed.

During the late 1950s and 1960s many workers in the field of taphonomy (for example, Brongersma-Sanders, 1957) examined the causes and effects of so called 'mass mortalities' considered once to be the primary 'source' of recovered fish fossils. The causes of such 'mass mortalities' were considered to related to algal blooms, severe storms, lack of oxygen, temperature changes etc. (Brongersma-Sanders, (1957). However, many of the known concentrations of 'fish material' in the geological record may result from the accumulation of lag concentrations during long intervals of non- or sporadic deposition where fish have died normally. In the modern aquatic realm most fish are killed by predators, though with the increase in size of the fish the chances of predation decreases. Those that die by other means such as old age, disease, and through parasite infestation are usually scavenged. Scavengers are active at most depths including deeper conditions. The conditions necessary for complete preservation, based on modern analogies, appear to improve with ocean depth (Schafer, 1972).

Extensive work by Schafer (1972) has been used widely by later researchers. Schafer showed that different species of fish decay in different ways under essentially the same external conditions. Most carcasses tend to sink initially on death. Some have a tendency to refloat (not necessarily reaching the surface) following the development of gas within the abdominal cavity but return to the sea floor once this cavity ruptures. Other carcasses remain on the sea floor, perhaps due to their small body cavities and low gas development. A full or empty gut at the time of death may also affect gas build up. Water temperature is another parameter which is relevant. Low water temperature may slow down decay; fishes that would normally float at moderate temperature may not do so at lower temperatures. If the temperature is very high, gas build up may be rapid, and even those fish with small abdominal cavities may refloat. High salinity retards the decay rate and can greatly delay reflotation.

A floating carcass is unlikely to sink again intact. Schafer (1972) suggests that fins and rays become detached, vertebral columns become disarticulated and many scales and bones are shifted from their life position. Agitation of the surface water can disarticulate a floating carcass, as can transport along the seafloor. Where both disarticulated and articulated material are found together, it has been suggested that the articulated remains are from fish which remained on the bottom without refloating, and the disarticulated remains from fish which refloated. In the case of the cartilaginous fishes, such as sharks and rays, only those parts composed of chemically and physically resistant phosphatic compounds - such as fins, scale and teeth - usually survive into the fossil record; hence it is only in exceptional circumstances that 'whole specimens' are recovered.

Many modern sharks release full sets of mouth teeth on death while other vertebrate 'hard parts' from non-cartilaginous fish become a valuable food source. The grinding teeth of sharks are also periodically replaced throughout the life-cycle often associated with the mating period when the fish tend to congregate in specific areas; smaller grasping teeth and smaller grinders are continually discarded and replaced over a wide area. Many fish swim long distances around the modern oceans and indeed migrate. It can only be surmised that these conditions of tooth dispersal (Schafer, 1972), 'swimability' and migration were possible or evolving through the fossil record.

9.2.2 MODERN FISH - CHEMICAL, MECHANICAL AND BIOTIC FACTORS

It is impossible to separate these factors as their effects are interrelated. The most important chemical factors controlling the lives of fishes are salinity, temperature, and oxygen content.

The salinity of the modern oceans is generally 33-37‰ with a mean of 35‰. A decrease in salinity can occur where high quantities of fresh water enter the ocean systems, for example as a result of monsoons, melting glaciers, etc. Salinity may increase in restricted shallow basins, hyperhaline lakes and semi-arid to arid regions of high evaporation. The salt tolerance of fish varies within wide limits. Where changes are regular many fishes may adapt to them, but sudden or prolonged changes from the norm may be intolerable and may have given rise (in conjunction with other factors) to some lagerstätten that contain fish such as the Solnhofen Lithographic Limestones (Viohl, 1990).

The average modern ocean temperature ranges from -2° to 30°C depending on the distance from the equator and depth; landlocked areas may experience higher temperatures. Recent fish occur from -2° to 37°C with tolerance ranges rarely including both extremes; it is known that perennial species of the littoral zone frequently move to deeper water during cold spells unless they are cold resistant (Brongersma-Sanders,

1957). Sudden and unpredictable drops in temperature, if prolonged, may cause mortality.

In the average modern ocean, sea water contains about 8ml/L of dissolved oxygen. Oxygen is one of the essential elements for living vertebrate. Changes in the amount of dissolved oxygen in the seawater may have detrimental effects not only on the living organism but may enhance or impede the chances of preservation of a vertebrate following death. Under normal conditions oxygen is removed from the system by respiration and returned by photosynthetic activity of plants and phytoplankton and by diffusion from the air. Fluctuations in oxygen levels may have many causes such as the restrictions of deep narrow water bodies where diffusion is reduced allowing H_2S to rise; prolonged ice cover of shallow waters; excessive oxygen consumption as a result of oxidation of organic material, etc..

Plankton, although both a direct and indirect food source for fish may have a detrimental effect on the availability of oxygen. Red blooms, explosive increases in dinoflagellate populations or so called 'red waters' can deplete the available dissolved oxygen - these blooms are usually associated with temperature rises.

After death and decay of the fish, the hard tissues are subject to transport by currents which may be tidal or induced by storms or other causes.

Although transport may seem at the outset to be high on the list of important factors within a taphonomic regime, modern analogues (Behrensmeyer, 1990) and laboratory experiments suggest that vertebrate material (including teeth, though usually macroscopic) do not travel as far as might be expected - only a matter of several kilometres rather than very long distances - as teeth have densities approaching c. 3.0 and would require relatively strong currents to be moved at all. Of course, this does not take into account the possible biological transport caused by ingestion of fish material by predators and scavengers and subsequent travel by the predators and scavengers. If the prey is ingested whole the predator may leave the area prior to the regurgitation of indigestible material or excretion. However, selective predation of soft body parts may leave the rejected hard-parts within the original habitat of the prey.

The final burial of the fish material will be controlled largely by the nature of the sedimentary regime: in shallow water, high energy environments, the chances of burial, but also of exhumation will be high; in lower energy environments although sedimentation rates and their rates of burial may be lower, the chances of later exhumation are also lower.

9.3 THIS STUDY

9.3.1 GENERAL

All the fish microvertebrate specimens isolated for this study occur as disarticulated material. Although the specimens have been picked from acid insoluble residues, they seem to have been preserved only in this state. Thin sections of rock samples taken prior to acid digestion from all but the Urlingford core show only small disarticulated phosphatic particles, (i.e. teeth, scales/denticles and bone fragments). The thin sections also show that it is unlikely that microvertebrates were lost by dissolution of phosphate during burial and diagenesis: no examples of mouldic preservation of teeth or scales was observed.

Evidence from the invertebrate as well vertebrate faunas from the localities studies was taken into account. The biostratinomic processes (mechanical) affecting the invertebrates are likely to have also affected the microvertebrates.

It has not been possible to distinguish teeth released by disarticulation of the cartilaginous fish after death from those shed naturally during life. At the very least it would require the special preservation of articulated specimens together with 'shed teeth' to investigate this question with any hope of success.

It has also not been possible to distinguish the different process of disarticulation of the bony and spiny sharks. The broken tips of cusps and bases could equally be the result of mechanical abrasion due to transport, or of compaction during burial, or of predation during the process of disarticulation of the fish.

The degree of abrasion observed varies within and between the different faunas. In some cases robust skeletal elements show the effects of abrasion in rounding and in the reduction in sharpness of the surface ornament; in others delicate structures much as the fragile acrodin tips of the actinopterygians have survived.

A remarkable feature is that although there are many easily identifiable osteichthyan teeth (and in particular actinopterygian conical teeth with the acrodin tip intact) and scales, very few identifiable 'bones' have been found. Amongst the broken scale and teeth fragments recovered there is only a small amount of unidentifiable bone pieces. Whether this lower preservation potential of the bone is related to the shape of the fragments, or to the structure of the bone, or to some other factor is not known.

9.3.2 LYRAUN COVE, HOOK HEAD, CO. WEXFORD

There is abundant evidence of relatively high energy conditions in the beds which contain the microvertebrates and the invertebrate fossils within the Lyraun Cove Shale Member of Hook Head. The invertebrate fauna is disarticulated; the echinoderms, mostly crinoids, occur mainly as discrete single ossicles: the brachiopods are found as single valves; and the ostracodes also occur as single valves, or, quite commonly, as stacks of single valves cupped one inside another (Figure 9.1 shows an example of a bedding plane surface). The levels containing the fossils also contain granules of quartz which contrast, with the mud and sand grade sediments of the 'background' sedimentation.

Some of the microvertebrate material is worn and there is little doubt that the material is not autochthonous in that it has undergone sorting and some transport before being finally deposited. However, there is no evidence that the microvertebrates have been transported in from a radically different environment. Rather the coarser fossil bearing horizons probably represent storm deposits in which microvertebrate material and diagenetic phosphate which may have been buried and exhumed several times was concentrated.

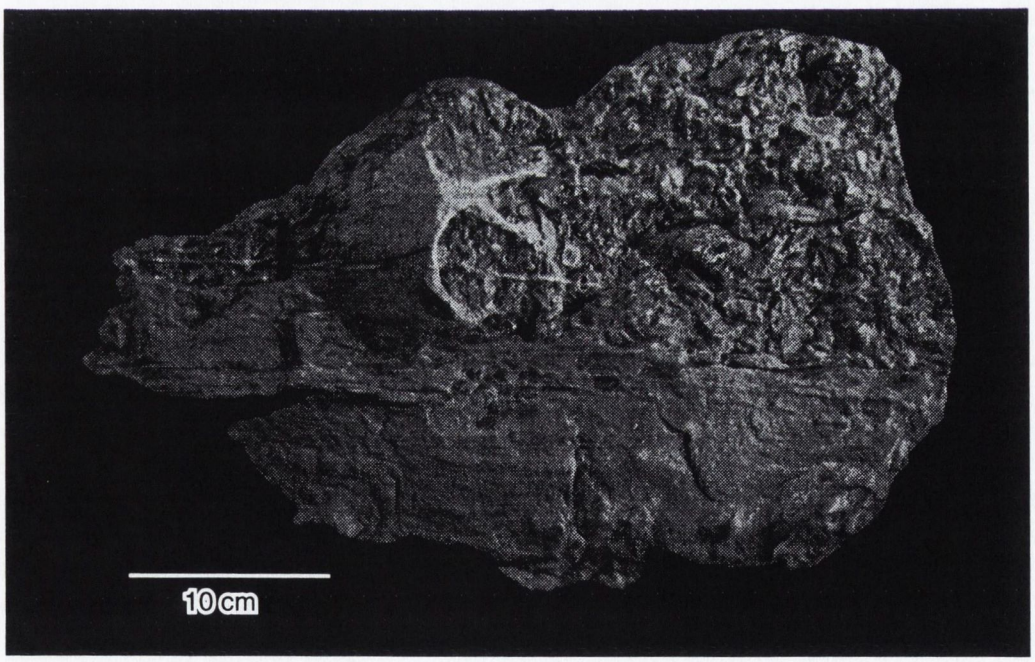
9.3.3 KILBRIDE QUARRIES, NOBBER, CO. MEATH

The limestones at Kilbride Quarries contain mostly disarticulated invertebrate skeletal grains. The most abundant elements of the fauna are crinoids, which occur as pluricolumnals and discrete single ossicles. Brachiopod shells are preserved as disarticulated single valves. Both relatively complete and also fragmented brachiopod material may be seen in thin section.

Post-depositional compaction leading to the development of microstyolites and pressure solution seams is widespread in the limestones.

The microvertebrate material is generally very well preserved. Although a very small number of abraded specimens are present. It is remarkable how much original ornamentation and detailed morphology has survived transport, *in situ* reworking and compaction. The 'cusped' teeth (i.e. chondrichthyan *Thrinacodus*, *Denaea* sp. and acrodin-tipped actinopterygian) have suffered more mechanical abrasion than the labio-lingually compressed blade-like teeth (for example: the chondrichthyans *Lissodus* sp., and *Protacrodus* sp.) and the straight and complex Bars. The chondrichthyan denticles and very delicate heart-shaped hybodont scales overall show little evidence of

A



B

Figure 9.1 A. Sample from Bed 21 Lyraun Cove, Hook Head, Co. Wexford (TCD 3687); B. second sample (TCD 36866) from the same bed. Both samples show *Vaughania* and *Palaeacis* together with crinoid ossicles of various sizes lying over and within the corals.

abrasion, whilst the osteichthyan scales being flat and therefore liable to a lot more breakage are also commonly found intact although many incomplete and fragmented scales are also found. Few acanthodian scales show their distinctive growth pattern. This may be a result of mechanical abrasion as the shape of the scales is cubic which may result in them rolling rather than being entrained and lifted by bottom currents.

Although there is abundant evidence of current activity in the Kilbride Limestones, it appears that the fish microvertebrates did not experience very much transport and is therefore likely to be essentially autochthonous in the sense of being deposited in the sedimentary environment which the fish inhabited.

9.3.4 URLINGFORD CORE, KILKENNY, CO. KILKENNY

As material from the Urlingford Core was supplied without hand samples or thin sections, it is not possible to make any reasoned taphonomic conclusions. However, the similarity of the fish microvertebrates both taxonomically and in their preservation to those from the Kilbride Quarries, suggests that although the environment is believed to have been of deeper, the taphonomic processes may have been similar.

9.3.5 MOYOLA RIVER, DRAPERSTOWN, CO. LONDONDERRY

Samples examined from the Moyola River area have been subjected to differing mechanical processes as the result of transportation, and abrasion. The material has suffered strong post-mortem compaction leading to the development of numerous micro-fractures. Since much of the fragmentation of material released by acid digestion is clearly related to compaction it is difficult to assess the degree of pre-burial fragmentation.

Large angular quartz grains appear to coincide with the larger size fish microvertebrates recovered from the residues. This agrees with the field and hand specimen observations of reworking of the sediments prior to lithification and the suggestion that the fish microvertebrates were not autochthonous. The distance of transport and the degree to which the microvertebrate material might have been derived from environments not represented by the rocks of the Mormeal Member is open question.

9.4 CONCLUSIONS

The faunas from the Kilbride Quarries and, by inference those from the Urlingford borehole are considered to be essentially autochthonous. The degree to which the relative proportions of the different fish microvertebrates in the faunas reflect the proportions of the parent fish in the Late Tournaisian seas is considered in Chapter 10,

but clearly the evidence of current activity suggests that this is likely to have been some hydrodynamic sorting with a resulting bias.

The microvertebrate fauna from the Lyraun Cove Shale Member at Hook Head may also be autochthonous only in the sense that it is representative of the fish fauna of the environment in which it is preserved rather than that of another environment, but it probably has undergone considerable commutative transport and concentration. It is therefore likely to be extremely biased in relation to the composition of the parent fish fauna.

The fauna from the Moyola River is probably allochthonous and may contain transported material from outside the immediate environment of deposition.

CHAPTER 10: FACIES, ABUNDANCES AND ASSEMBLAGES

10.1. GENERALIZED FACIES

Recent fish inhabit a wide range of environments, from hadal depths in the oceans, to shelf seas, littoral environments, estuaries, rivers, and permanent and ephemeral lakes. Their fossil remains might therefore be anticipated in a similarly wide range of palaeoenvironments. The concentration of fish material, however, is probably controlled largely by taphonomic processes. In the case of disarticulated fish microvertebrate material, high concentrations occur in so called "lag" deposits and "bone beds" (condensed deposits) (Seilacher, 1990) resulting from hydrodynamic sorting (see below).

The Lower Carboniferous rocks of Ireland from which fish material has been identified encompasses facies spanning from non-marine, fluviatile, to marginal marine, shoreface, inner, mid and outer carbonate and siliciclastic shelf (or ramp) and basinal (Sevastopulo, in press). Little is known about the distribution and relative abundance of fish remains within recent examples of these broad facies groupings. The four study areas described in this thesis are assigned to different broadly defined facies which may serve as a means of comparison with fish microvertebrate bearing facies elsewhere.

10.1.2 REGIONAL FACIES TYPES

The following generalized facies may used to describe the microvertebrate-bearing strata in the Urlingford borehole, the Kilbride Quarries, Lyraun Cove in Hook Head and Moyola River.

10.1.3 CARBONATE SHELF (RAMP)

A shelf is taken to refer to an area of extensive shallow-water environments bordered by land and littoral environments on one side and by deeper water slope and basinal sediments on the side; where there is little change of slope between shoreface and basin, the shelf is referred to as a ramp (Ahr, 1973). Shelf facies may be sub-divided, somewhat arbitrarily, into Inner, Middle and Out Shelf. The shelf environment is characterized by normal marine salinity and depths of a few metres to 200 metres. At the latitude of Ireland during the Carboniferous the temperature most likely was within the subtropical and tropical ranges (10°-30°C depending on the depth). The rocks of the carbonate shelf range from grainstones in the shallower inner shelf to packstones and

wackestones commonly with shales in the middle and outer shelf. The late Palaeozoic carbonate shelf faces were dominated by stalked crinoids together with bryozoans, brachiopods, corals, sponges, etc. (Wilson and Jordan, 1983).

10.1.4 MIXED CARBONATE/SILICICLASTIC INNER SHELF

Storm-wave dominated sedimentation:
This facies represents shallow water environments in which there is substantial input of siliciclastics sediment. Sedimentary processes may be dominated by wave generated currents, tidal currents, or, in protected environments, by sediment fall out from suspension.

During modern tropical storms it is not unusual for storm tide or surges to rise to some 4m (Dott, 1983), but within short periods of time, the sediment deposited as a result of the storm becomes eroded and bioturbated to the extent that its preservation potential is considerably lower than intuitively expected.

However, many examples of ancient storm deposits have been recognized. Many of them exhibit some or all of the following features - erosion surfaces, bioturbation, shell lags, parallel laminae, hummocky cross-stratification, etc. Some storm bed sequences probably represent a single event with a basal erosion surface, hummocky cross-stratification, wave rippled sand layer and fair-weather mud (Johnson & Baldwin, 1996). Phosphatic material, including fish microvertebrates, tends to be concentrated on the surface of such beds.

Tidal/current dominated sedimentation:
Inner shelf deposits formed under the dominant influence of tidal currents may show cross-stratification at a variety of scales, including bi-polar or 'herring-bone' cross-stratification, mud drapes, erosion surfaces ranging from those formed over periods to those that were active over longer periods, which may have phosphate lags developed on them; long term winnowing processes and tidal sandbars (Johnson & Baldwin, 1996).

Mud dominated sedimentation:
In sheltered areas such as occur in lagoons protected from the open sea by barrier islands, sedimentation may be dominated by fall out of clay and silt from suspension.

Condensed beds:

Whilst shell lags are found in storm wave dominated, tidal current dominated and occasionally within mud dominated facies, it is perhaps within so called "condensed beds" which represent long periods of time with little net deposition and much reworking and erosion that very high concentrations of fish microvertebrates occur.

The sedimentological contexts in which such condensed beds occur are probably varied but all involve a reduction in sediment supply so that material at the surface does not become buried rapidly. One circumstance that may lead to the cut off of sediment supply is rapid sea level rise which may result in transgression and the dumping of sediment in the newly formed coastal zone.

Characteristically "condensed beds" show high amounts of broken shell at the base which is often scoured and refilled with the same or similar material suggesting that removal of soft sediment occurred on more than one occasion. Evidence of long residence time is seen by the presence of such resistant particles as phosphatic nodules and fish remains; corrosion of fossils, fossils overgrown by epibionts capped by a barren mud layer deposited quickly enough to preserve the delicate fossils on the top of each bed. Caution must be used when interpreting the palaeoecology of such beds as the last communities occupying the sea floor in times of non-deposition may be over represented and all the earlier organisms may be represented only by broken skeletal hash.

10.1.5 TIDAL FLAT (Supratidal/Sabkha)

Modern carbonate tidal flats are integrated systems. Those that are not wind dominated have seaward subtidal environments that are rarely emergent; intertidal areas within normal high tide and low tide, exposed daily between tides; the landward supratidal environments above normal or mean tidal ranges are exposed most of the time but are flooded by spring and storm tides. In arid conditions the supratidal environments include the sabkha environment merging with a continental environment (Shinn, 1983). Evaporitic minerals such as halite, anhydrite and gypsum occur in many modern sabkha.

Supratidal-type environments also occur land-ward of levees or low beach ridges but the marsh and sabkha environments are the most extensive. Sedimentary structures common with sub-aerial exposure are desiccation cracks, laminated beds - thick in the marsh/sabhka areas thinning towards the sea; fenestrae; algal layering or stromatolites and intraclasts.

Hypersaline and algal laminated sediments also form part of the upper intertidal zones extending into the supratidal cut by tidal channels. Tidal channels in the modern Andros Islands (Shinn, 1983) migrate laterally. Here the base of the channels are marked by channel lags - conglomerates of intraclasts in a matrix grading into finer grained carbonate sand and packstones, these finer grained elements may carry concentrated faunal remains such as bivalves, ostracodes and fish material.

10.2 FACIES ASSOCIATED WITH STUDY AREAS

The four study areas may be classified in terms of the broad facies types outlined in 10.1.

10.2.1 URLINGFORD CORE, KILKENNY, CO. KILKENNY

The limestone and shale in this core falls within the Carbonate Shelf Facies described above. The levels sampled probably correspond to increasing water depth, since the Lisduff Oolite Member below represents a shallow inner shelf environment while the Waulsortian Limestone above represents relatively deep water. Since almost all the fish microvertebrate taxa recorded at Urlingford are present in the higher samples, these may be taken to represent the deeper, middle or outer part of the carbonate shelf.

10.2.2 KILBRIDE QUARRIES, NOBBER, CO. MEATH

Using the criteria described previously, the two quarry sections at Kilbride fit best into that of a regional Carbonate Middle Shelf Facies. In terms of this study, this is described as an Carbonate Shelf facies. There is an abundant and diverse invertebrate fauna with an unusually high number of mechanically isolated fish microvertebrates. The occurrence of algae and plurilocular foraminifera is suggestive of water no deeper than c. 100m whilst the sedimentology suggests that the area was above storm wave base. In comparison with Urlingford, it seems probable that the Kilbride Quarries reflect shallower water conditions.

10.2.3 LYRAUN COVE, HOOK HEAD, CO. WEXFORD

The sections at Lyraun Cove are interpreted as including storm-wave dominated sedimentation, tidally dominated sedimentation, mud dominated sedimentation, and the condensed beds. They are subtidal near shore, shallow water deposits which reflect gradual increasing depth over time. In terms of this study, they are assigned to the Mixed Carbonate/Siliciclastic Inner Shelf facies. The lower parts of the section appear to be sub-tidal with considerable evidence of storm reworking of localized sandbodies. This gives way to a more mud dominated facies, within which are condensed beds.

10.2.4 MOYOLA RIVER, DRAPERSTOWN, CO. LONDONDERRY

Evidence of hypersaline inter- to supratidal sediments suggests that the material from the Altagoan Formation falls within the Tidal Flat (supratidal/sabkha) Facies and specifically from a channel fill, possibly tidal.

10.3 NUMERICAL ABUNDANCE OF FISH MICROVERTEBRATES AND PALAEOENVIRONMENT

- Numerical abundances of microvertebrates are shown in Figure 10.1

10.3.1 URLINGFORD CORE

The small samples (0.5kg) from the Urlingford core yielded quite a high number of fish microvertebrates but these are mostly actinopterygian teeth. Relatively small numbers of chondrichthyan teeth were recovered in comparison to the higher faunas from Kilbride Quarries, which however were derived from much larger samples. It seems probable that the lower taxonomic diversity of the Urlingford faunas may reflect the small sample sizes.

10.3.2 KILBRIDE QUARRIES

The fish microvertebrate fauna from Kilbride Quarries is the most taxonomically diverse and numerically the richest of those studied. The absolute number of fish microvertebrates per kilogram of limestone is of course a function of the sedimentation rate as well as the number of fish living in this environment and contributing skeletal material to the sediment. The fact that Geraghty (1996) recorded conodont yields of up to 200 per kg of limestone, an order of magnitude greater than from most Carboniferous limestone sample in Ireland (Sevastopulo, pers. comm. 1999), suggests that either both conodonts and fish were particularly abundant in this environment or that both were

concentrated as the result of sedimentary processes. The relatively coarse crinoidal limestones of the Kilbride locality may reflect current energy high enough to concentrate the fish material and winnow fine grained carbonate, although there is no evidence from the limestones themselves of discrete laminae with very high density of phosphatic fossils. In fact, the overall abundance of fish microvertebrates varies from bed to bed (see Figure 10.1).

The absolute and relative abundances of chondrichthyan and osteichthyan fish is difficult to estimate. Unlike the situation with conodonts where each animal contained thirteen elements, the number of teeth in the mouth of a chondrichthyan or osteichthyan fish is not known. The same may argument applied to the scales of osteichthyan and acanthodian fish.

The overall abundance of microvertebrate remains from these quarries varies from bed to bed. The most numerous remains come from a limestone bed low in the first quarry, with other beds within this quarry yielding comparatively less. The upper quarry provided more consistently abundant faunas than Quarry One although no single bed revealed an abundance as numerically high as sample KQ1(2).

10.3.3 LYRAUN COVE

The quantity of fish microvertebrates is very low (Figure 10.1) especially in the lower section, Section LC1, despite the fact that the horizons sampled appeared to be lag deposits with common phosphate. Since this area was initially a very shallow shelf region, subject to storm reworking, the absence of vertebrates is perhaps not surprising. The chondrichthyans, most of which would have been active predators of other vertebrates, as well as feeding on invertebrates such as crustaceans and molluscs, may not have found sufficient food within such an environment. As the seas deepened and the invertebrate fauna increased, a greater food source would have been available. Osteichthyan and acanthodian fish (some of which may have been active predators) also may have found food sources in the environment of the lower section somewhat depleted, but increased in relative abundance with the incoming of deeper water, richer in nutrients.

10.3.4 MOYOLA RIVER AREA

The number of fish microvertebrate remains from the Moyola River locality is moderately high but the fauna recovered is dominated by actinopterygian scales and the taxonomic diversity is low. This is attributed to the environmental conditions.

Locality	Lyraun	Lyraun	Jrlingfor	Jrlingfor	Jrlingfor	Jrlingfor	Jrlingfor	Jrlingfor	Jrlingfor	Moyola	Klbride	Klbride	Klbride	Klbride	Klbride	Klbride	Klbride	
Residue number	HHLC1.2	HHLC1A	252.30	241.50	226.0	218.70	205.60	195.70	181.60	Moyola	KQ1(2)	KQ1(3)	KQ1(4)	KQ1(5)	KQ2(1)	KQ2(2)	KQ2(3)	
			252.70	241.90	226.40	219.10	205.90	196.0	182.10									
VERTEBRATE FAUNA																		
Chondrichthyan: teeth																		
Thrinacodus incurvus ferox morphotype		1*			1*			1*			9*			1*				
Thrinacodus incurvus nanus morphotype											2*							
Lissodus Morphotype1					1*						9*				1*	1*	1*	
Lissodus Morphotype 2											2* (1*)							
Lissodus Morphotype 3											3* (1*)							
Lissodus Morphotype 4											4*				1*			
Lissodus Morphotype 5											8*			1*	2*	1*	2*	
cf. *Denaea*											6* 1					1	1*	
Protacrodus Morphotype 1											1*							
Protacrodus Morphotype 2											1*							
Protacrodus Morphotype 3						1*												
Chondrichthyan Pavement Dentition (CPD) 1											3*							
CPD 2											1*							
CPD 3		2*									1*							
CPD 4					1*						2*							
CPD 5											1* 1							
CPD 6											1*							
CPD 7											1*							
Chondrichthyan: scales/denticles **																		
Denticles Morphotype 1											1*							
Denticles Morphotype 2											1*							
Denticles Morphotype 3											1*							
Denticles Morphotype 4															1*			
Denticles Morphotype 5																1*		
Composite Scales/denticles m'type 1											1*							
Composite Scales/denticles m'type 2								1*			1*							
"Ctenacanth-type" scales									1*		2*							
Mucous Membrane denticles m'type 1											1*				1*			
Mucous Membrane denticles m'type 2											1*				1*			
Body scales											1*							
Possible *Thrinacodus* denticle											1*							
Hybodont m'type 1 heart shaped denticles											2*				2*	2*	2*	
Hybodont m'type 2 raised button-like denticles										4*	2*					1*		
Hybodont m'type 3 thorn like										1*1	1*				1*			
Hybodont m'type 4 thorn like										1*						1*		
Chondrichthyan non-figured	1			1	4	2		2	2		108							

Figure 10.1a Occurrences of fish microvertebrates from acid insoluable residues and invertebrate fossils from thin section and hand samples from the four study areas (continues over next two pages).

Locality	Lyraun	Lyraun	Jrlingfor	Jrlingfor	Jrlingfor	Jrlingfor	Jrlingfor	Jrlingfor	Jrlingfor	Moyola	Klbride	Klbride	Klbride	Klbride	Klbride	Klbride	Klbride	
Residue number	HHLC1.2	HHLC1A	252.30	241.50	226.0	218.70	205.60	195.70	181.60	Moyola	KQ1(2)	KQ1(3)	KQ1(4)	KQ1(5)	KQ2(1)	KQ2(2)	KQ2(3)	
			252.70	241.90	226.40	219.10	205.90	196.0	182.10									
Osteichthyan: teeth **																		
Actinopterygian	3	2	52	17	113	66	6	13	12	6				27	95	128	145	
Non-identified probable Osteichthyan										12								
Sarcopterygian: Teeth **										4*18								
Osteichthyan: scales **																		
Actinopterygian scales	1* 55	8	10	3	24	2* 19	2	1* 13	6	12*279	3* 140			19	2* 50	1* 30	4* 25	
Actinopterygian smooth scales											4*							
Actinopterygian tooth plate											1*							
Possible Shoulder Girdles											9							
Lepidotrichia											20							
Acanthodian: scales**	2* 4	1* 5	3	2		1* 3	3	1* 1	2	1	3* 53				1* 7	1* 12	8	
Unknown Affinity: **																		
Possible Gill Rakers or Spines											4*							
Odd denticles 1. Handle Bar Moustache											1*							
Odd denticles 2. Possible Chondrichthyan											1*							
Odd denticles 3. Possible Chondrichthyan									1*									
Odd denticles/teeth mamalian like										2*6								
Odd dents/teeth teeth like										33								
Unidentified Bone/Scale Frags.	70	38	49	17	30	30	21	35	53	82	200		40	60	64	60	120	
[picked but not figured]																		
[* figured, picked samples]																		
[** representative values only]																		
Non-Assigned **																		
Bar Morphotype A				1		1					7* 1				2*		1*	
Bar Morphotype B											3* 1						1*	
Bar Morphotype C											1*				1		1	
Bar Morphotype D					1	1*					7* 2						2*	
Bar Morphotype E											1*				9	2	1	
Bar Morphotype F		2*	4	2		2		2			3* 13						2* 17	
Bar Morphotype G		1	1	6	5	7		1	1* 3		1* 12				2* 6	4	19	
Oddments**										5	20							

Figure 10.1b Occurrences of fish microvertebrates from acid insoluable residues and invertebrate fossils from thin section and hand samples from the four study areas (continues over next page).

Locality	Lyraun	Lyraun	Jrlingfor	Jrlingfor	Jrlingfor	Jrlingfor	Jrlingfor	Jrlingfor	Jrlingfor	Moyola	Klbride	Klbride	Klbride	Klbride	Klbride	Klbride	Klbride
Residue number	HHLC1.2	HHLC1A	252.30	241.50	226.0	218.70	205.60	195.70	181.60	Moyola	KQ1(2)	KQ1(3)	KQ1(4)	KQ1(5)	KQ2(1)	KQ2(2)	KQ2(3)
			252.70	241.90	226.40	219.10	205.90	196.0	182.10								
Totals	3* 63	6* 54	119	49	3* 177	5* 130	32	4* 67	3* 78		114* 720		40	2* 106	17* 232	9* 237	16* 336
	66	60	119	49	180	135	32	71	81		834		40	108	249	246	352
(Conodont yields)	nominal	nominal								none	2154	none	167	341	129	108	157
Sample Weights	8.4kg	4.0kg	0.5kg	0.5kg	0.5kg	0.5kg	0.5kg	0.5kg	0.5kg	4.75kg	10kg	none	7.25kg	5.5kg	4.25kg	5.0kg	6.25kg
INVERTEBRATE FAUNA																	
Bryozoa - Fenestrate Hash																	
Bryozoa - Stick																	
Bryozoa - Encrusting																	
Brachipods																	
Crinoid ossicles																	
Echinoderm spines/plates																	
Mollusc - Gastropod																	
Mollusc																	
Mollusc - Bivalve																	
Coral (Tabulate) - Vaughania																	
Coral (Tabulate)- Palaeacis																	
Ostracodes																	
Foraminifera - Pluri Forams																	
Foraminifera - Earlanditia																	
Problematica - Aoujgaliids																	
Problematica - Salebrids																	
Problematica - Calcispheres																	
Problematica - Problematica																	
Unidentified Algal material																	
Trace Fossils - Teichichnus																	
Trace Fossils - possible Planolites																	
Trace Fossils - unidentified																	
Plant Debris																	

Figure 10.1c Occurrences of fish microvertebrates from acid insoluable residues and invertebrate fossils from thin section and hand samples from the four study areas.

Both its palaeogeographical position close to the limit for the late Tournaisian sea and the presence of plant and algal material, ostracodes, serpulid worm tubes and in particular the bivalve *Modiolus*, a salt marsh resident (Clarkson, 1986) suggest that the Moyola River locality represents brackish to marginal marine conditions with the fish fauna of osteichthyan scales and teeth, occasional chondrichthyan and some sarcopterygian remains being washed into the area. It has not been possible to ascertain whether the resulting microvertebrate remains were totally disarticulated prior to their arrival or whether the entire animal may have been washed into, and isolated within the environment prior to death as bedding plane exposure of some of the larger remains shows only disarticulate material including part of a dentary.

10.4. ASSEMBLAGES

10.4.1 INTRODUCTION

The word "assemblage" has several interpretations: according to Fürsich (1992) .."*assemblages consist of organisms derived from more than one community (i.e. they exhibit signs of mixing)*...; another interpretation of broader scope is ..."*the term refers to any group of organisms from a geographical locality*"... Here the term is used to describe a group of fossils both vertebrate and invertebrate, which occur together within a specific sedimentological regime.

10.4.2 ASSEMBLAGES FROM STUDY AREAS (INVERTEBRATE AND VERTEBRATE)

As discussed above, the palaeoenvironments covered by this study range from sabkha/tidal flat through mixed carbonate/siliciclastic inner shelf, and middle or outer carbonate shelf. Time constraints have restricted investigation into more than one example of each environment, so the results are necessarily preliminary.

Occurrences of chondrichthyan denticles/ scales, osteichthyan and acanthodian remains are common to all four study areas. The chondrichthyan *Thrinacodus incurvus* and pavement dentitions, bars (straight) and the invertebrate fauna of bryozoa, brachiopods and echinoderms (especially crinoids) occur in all the environments with the exception of the sabkha/tidal flat. Sarcopterygian vertebrate remains, the bivalve *Modiolus* and plant

material were found only in the Sabkha/tidal Flat. Full environmental occurrences are detailed below and in Figure 10.2.

10.4.2.1 MIDDLE OR OUTER CARBONATE SHELF (Ramp) URLINGFORD (i)

Chondrichthyans are less varied in this facies than in the shallower carbonate shelf environment at the Kilbride Quarries (see below) sequences as argued above. The chondrichthyan denticles/scales, pavement dentition (Morphotype 4 only), the probable phoebodont *Thrinacodus incurvus* ferox morphotype, *Lissodus* (Morphotype 1 only), and *Protacrodus* occur, together with the osteichthyan and acanthodian remains (and bars - straight and complex). The invertebrate fauna appears more restricted (bryozoa, brachiopods and echinoderms-crinoids) but this is most likely a function of the lack of information rather than an actual fact. It is worth noting that the hybodont *Lissodus* morphotypes and *Protacrodus* (together with the complex "bars") are confined to environments(i) and (ii).

10.4.2.2 CARBONATE SHELF (Ramp) KILBRIDE QUARRIES (ii)

As well as the ubiquitous chondrichthyan scales/denticles and pavement dentition (Morphotype 3 only), osteichthyan and acanthodian remains (and "bars" - straight and complex), chondrichthyan hybodont scales, the probable phoebodont (?) *Thrinacodus incurvus* ferox morphotype and *Thrinacodus incurvus* nanus morphotype, the hybodont *Lissodus* Morphotypes, the symmoriid cf. *Denaea*, the *Protacrodus* and the tricuspid tooth were found in this facies. The invertebrate fauna is more diverse than in the shallow open marine shelf with the addition of gastropods and foraminifera. Exclusive to this facies are the probably phoebodont *Thrinacodus incurvus* nanus morphotype, cf. *Denaea* and the tricuspid tooth together with gastropods and foraminifera.

10.4.2.3 MIXED CARBONATE/SILICICLASTIC INNER SHELF LYRAUN COVE, HOOK HEAD. (iii)

Vertebrates from this environment are chondrichthyan scales/denticles, pavement dentition and teeth of the probable phoebodont *Thrinacodus incurvus* ferox morphotype, osteichthyan and acanthodian remains (and "bars"). The invertebrate fauna comprises bryozoa, brachiopods, echinoderms (crinoids and echinoid spines), molluscs, tabulate corals, ostracodes, trace fossils, serpulid worm tubes and micro-problematica. Of these the tabulate corals and the trace fossils appear to be restricted to this environment.

10.4.2.4 SABHKA/TIDAL FLAT MOYOLA RIVER (iv)

This restricted environment has yielded chondrichthyan denticles/scales and hybodont scales, osteichthyan and acanthodian remains which are common to the other environments but in, addition, contains a sarcopterygian - rhizodont dentary and unidentified sarcopterygian teeth. Bivalves (*Modiolus*), algal and plant material are confined to this environment, whilst ostracodes also occur in the mixed carbonate/siliciclastic inner shelf and the carbonate shelf (ramp).

10.4.3 ASSEMBLAGES - CONCLUSIONS

It appears that the diversity and abundance of chondrichthyans increases from deeper (i) to shallower waters (ii) of the carbonate shelf, although this may be an artifact of sample size. The greatest diversity appears to occur in the shallower part of the carbonate shelf. Diversity decreases again in the mixed carbonate/siliciclastic shelf (iii) falling to very low levels in the sabhka/tidal flat environment.

The abundance of osteichthyan scales is lower in the deeper water environment (i) and increases dramatically into the carbonate shelf (ii) decreasing again towards mixed carbonate siliciclastic inner shelf (iii) but the density is still higher than the deeper water environment (i). Interestingly the abundance of osteichthyan teeth is very low in the sabkha/tidal flat environment (iv) compared to all the other environments but the scales are numerous. Acanthodian scales (no identifiable teeth were recovered) show a similar pattern, peaking within the carbonate shelf (ramp) with only a single representative recovered from the sabhka/tidal flat samples. Diversity of the osteichthyan and acanthodian fauna has not been considered during this study but is an area worthy of further study.

(Straight "bars" are also most numerous in environment (ii) with the complex Bars only occurring in environments (ii) and (iii) - none were recovered from environment (iv).)

In summary it appears that

1. a medium to high abundance and medium diversity fish microvertebrate assemblage of **chondrichthyan (denticles)-chondrichthyan (pavement dentition)-hybodont (teeth and scales)-phoebodont(?)-protacrodont-osteichthyan-acanthodian (and bars)** occurs in the deeper carbonate shelf (ramp) environment.

2. a high abundance and diversity fish microvertebrate assemblage of **chondrichthyan (denticles)-chondrichthyan (pavement dentition)-hybodont (teeth and scales)-phoebodont(?)-symmoriid-protacrodonts-osteichthyan-acanthodian (and bars)** occurs in the shallower part of the carbonate shelf (ramp) environment.

3. a low abundance and diversity fish microvertebrate assemblage of **chondrichthyan (denticles)-chondrichthyan (pavement dentition)-phoebodont(?)-osteichthyan-acanthodian (and bars)** occurs in the mixed siliciclastic/carbonate inner shelf environment.

4. a medium abundance and low diversity fish microvertebrate mixed assemblage of **chondrichthyan (denticles)-osteichthyan-acanthodian-sarcopterygian** occurs in a sabhka/tidal flat environment.

Further study of different locations within each environment should give a truer overall picture of assemblages from the Irish Lower Carboniferous. However, occurrences of the fish microvertebrates and their associated invertebrate fauna that have so far been studied may give an indication of the sort of assemblages likely to found within the environments.

In general, assemblages of fish microvertebrates from the Late Devonian and Early Carboniferous (based on findings outside this study) seem to be biased towards chondrichthyan remains with assemblages of ..."*phoebodont, symmoriid, stethacanthid and protacrodontid sharks, and scales of possible ctenacanthid sharks*"...(Derycke *et al.*, 1995a) being found at La Serre, France at the Devonian/Carboniferous boundary stratotype. Derycke remarked that her assemblage compares well with similarly dated assemblages from ..."*Europe [northern France and southern Belgium (Crasquin, 1984), Germany (Gross, 1973; Mader & Schultze, 1987), Russia and Poland (Ginter, 1990, Ginter & Ivanov, 1996), and has elements in common with roughly contemporaneous sites in Morocco (Derycke, 1992), southeast Asia (Long, 1990; Wang & Turner, 1985), and the USA (Kietzke & Lucas, 1992). ..*"

Acanthodian scales also occur in many of these areas, with remains of bony fish very rare (Derycke *et al*, 1995a). However, bony fish remains in the form of actinopterygian scales and teeth are found in all the environments examined for this study.

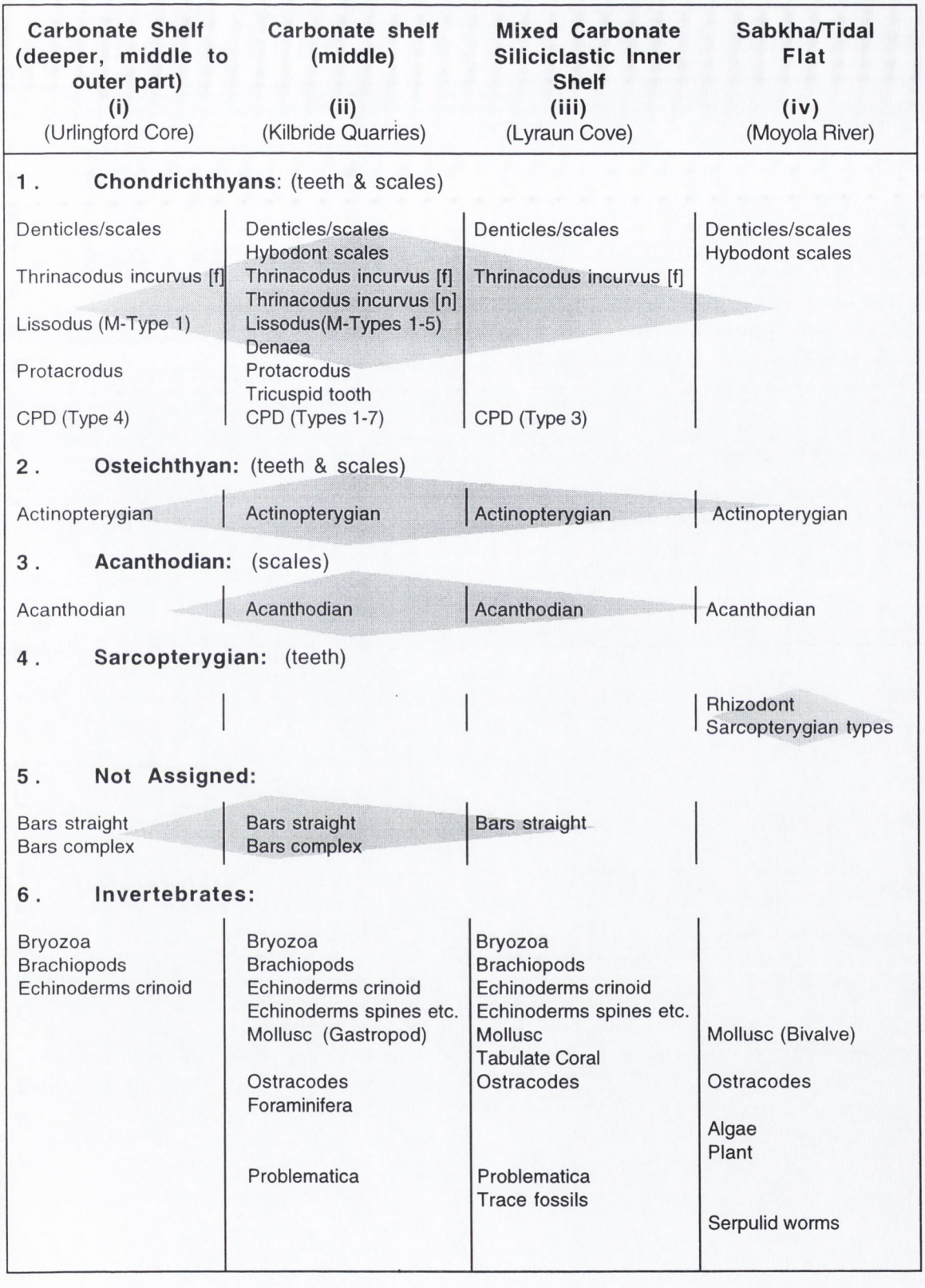


Figure 10.2. Assemblages of vertebrate and invertebrate remains from the four study areas shown in terms of inferred palaeoenvironment. The shaded diamonds show the relative abundance of the teeth, scales and invertebrates from environment to environment.

CHAPTER 11. BIOSTRATIGRAPHY and INTERNATIONAL CORRELATION

11.1 BIOSTRATIGRAPHY - BACKGROUND

Early in the nineteenth century Smith (Holland, 1990) realized that lithostratigraphic characters alone were not the only means of correlation of stratigraphic successions but that fossils contained within specific strata could be used as a means of correlation. Thus biostratigraphy - the use of fossils as stratigraphic correlators - came into being. Albert Oppel (Hancock, 1977) refined this idea in the mid nineteenth century by introducing the concept of biozonation. Stratigraphic divisions could be based on the assemblage of fossils contained within them. One fossil should be chosen as an index (or zone) fossil. It should be a characteristic form for the strata as well as being abundant.

11.1.2 USE OF INDEX OR ZONE FOSSILS

Index or zone fossils should where possible be defined at the level of species rather than genera or higher. Their characteristics should include a high preservation potential; independence of facies; a short vertical range (rapid evolution); and a wide horizontal distribution. Many fossil groups, for example miospores, graptolites, foraminifera, ammonoids, corals and conodonts meet some or all of these criteria and are commonly used in biostratigraphy (Bassett, 1990). The most frequently used zonations of the Lower Carboniferous (Dinantian) within the British Isles and Ireland are those based upon conodonts, foraminifera, miospores, ammonoids, brachiopods and corals. Throughout this study, the conodont biozones appropriate to the mid-inner shelf environments (Riley, 1993) have been used to relate the various strata which have yielded fish microvertebrates, with the exception of the Altagoan Formation of Northern Ireland where, in the absence of conodonts, the miospore zonation has been used (see Chapter 6).

British/Irish/Belgian and Eastern European conodont zonations are shown in Figure 11.1. Chronostratgraphic units for the Dinantian and an explanation of the chronostratigraphy used within this thesis are outlined and illustrated in Chapter One.

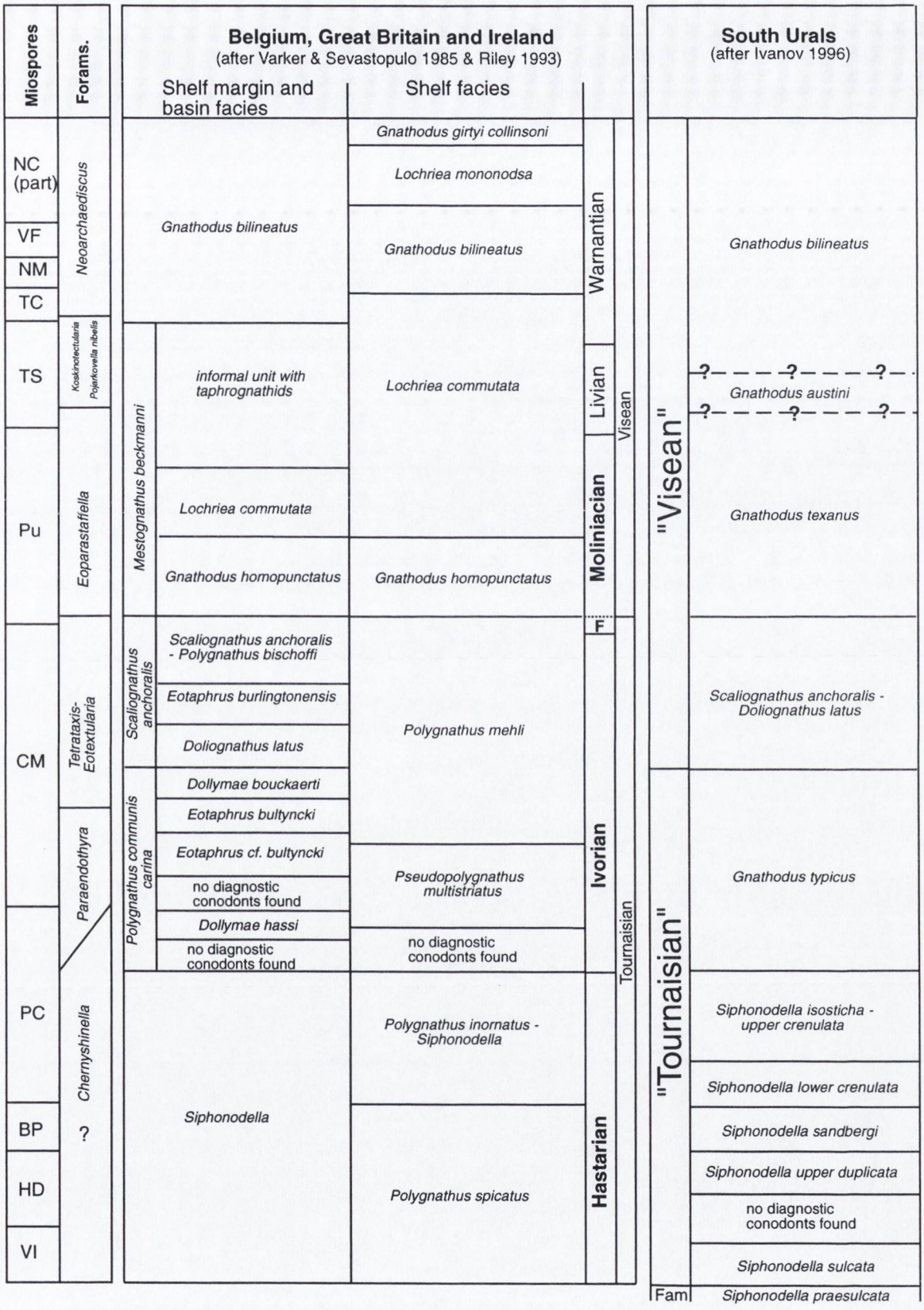


Figure 11.1. Conodont, foraminiferal and miospore biozonations of Belgium, Great Britain and Ireland and the South Urals, Russia. (For chronostratigraphic divisions see also Figure 1.1)

11.2 IRISH LOWER CARBONIFEROUS MICROVERTEBRATES

11.2.1 BIOSTRATIGRAPHY OF FISH MICROVERTEBRATES IN IRELAND

The faunas studied have been confined to the Tournaisian and represent four stratigraphical levels. Because the richness and diversity of the faunas from the four horizons differ, it is difficult to be confident about the stratigraphical ranges of the taxa identified. However, at the level of taxonomy employed, the fish microvertebrates appear to have limited biostratigraphical value. For example, the one tooth type identified to the level of species *Thrinacodus ferox*, occurs both in the oldest horizon studies at Hook Head (Hastarian; *Polygnathus inornatus* conodont Biozone) and at one of the younger horizons (Kilbride Quarry; Ivorian, probably Freyrian; *Polygnathus mehli* conodont Biozone). The extension of its range in Ireland both stratigraphically upward and downward needs to be delimited by sampling of the earliest Carboniferous and of the Viséan and Namurian, but information about its range elsewhere (see below; Section 11.2.2) suggests that it is even more long ranging than shown in this study.

The *Lissodus* morphotypes occur in the "pre-Freyrian" Ivorian (Urlingford core) and are relatively abundant in the "Freyrian" part of the Ivorian (Kilbride Quarries). Their abundance from the Hastarian-aged fauna from Hook Head may reflect the relatively low diversity and lack of abundance of microvertebrates there. The first occurrence of *Lissodus* needs to be established by additional sampling of the Ballysteen Limestone Formation (*Pseudopolygnathus multistriatus* conodont Biozone). It is not known from this study if they extend stratigraphically higher in Ireland. However, information from elsewhere (see below; Section 11.2.2) suggest that they may do.

Specimens identified as cf. *Denaea* were recovered only from the probable Freyrian horizon (Kilbride Quarries). More extensive sampling of the "pre-Freyrian" Ivorian and Hastarian may established a lower limit for this taxon which has not so far been found in order rocks elsewhere in the world.

Protacrodus morphotypes 1 and 2 are also restricted to the Kilbride fauna (probably Freyrian) but they occur in such low numbers that their absence in the less rich faunas from the earlier horizons may reflect collection failure. *Protacrodus* morphotype 3 does occur in the pre-Freyrian Ivorian at Urlingford. Evidence from elsewhere (see below; Section 11.2.2) suggests that the range of *Protacrodus* extends into the Devonian.

The probable sarcopterygian teeth and dentary fragment from the Moyola River were recovered from the youngest horizon (Pu Biozone), but the fauna is the only one representing a non-marine to marginal marine environment. It seems likely that the occurrence of the probable sarcopterygian material is a reflection of the facies in which it

was found. Investigation of similar facies of different ages are required before the ranges of these fishes can be established.

The Chondrichthyan Pavement Dentition type teeth due to their identification only to the Class Chondrichthyes must also be discounted in terms of biostratigraphy. As this study concentrated on teeth rather than scales and denticles, denticles from this Class were only tentatively classified to lower taxonomic levels.

Many osteichthyan teeth and scales and fewer acanthodian scales were recovered from all four study areas but these have not yet been classified below the level of class and therefore their biostratigraphic significance is not known.

11.2.2. INTERNATIONAL CORRELATION

From the information available in the literature and through personal communications with other workers on Carboniferous fish microvertebrates, it appears that although some fish microvertebrates similar to those found in Ireland do occur in similar facies of the Lower Carboniferous in other areas including Western and Eastern Europe, South-east Asia, North Africa, New Mexico (Derycke *et al.* 1995) and Brazil (Duffin *et al.* 1996); the initial findings from this study suggest that the Irish Lower Carboniferous may not be immediately correlated with these areas. This is however, based on only four study areas and further sampling of some of these and wider investigation of others may lead to a more substantiated conclusion. (See Chapter 7 - Systematic Palaeontology and Chapter 10 - Facies, Palaeoenvironment and Assemblages).

Possibly the best known late Devonian/early Carboniferous chondrichthyan microvertebrate is *Thrinacodus* (classified here in Chapter 7 as a phoebodont), not least because of its particular morphology, similar to a three-pronged fish hook, and its dissimilarity (in shape) to many other fish microvertebrates. According to the current literature (see Chapter 7) the asymmetric form described elsewhere as *Thrinacodus ferox* (*Thrinacodus incurvus* ferox morphotype of this thesis) is known to range from the Late Devonian (Famennian) (Derycke *et al.* 1995a; Ginter and Ivanov, 1996) of France, Poland and Australia to the Namurian (Serpukhovian) of the Moscow Region (Ginter and Ivanov, 1996). The rarer symmetric *Thrinacodus nanus* (*Thrinacodus incurvus* nanus morphotype of this thesis) having as yet an non-established root probably in the late Devonian but certainly occurs in the Tournaisian of Poland (Ginter pers. comm. 1999).

The most numerically abundant type of teeth recovered are those identified as *Lissodus* morphotypes. *Lissodus* type teeth have been recorded from other countries: in particular from Britain (Duffin, 1985), where *Lissodus wirksworthensis* is recorded from

the P_1 sub-zone (Brigantian) of the Upper Viséan. Some of the Irish specimens of *Lissodus* (Chapter 7.3) are similar to *Lissodus wirkworthensis* and their occurrence in the *P. mehli* conodont Biozone extends the range of the genus into the Tournaisian as does the description of another species *Lissodus pectinatus* which has been recorded from the central region of Russia (Lebedev, 1996) from a borehole which spans most of the Russian Tournaisian (except the uppermost part). *Lissodus pectinatus* is similar to some of the *Lissodus* morphotypes recovered from the Irish Tournaisian.

The symmoriid cf. *Denaea* teeth described in this work are very similar to specimens from Poland of a similar or slightly younger Lower Carboniferous age (Ginter, pers. comm. 1997) and from Belgium. They are also similar to those described from the Late Carboniferous (Westphalian/Stephanian) of Brazil (Duffin *et al.* 1996).

At least one of the protacrodonts, *Protacrodus* Morphotype 1 (Chapter 7.5), from the *P. mehli* conodont Biozone appears similar to *Protacrodus vetustus* Jaekel, known from the Middle to Late Devonian in Germany. It is even closer morphologically to *Protacrodus* sp. Cf. *P. vetustus* of Derycke *et. al.* (1995a) which was recorded from the Devonian/Carboniferous boundary in southern France. Other protacrodonts have been recovered from the Upper Devonian of North America, Europe, North Africa (Morocco), Iran, India, eastern Turkey and Australia (Turner, 1982). Ivanov (1996, figure 3 page 420) showed a range for *Protacrodus cf. vetustus* from the late Devonian to the Lower Viséan (Figure 10.1 this thesis) although the basis for this range is not explained. Representatives of the Protacrodontoidea have been recovered from the Upper Carboniferous of North America (Zangerl, 1981).

The probable Sarcopterygian rhizodont fish remains from the sabhka/tidal flat facies are known from upper Devonian and Carboniferous rocks world-wide and their presence within the fauna of the Irish Dinantian (Pu Biozone) is slightly later than a similar (small) rhizodont found in Scotland (Andrews, 1985) in the Foulden Beds of CM miospore Biozone age.

11.2.3 INTERNATIONAL GEOLOGICAL CORRELATION PROGRAMMES - IGCP 328 AND IGCP 406

In 1967 at a conference in Czechoslovakia (now the Czech Republic) the idea of the IGCP was conceived. This was to be a consortium of the International Union of Geological Sciences (IUGS) and the United Nations Educational, Scientific and Cultural Organization (UNESCO). The first Board sat in 1973. The main aims of the IGCP are to encourage international research on geological problems related to the identification and assessment of natural resources and the improvement of man's environment. Less

than twenty percent of the projects involve palaeontology though many projects encompass biostratigraphy and stratigraphy and thus have a palaeontological input. In February 1991, IGCP 328 came into being as "Palaeozoic Microvertebrate Biochronology and Global Marine-Non-Marine Correlation" under the co-leadership of Dr. Alain Blieck (Lille) and Dr. Susan Turner (Brisbane). It was to run for five years with a final meeting to be held in Paris. This meeting took place in 1995 where the great success of the project was announced by the Secretary-General of IGCP. Although this thesis project on Irish Carboniferous fish microvertebrates was commenced towards the end of IGCP 328, initial international communications were established as a result of involvement with the project and attendance at the final meeting, which have proved to be an invaluable source of reference and assistance.

A one year extension of IGCP 328 saw it overlap with the start up of IGCP 406 "Circum-Arctic Lower-Middle Palaeozoic Vertebrate Palaeontology and Biostratigraphy" which became the initial follow-on project with Dr. Mark Wilson (Edmonton) and Dr. Tiiu Marss (Tallinn) as co-leaders (joined in 1997 by Dr. Peep Mannik (Tallinn).

IGCP 406 is focused on the upper Lower and Middle Palaeozoic and explicitly includes both macrovertebrate and microvertebrates together with their associated fauna (rather than concentrating on micro-vertebrates) in the far north. Although essentially circum-arctic (northernmost parts of Laurentian, Baltican, Barentsian and Siberian palaeocontinents) (Wilson, 1996) and Lower to Middle Palaeozoic in emphasis, this project has welcomed the few Carboniferous microvertebrate workers affiliated to IGCP 328 to their ranks allowing continuity of collaboration amongst all the Palaeozoic microvertebrate workers. Thus this thesis project has affiliations with both IGCP 328 and 406.

11.3 GENERAL BIOSTRATIGRAPHIC CONCLUSIONS

With the current state of knowledge, it appears that the assemblages of fish microvertebrates recovered for this project do not provide good biostratigraphic tools. However, the incoming of cf. *Denaea* and of the *Lissodus* morphotypes might prove valuable in the absence of other biostratigraphic indicators when further research is carried out on the Lower Carboniferous of Ireland.

The Tournaisian ages of the fish microvertebrate taxa described in this study do not lead to any major changes in their stratigraphical ranges established elsewhere except that the first occurrences of some, such as *Lissodus*, are stratigraphically slightly older than previously recorded. It appears that while many of the fish microvertebrates identified from Irish Carboniferous rocks are geographically wide-spread, most of the genera or

species where they can be identified are long ranging. Ranges of such genera as *Lissodus* (L. Carboniferous - Cretaceous) seem to be exceptionally long. This may be a consequence of a taxonomy based largely on the morphology of individual teeth, which may be evolutionary very conservative, rather than on the anatomy of whole organism.

CHAPTER 12: FISH MACROVERTEBRATES AND MICROVERTEBRATES FROM THE IRISH CARBONIFEROUS NOT INCLUDED WITHIN THE DESIGNATED STUDY AREAS

12.1 INTRODUCTION

At the outset of this study one of the aims had been to examine in detail some of the large collection of Carboniferous fish material (macroscopic) from the well known "Armagh collections", together with what was thought to be a semi-articulated fish from the late Viséan of Ballybunion, Co. Kerry, and also to examine Carboniferous conodont residues stored in the Department of Geology of Trinity College to ascertain whether they contained fish microvertebrates. However, in view of the large volume of material (microscopic) available from the study areas outlined previously, it was decided that only a brief examination of this material could be undertaken.

12.2 MACROVERTEBRATES

12.2.1 ARMAGH MATERIAL

The paucity of published research on palaeoichthyology pertaining to Ireland and in particular to the Irish Carboniferous has been outlined in Chapter 1.5, with the exception of a monograph by Davis (1883) entitled "*On the fossil fishes of the Carboniferous Limestones of Great Britain*" in which a number of specimens from the Armagh area from the Egerton Collection (see Chapter 1) were illustrated. Fish material from the Armagh quarries has found its way into many collections around the world. It was collected and sold by the quarrymen working on the excavation of stone for general building stones, the building of the local railway and associated bridges.

Armagh, Co. Armagh is situated in the southern part of Northern Ireland (Figure 12.1). Armagh itself features in Irish Legends, particularly connected with Navan Fort situated west of the city. Although the labels on the specimens held in the Department of Geology, Trinity College Dublin (see Appendix III) are very difficult to read; some of them show the name "Navan" and it is assumed that the specimens originated close to this Fort, which is now an "Interpretative Centre". The original quarries are difficult to identify. Other labels show what appears to the be word "quarry" and a number, "index" with a number or "hut" with a number, these may be the fossil sites marked on the recently published Sheet 47 (Geological Survey of Northern Ireland, 1985) to the north east of the present city. By far the most common name on the original labels is "Red Barn" which is situated on the southern edge of the modern city of Armagh in a townland of that name.

Other labels give the name "Loughgall"; this is a town north east of Armagh city, just north of the lough of Loughgall; old six-inch-to-one-mile field sheets show limestone quarries surrounding this lough.

The fish material is from rocks of the Armagh Group (Figure 12.1) which ranges in age from early Viséan to Brigantian (Geological Survey of Northern Ireland, 1985). At the base a transgressive sequence of sandstone and sandy limestones is ended by a regressive phase which appears to have led to the local erosion of the Lower Viséan (i.e. the late Chadian of Riley, 1993) rocks. Deposition recommenced in the Arundian with formation of limestone. The Drumman More Sandstone Formation represents a deltaic environment. The younger Dinantian strata are rocks that originated on a clastic free carbonate platform developed near the south-eastern margin of the basin; it is probable that the specimens from Armagh are from this part of the Group above the Drumman More Sandstone. The rock matrix hosting the fish teeth consists of light grey to bluish/buff to yellow, to pinky-purple crinoidal limestone also containing other skeletal fragments (for example: brachiopods, corals, bryozoans) of a shallow water shelf facies. The Carboniferous rocks are overlain unconformably by either Permian or Triassic rocks.

The macrovertebrate fish material identified and recorded during the active quarrying period (using nomenclature current in the nineteenth century) include: at 'cladodont' level - *Cladodus mirabilis*, *Cladodus striatus*; *Cochliodus contortus*, *Ctenacanthus tenuistriatus* (defense spine), *Ctenopetalus serratus*, *Deltoptychius acutus*, *Helodus didymus* (or *gibberulus*), *H. laevissimus*, *Petalodus laevissimus*, *Paecilodus Jonesii* (sic), *Psammodus porosus*, *Psammodus rugosus*, *Psephodus magnus*, *Streblodus Colei* (sic), *Streblodus oblongus*.

A catalogue of material housed in the Museum of the Geological Department of Trinity College and other Irish Institutions is given in Appendix III. Much of the material housed in the Geology Department of Trinity College was cleaned, boxed and catalogued as part of this project though no attempt was made to identify more than a small percentage of the specimens; it will remain in this state pending future research. It is known that the Ulster Museum holds at least forty drawers of material from the area, in particular the Charles Buller Collection from the early twentieth century together with recent collections by staff members. Some material is housed in University Colleges Cork and Galway. The Geological Survey of Ireland also houses a large number of specimens. The British Geological Survey at Keyworth houses the Admiral Jones Collection. The Enniskillen Collection is in the British Museum. The National Museum of Scotland at Edinburgh also holds some material.

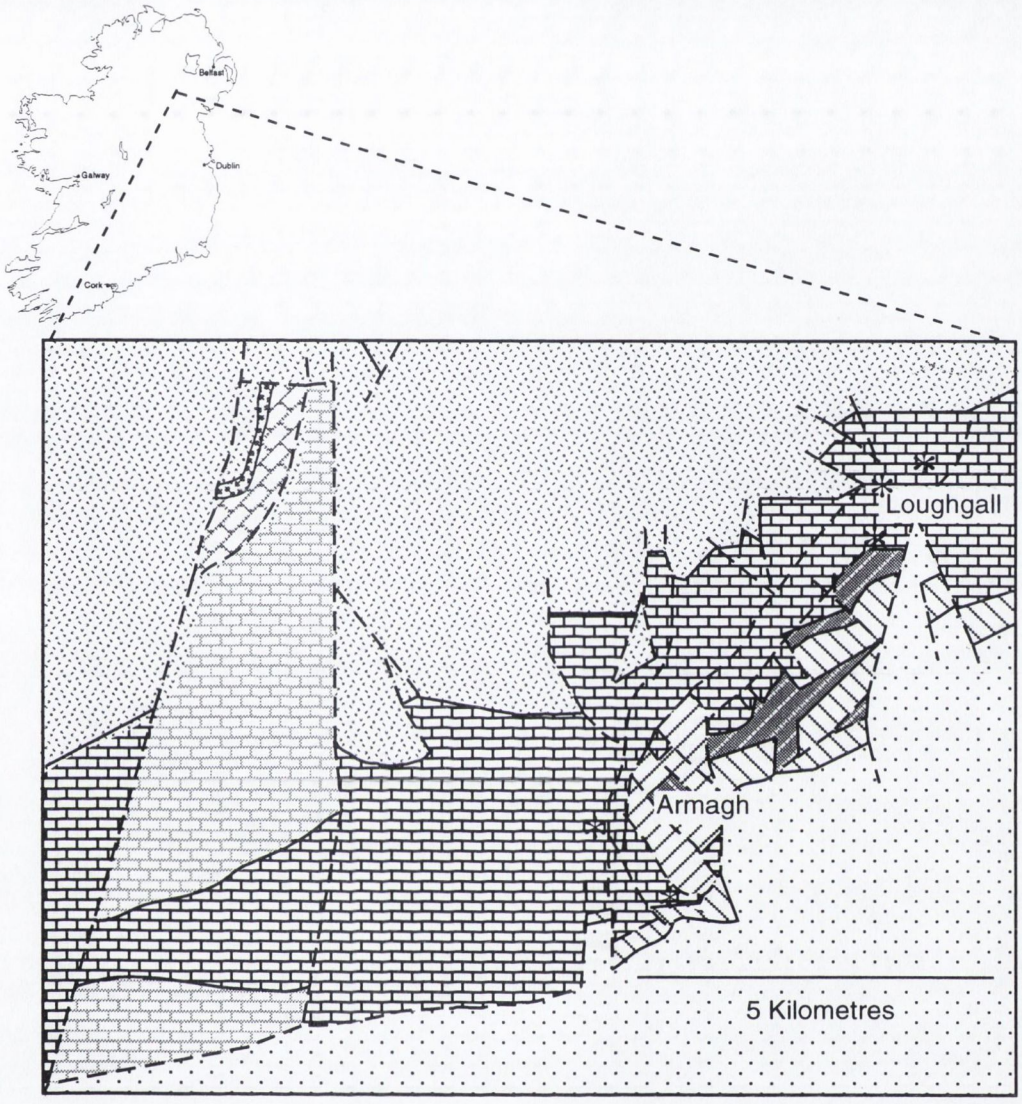


Figure 12.1. A. Geology of the Armagh City area. B. Vertical Section of Armagh Group. (after Geological map of Northern Ireland 1:250,000 (Geological Survey of Northern Ireland, 1997) and Sheet 47 (Geological Survey of Northern Ireland,1985))

12.2.2 BALLYBUNION

A specimen originally thought to be a articulated fish was collected by Dr. G.D. Sevastopulo from a quarry south of Doon Point, near Ballybunion, Co. Kerry (Figure 12.2). Initially two teeth were partially exposed on the upper surface of the a small slab (Specimen number: TCD 31087).

Ballybunion is situated east-north-east of Kerry Head. During the Carboniferous the locality was in the axial region of the Shannon Basin. The quarry south of Doon Point, is within the upper part of the Corgrig Lodge Formation (previously the Inistubbrid Formation) which is stratigraphically immediately below the Clare Shale Formation. Within the quarry the rocks are predominantly calcareous mudstone, shale and micrite, commonly with chert and some rare skeletal packstone beds interpreted as calciturbidites. Goniatites (which indicate a Brigantian age) together with thin shelled bivalves are the dominant fauna (Sevastopulo, 1998). The succession represents a basinal facies; it is overlain by deep water black shales of late Brigantian and Namurian age.

As the specimen was originally in four pieces, these were glued together prior to further preparation. In order that the fish material could be examined, the slab was prepared as follows: the matrix was tested for its calcium carbonate/dolomite/mud content in order to establish the best method of removing enough matrix to expose the teeth. The matrix was found to be a laminated calcareous mudstone so the rock containing the specimen was initially suspended in buffered 80% Acetic acid as outlined in Chapter 2.2.2.

Following initial acid digestion and preparation of the surface exposing the teeth with a mounted needle, it soon became apparent that considerably more than two teeth were in the matrix and that they were not confined to a single lamina. In order to avoid excessive acid etching of the teeth as they became exposed during the preparation, areas that had been prepared were painted with a polyvinyl butyral, acetone soluble glue which served to harden the surface. The slab was then re-immersed in acid for a short period and the softened matrix removed with a needle. After newly exposed areas had been coated with the acetone soluble glue, the process of acid maceration and preparation with a mounted needle was repeated.

The preparation revealed thirteen partially exposed (not all intact) teeth on the 'upper' surface of the rock and at least seven more partly exposed on the lower surface and between lamina. Once it became apparent that the rock was starting to split between laminae and before valuable material was lost (macroscopic tooth fragments and what appear to be denticles on the surface probably associated with the teeth) preparation

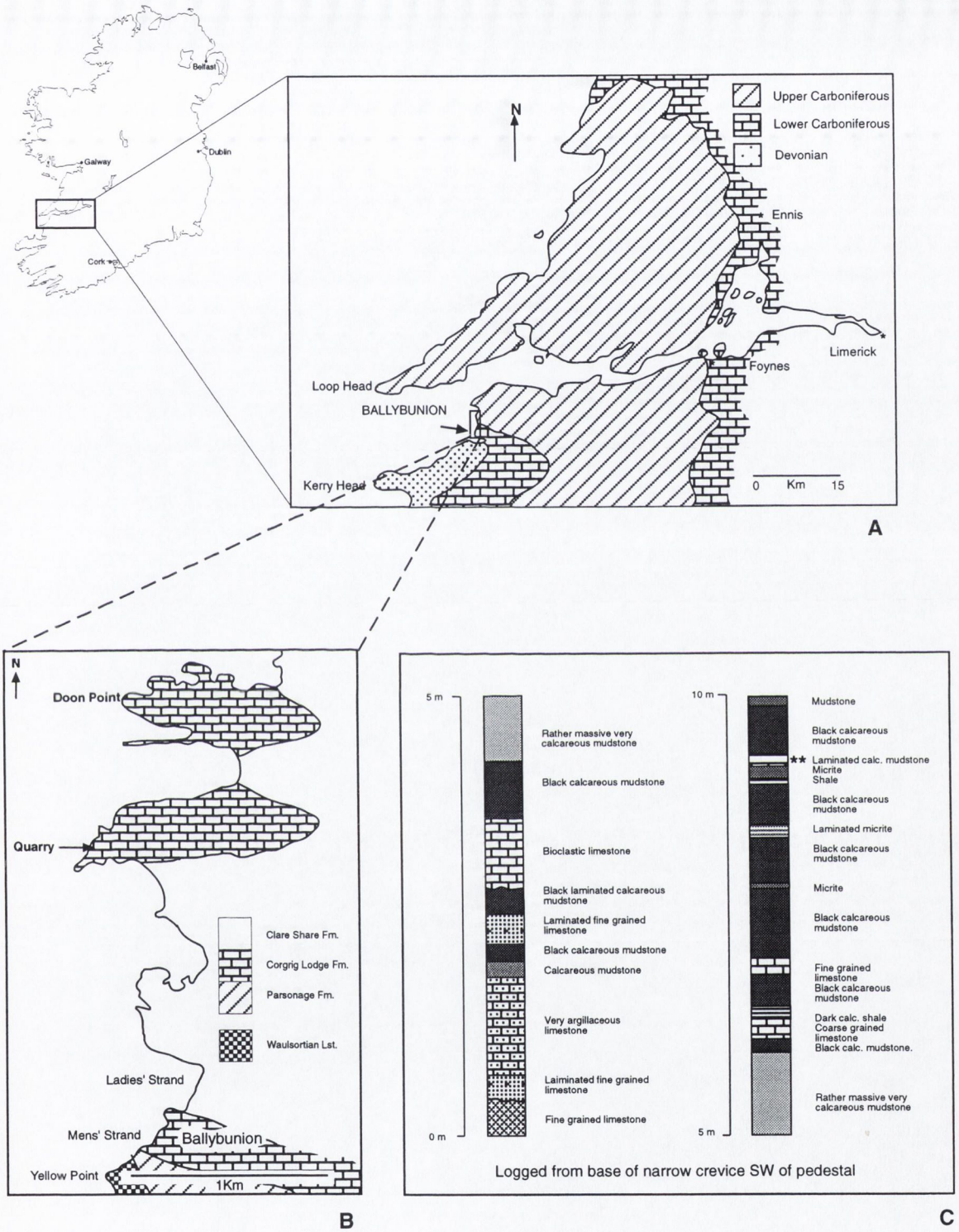


Figure 12.2. A. Outline of geology of the Shannon Region. B. Outline of the geology around the coast of Ballybunion. C. Logged section in Corgrig Lodge Formation (quarry) with bed from which petalodont fish teeth recovered marked **. (after Sevastopulo, 1998)

Figure 12.3. Photograph of collection of petalodont teeth from Ballybunion, Co. Kerry (TCD 31087).

was suspended. This specimen will require more preparation and conservation by an experienced preparator to be fully exposed.

The teeth appear to be a collection of petalodontid teeth. Petalodontids are a small group of chondrichthyans known from the Carboniferous and Permian which exhibit petal-shaped teeth and which until recently were known only from isolated teeth and poorly preserved specimens of a single genus, *Janassa* (Janvier, 1996). However, work by Lund (1989) on the Upper Mississippian Bear Gulch Limestone of Montana has revealed petalodonts based on whole individuals and dentitions. However Lund (1989) stated that it is still not feasible to relate ..*"petalodont tooth taxonomy to taxonomy based on whole animal or whole dentitions until more whole dentitions or individuals are found"*... Hence the teeth relating to the dentition described herein is tentatively assigned to:

Class CHONDRICHTHYES, HUXLEY, 1880; Order PETALODONTIDA, ZANGERL, 1981; Family PETALODONTIDAE, NEWBERRY & WORTHEN, 1866.

Although as indicated above, the teeth have not been completely uncovered, they can be seen to be labio-lingually compressed, and transversely elongate. They are drawn out into a rounded point (median crest may undulate) or are arcuate along the median crest. The transverse length of the exposed teeth ranges from just greater than 10mm (overall smaller teeth) to slightly in excess of 40mm (accurate measurement is not feasible due to post-mortem compaction). The median crest forms a relatively subdued cutting edge positively crimped below along its length. The crown above the crown-base interface is imbricated with the number of imbrications varying from five to ten which may be size dependent. Raised ridges radiate from the crown-base interface, being very subdued across the imbrications becoming more prominent towards the top of the crown; the base in all instances appears short (and transversely shorter than the crown), varying from less than one-quarter of the length of the crown vertically to one-third the vertical length of the crown. The base is crenulated (where exposed). The overall vertical height of both base and crown ranges from less than 10mm (overall smaller teeth) to c. 30mm in the larger teeth. Nearly all of the teeth overlap each other and appear concave; this is not known whether these teeth exhibited transverse curvature in life or whether it is a result of being separated by thin calcareous mudstone laminae.

12.3 MICROVERTEBRATES

Although a number of acid insoluble residues from which conodonts have already been extracted are stored in the Department of Geology, Trinity College, the time constraints of working with samples from the areas designated for this thesis did not allow them to be examined. There is therefore, an opportunity for further study of these Dinantian and

Namurian residues which in many instances are accurately dated by the conodont faunas they contain.

CHAPTER 13: SUMMARY OF CONCLUSIONS AND FURTHER WORK

13.1 CONCLUSIONS

- Many limestones from the Dinantian of Ireland (Lower Carboniferous) contain fish microvertebrates.

- Fish microvertebrate faunas from the Tournaisian of Hook Head, Co. Wexford (Hastarian); Urlingford (borehole), Co. Kilkenny (pre-Freyrian, Ivorian); Kilbride Quarries, Co. Meath (probably Freyrian, Ivorian) and Moyola River, Draperstown, Co. Londonderry (?Ivorian, ?Freyrian) include representatives of chondrichthyans, osteichthyans and acanthodians; with only Moyola River, Draperstown, Co. Londonderry yielding any sarcopterygians.

- The taxonomy of the discrete microvertebrate elements (teeth, scales, etc.) is complicated by the lack of articulated specimens of fish. As a result, most teeth can only be identified to the level of genus or family.

- Fish microvertebrates identified to this taxonomic level appear to be both stratigraphically long-ranging and relatively eurytopic. The exception to the last statement is the probable sarcopterygian teeth and dentary fragment which were found only in rocks interpreted as being of sabhka-carbonate tidal flat origin.

- Fish microvertebrate faunas found in Lower Carboniferous rocks in Ireland appear only superficially similar to those found elsewhere in the world. Whilst some elements may occur in many areas worldwide others do not and appear restricted to the more localized settings described herein.

- Enigmatic phosphatic bar-like elements, assigned by some authors to fish or conodonts are more likely to represent parts of the integument of conulariids.

13.2 FUTURE WORK

- Expand the stratigraphical and palaeoenvironmental range of samples to be studied for their fish microvertebrate fauna.

- Extend the scope of the study to include histological examination of the fish microvertebrates isolated.

- Extend the study to expand the morphology of the osteichthyan fish microvertebrates recovered during this study and undertake histological work.

- Prospect for articulated fish to underpin a more securely based taxonomy.

- Collect further samples from the Kilbride Quarries, Co. Meath to extend the scope of the study of this fauna.

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APPENDIX I

Log of specimens used for Plates from the four study areas, incorporating the local specimen number which relates to field logs and bulk collection samples; identification; TCD catalogue number; the length of the scale bar of each separate SEM photograph; and the Plate and Figure number.

I.1 HOOK HEAD SAMPLES

No	Specimen No	Identification	TCD No	Scale µm	Plate & Figure
1	HHLCI.21.A.3a	Actinopterygian scale	36872	1000	50A
2	HHLCI.21.A.3b	-ditto-	"	1000	50B
3	HHLCI.21.A.3c	-ditto-	"	100	50C
4	HHLCI.21.C.7a	Acanthodian scale	36854	200	65C
5	HHLCI.21.C.36a	Acanthodian scale	36855	200	65D
6	HHLCIA.I.I.20a	Acanthodian scale	36853	200	65A
7	HHLCIA.I.I.20b	-ditto-	"	200	65B
8	HHLCIA.I.2.11a	*Thrinacodus incurvus* ferox M'type	36803	200	8A
9	HHLCIA.I.2.11b	-ditto-	"	200	8B
10	HHLCIA.I.2.11c	-ditto-	"	200	8C
11	HHLCIA.I.2.11d	-ditto-	"	100	8D
12	HHLCIA.I.2.32a	CPD 3	36736	500	45E
13	HHLCIA.I.2.33a	CPD 3	36737	500	45F
14	HHLCIA.I.2.33b	-ditto-	"	500	45G
15	HHLCIA.I.2.33c	-ditto-	"	500	45H
16	HHLCIA.2.2a	Bar - Morphotype F	36725	200	90A
17	HHLCIA.2.2b	-ditto-	"	200	90B
18	HHLCIA.2.2c	-ditto-	"	200	90C
19	HHLCIA.2.3a	Bar - Morphotype F	36726	100	90D
20	HHLCIA.2.3b	-ditto-	"	100	90E

I.2 KILBRIDE QUARRIES

I.2.1 Kilbride Quarries - KQ1(2)

No	Specimen No	Identification	TCD No	Scale µm	Plate & Figure
1	KQ1(2)I.I.1a	Unknown poss. gill raker/spine	36878	500	53A
2	KQ1(2)I.I.1b	-ditto-	"	500	53B
3	KQ1(2)I.I.1c	-ditto-	"	500	53C
4	KQ1(2)I.I.2a	-ditto-	36879	200	53D
5	KQ1(2)I.I.2b	-ditto-	"	200	53E
6	KQ1(2)I.I.3a	Unknown poss. gill raker/spine	36880	200	53F
7	KQ1(2)I.I.3b	-ditto-	"	500	53G
8	KQ1(2)I.I.3c	-ditto-	"	500	53H
9	KQ1(2)I.I.4a	Unknown poss. gill raker/spine	36881	200	53I
10	KQ1(2)I.I.4b	-ditto-	"	200	53J
11	KQ1(2)I.II.6a	Acanthodian scale	36847	100	64A

No	Specimen No	Identification	TCD No	Scale µm	Plate & Figure
12	KQ1(2)I.II.12a	Acanthodian scale	36848	200	64B
13	KQ1(2)I.II.23a	Acanthodian scale	36849	200	64C
14	KQ1(2)I.III.16a	Actinopterygian scale	36859	500	51A
15	KQ1(2)I.III.40a	Actinopterygian scale	36860	500	51B
16	KQ1(2)I.V.2a	Hybodont scale Morphotype 1	36838	200	62A
17	KQ1(2)I.V.5a	Hybodont scale Morphotype 1	36839	200	62B
18	KQ1(2)I.V.5b	-ditto-	"	100	62C
19	KQ1(2)I.V.17a	Actinopterygian flat scale	36833	200	58A
20	KQ1(2)I.V.17b	-ditto-	"	200	58B
21	KQ1(2)I.V.18a	Actinopterygian flat scale	36834	200	58C
22	KQ1(2)I.V.22a	Actinopterygian flat scale	36835	500	58D
23	KQ1(2)I.V.33a	Actinopterygian flat scale	36836	500	58E
24	KQ1(2)I.VIII.15a	Actinopterygian scale	36861	500	51C
25	KQ1(2)II.I.1a	Bar - Morphotype A	36694	200	72A
26	KQ1(2)II.I.1b	-ditto-	"	200	72B
27	KQ1(2)II.I.1c	-ditto-	"	200	72c
28	KQ1(2)II.I.1d	-ditto-	"	200	72D
29	KQ1(2)II.I.1e	-ditto-	"	100	72E
30	KQ1(2)II.I.3a	Bar - Morphotype A	36695	200	72F
31	KQ1(2)II.I.3b	-ditto-	"	200	72G
32	KQ1(2)II.I.3c	-ditto-	"	200	72H
33	KQ1(2)II.I.3d	-ditto-	"	200	72I
34	KQ1(2)II.I.3e	-ditto-	"	200	72J
35	KQ1(2)II.I.6a	Bar - Morphotype B	36704	200	77A
36	KQ1(2)II.I.6b	-ditto-	"	200	77B
37	KQ1(2)II.I.6c	-ditto-	"	200	77C
38	KQ1(2)II.I.6d	-ditto-	"	200	77D
39	KQ1(2)II.I.6e	-ditto-	"	200	77E
40	KQ1(2)II.I.8a	Bar - Morphotype A	36696	200	73A
41	KQ1(2)II.I.8b	-ditto-	"	200	73B
42	KQ1(2)II.I.8c	-ditto-	"	200	73C
43	KQ1(2)II.I.8d	-ditto-	"	100	73D
44	KQ1(2)II.I.9a	Bar - Morphotype C	36708	200	79A
45	KQ1(2)II.I.9b	-ditto-	"	200	79B
46	KQ1(2)II.I.9c	-ditto-	"	200	79C
47	KQ1(2)II.I.9d	-ditto-	"	100	79D
48	KQ1(2)II.I.10a	Bar - Morphotype A	36697	500	73E
49	KQ1(2)II.I.10b	-ditto-	"	200	73F
50	KQ1(2)II.I.10c	-ditto-	"	200	73G
51	KQ1(2)II.I.10d	-ditto-	"	200	73H
52	KQ1(2)II.I.10e	-ditto-	"	200	73I
53	KQ1(2)II.I.11a	Bar - Morphotype A	36698	200	74A
54	KQ1(2)II.I.11b	-ditto-	"	200	74B
55	KQ1(2)II.I.11c	-ditto-	"	200	74C
56	KQ1(2)II.I.11d	-ditto-	"	100	74D
57	KQ1(2)II.I.13a	Bar - Morphotype D	36709	200	80A
58	KQ1(2)II.I.13b	-ditto-	"	200	80B
59	KQ1(2)II.I.13c	-ditto-	"	200	80C
60	KQ1(2)II.I.13d	-ditto-	"	100	80D
61	KQ1(2)II.I.14a	Bar - Morphotype A	36699	200	74E
62	KQ1(2)II.I.14b	-ditto-	"	200	74F

No	Specimen No	Identification	TCD No	Scale µm	Plate & Figure
63	KQ1(2)II.I.14c	Bar - Morphotype A	"	200	74G
64	KQ1(2)II.I.14d	-ditto-	"	100	74H
65	KQ1(2)II.I.15a	Bar - Morphotype D	36710	200	80D
66	KQ1(2)II.I.15b	-ditto-	"	200	80F
67	KQ1(2)II.I.15c	-ditto-	"	200	80G
68	KQ1(2)II.I.15d	-ditto-	"	100	80H
69	KQ1(2)II.I.19a	Bar - Morphotype F	36720	200	87A
70	KQ1(2)II.I.19b	-ditto-	"	200	87B
71	KQ1(2)II.I.19c	-ditto-	"	200	87C
72	KQ1(2)II.I.19d	-ditto-	"	100	87D
73	KQ1(2)II.I.20a	Bar - Morphotype G	36727	200	91A
74	KQ1(2)II.I.20b	-ditto-	"	200	91B
75	KQ1(2)II.I.20c	-ditto-	"	200	91C
76	KQ1(2)II.I.20d	-ditto-	"	100	91D
77	KQ1(2)II.I.26a	Bar - Morphotype F	36721	200	88A
78	KQ1(2)II.I.26b	-ditto-	"	200	88B
79	KQ1(2)II.I.26c	-ditto-	"	200	88C
80	KQ1(2)II.I.26d	-ditto-	"	100	88D
81	KQ1(2)II.I.42a	Bar - Morphotype F	36722	500	88E
82	KQ1(2)II.I.42b	-ditto-	"	500	88F
83	KQ1(2)II.I.42c	-ditto-	"	500	88G
84	KQ1(2)II.I.42d	-ditto-	"	100	88H
85	KQ1(2)II.I.47a	Bar- Morphotype B	36705	500	77F
86	KQ1(2)II.I.47b	-ditto-	"	500	77G
87	KQ1(2)II.I.47c	-ditto-	"	500	77H
88	KQ1(2)II.I.47d	-ditto-	"	100	77I
89	KQ1(2)II.I.49a	Bar - Morphotype D	36711	200	81A
90	KQ1(2)II.I.49b	-ditto-	"	200	81B
91	KQ1(2)II.I.49c	-ditto-	"	200	81C
92	KQ1(2)II.I.49d	-ditto-	"	200	81D
93	KQ1(2)II.I.51a	Bar - Morphotype D	36712	200	81E
94	KQ1(2)II.I.51b	-ditto-	"	200	81F
95	KQ1(2)II.I.51c	-ditto-	"	200	81G
96	KQ1(2)II.I.51d	-ditto-	"	100	81H
97	KQ1(2)II.I.52a	Bar - Morphotype B	36706	200	78A
98	KQ1(2)II.I.52b	-ditto-	"	200	78B
99	KQ1(2)II.I.52c	-ditto-	"	200	78C
100	KQ1(2)II.I.52d	-ditto-	"	200	78D
101	KQ1(2)II.I.55a	Bar - Morphotype A	36700	200	75A
102	KQ1(2)II.I.55b	-ditto-	"	200	75B
103	KQ1(2)II.I.55c	-ditto-	"	200	75C
104	KQ1(2)II.I.55d	-ditto-	"	100	75D
105	KQ1(2)II.I.57a	Bar - Morphotype D	36713	200	82A
106	KQ1(2)II.I.57b	-ditto-	"	200	82B
107	KQ1(2)II.I.57c	-ditto-	"	200	82C
108	KQ1(2)II.I.57d	-ditto-	"	200	82D
109	KQ1(2)II.I.62a	Bar - Morphotype D	36714	500	82E
110	KQ1(2)II.I.62b	-ditto-	"	500	82F
111	KQ1(2)II.I.62c	-ditto-	"	500	82G
112	KQ1(2)II.I.62d	-ditto-	"	200	82H
113	KQ1(2)II.I.63a	Bar - Morphotype E	36719	200	86A
114	KQ1(2)II.I.63b	-ditto-	"	200	86B

No	Specimen No	Identification	TCD No	Scale µm	Plate & Figure
115	KQ1(2)II.I.63c	Bar - Morphotype E	"	200	86C
116	KQ1(2)II.I.63d	-ditto-	"	200	86D
117	KQ1(2)II.I.64a	Bar - Morphotype D	36715	200	83A
118	KQ1(2)II.I.64b	-ditto-	"	200	83B
119	KQ1(2)II.I.64c	-ditto-	"	200	83C
120	KQ1(2)II.I.64d	-ditto-	"	100	83D
121	KQ1(2)II.I.64e	-ditto-	"	100	83E
122	KQ1(2)II.III.1a	*Thrinacodus incurvus* ferox M'type	36792	200	1A
123	KQ1(2)II.III.1b	-ditto-	"	500	1B
124	KQ1(2)II.III.1c	-ditto-	"	200	1C
125	KQ1(2)II.III.2a	*Thrinacodus incurvus* ferox M'type	36793	200	2A
126	KQ1(2)II.III.2b	-ditto-	"	500	2B
127	KQ1(2)II.III.2c	-ditto-	"	200	2C
128	KQ1(2)II.III.2d	-ditto-	"	200	2D
129	KQ1(2)II.III.2e	-ditto-	"	200	2E
130	KQ1(2)II.III.2f	-ditto-	"	200	2G
131	KQ1(2)II.III.3a	*Thrinacodus incurvus* nanus M'type	36802	500	11A
132	KQ1(2)II.III.3b	-ditto-	"	200	11B
133	KQ1(2)II.III.3c	-ditto-	"	200	11C
134	KQ1(2)II.III.3d	-ditto-	"	200	11D
135	KQ1(2)II.III.3e	-ditto-	"	200	11E
136	KQ1(2)II.III.4a	*Thrinacodus incurvus* nanus M'type	36808	200	12A
137	KQ1(2)II.III.4b	-ditto-	"	500	12B
138	KQ1(2)II.III.4c	-ditto-	"	200	12C
139	KQ1(2)II.III.4d	-ditto-	"	200	12D
140	KQ1(2)II.III.4e	-ditto-	"	200	12E
141	KQ1(2)II.III.4f	-ditto-	"	200	12F
142	KQ1(2)II.III.5a	*Thrinacodus incurvus* ferox M'type	36794	500	3A
143	KQ1(2)II.III.5b	-ditto-	"	500	3B
144	KQ1(2)II.III.5c	-ditto-	"	500	3C
145	KQ1(2)II.III.5d	-ditto-	"	500	3D
146	KQ1(2)II.III.5e	-ditto-	"	200	3E
147	KQ1(2)II.III.5f	-ditto-	"	200	3F
148	KQ1(2)II.III.5g	-ditto-	"	200	3G
149	KQ1(2)II.III.6a	*Thrinacodus incurvus* ferox M'type	36795	500	4A
150	KQ1(2)II.III.6b	-ditto-	"	500	4B
151	KQ1(2)II.III.6c	-ditto-	"	200	4C
152	KQ1(2)II.III.6d	-ditto-	"	200	4D
153	KQ1(2)II.III.6e	-ditto-	"	200	4E
154	KQ1(2)II.III.8a	*Thrinacodus incurvus* ferox M'type	36796	500	5A
155	KQ1(2)II.III.8b	-ditto-	"	500	5B
156	KQ1(2)II.III.9a	*Thrinacodus incurvus* ferox M'type	36797	500	5C
157	KQ1(2)II.III.9b	-ditto-	"	500	5D
158	KQ1(2)II.III.10a	*Thrinacodus incurvus* ferox M'type	36798	200	6A
159	KQ1(2)II.III.10b	-ditto-	"	200	6B
160	KQ1(2)II.III.10c	-ditto-	"	500	6C
161	KQ1(2)II.III.11a	*Thrinacodus incurvus* ferox M'type	36799	500	6D
162	KQ1(2)II.III.11b	-ditto-	"	500	6E
163	KQ1(2)II.III.11c	-ditto-	"	500	6F
164	KQ1(2)II.III.12a	*Thrinacodus incurvus* ferox M'type	36800	500	1C
165	KQ1(2)II.III.12b	-ditto-	"	500	1D

No	Specimen No	Identification	TCD No	Scale µm	Plate & Figure
166	KQ1(2)II.IV.1a	Chond. Pavement Dentition 1	36731	500	43A
167	KQ1(2)II.IV.1b	(CPD 1)	"	500	43B
168	KQ1(2)II.IV.1c	-ditto-	"	200	43C
169	KQ1(2)II.IV.2a	*Lissodus* Morphotype 2	36765	200	20A42A
170	KQ1(2)II.IV.2b	-ditto-	"	200	20B42B
171	KQ1(2)II.IV.2c	-ditto-	"	200	20C42C
172	KQ1(2)II.IV.3a	Chondrichthyan Body Scales	36837	200	61A
173	KQ1(2)II.IV.3b	-ditto-	"	200	61B
174	KQ1(2)II.IV.3c	-ditto-	"	200	61C
175	KQ1(2)II.IV.3d	-ditto-	"	200	61D
176	KQ1(2)II.IV.4a	*Lissodus* Morphotype 5	36775	200	26A
177	KQ1(2)II.IV.4b	-ditto-	"	200	26B
178	KQ1(2)II.IV.4c	-ditto-	"	200	26C
179	KQ1(2)II.IV.4d	-ditto-	"	100	26D
180	KQ1(2)II.IV.5a	*Lissodus* Morphotype 1	36752	500	13A
181	KQ1(2)II.IV.5b	-ditto-	"	200	13B
182	KQ1(2)II.IV.5c	-ditto-	"	500	13C
183	KQ1(2)II.IV.5d	-ditto-	"	100	13D
184	KQ1(2)II.IV.6a	*Lissodus* Morphotype 3	36767	200	21A
185	KQ1(2)II.IV.6b	-ditto-	"	200	21B
186	KQ1(2)II.IV.6c	-ditto-	"	200	21C
187	KQ1(2)II.IV.7a	*Lissodus* Morphotype 1	36753	200	13E
188	KQ1(2)II.IV.7b	-ditto-	"	200	13F
189	KQ1(2)II.IV.7c	-ditto-	"	200	13G
190	KQ1(2)II.IV.7d	-ditto-	"	200	13H
191	KQ1(2)II.IV.8a	*Protacrodus* - Morphotype 1	36789	200	40A
192	KQ1(2)II.IV.8b	-ditto-	"	200	40B
193	KQ1(2)II.IV.9a	CPD7	36743	200	49E
194	KQ1(2)II.IV.9b	-ditto-	"	200	49F
195	KQ1(2)II.IV.9c	-ditto-	"	200	49G
196	KQ1(2)II.IV.9d	-ditto-	"	200	49H
197	KQ1(2)II.IV.11a	*Lissodus* Morphotype 5	36776	200	26E
198	KQ1(2)II.IV.11b	-ditto-	"	200	26F
199	KQ1(2)II.IV.11c	-ditto-	"	200	26G
200	KQ1(2)II.IV.11d	-ditto-	"	100	26H
201	KQ1(2)II.IV.12a	*Lissodus* Morphotype 1	36754	200	14A
202	KQ1(2)II.IV.12b	-ditto-	"	200	14B
203	KQ1(2)II.IV.12c	-ditto-	"	200	14C
204	KQ1(2)II.IV.12d	-ditto-	"	200	14D
205	KQ1(2)II.IV.13a	*Lissodus* Morphotype 5	36777	500	27A
206	KQ1(2)II.IV.13b	-ditto-	"	500	27B
207	KQ1(2)II.IV.13c	-ditto-	"	500	27C
208	KQ1(2)II.IV.13d	-ditto-	"	200	27D
209	KQ1(2)II.IV.14a	CPD1	36732	200	43D
210	KQ1(2)II.IV.14b	-ditto-	"	500	43E
211	KQ1(2)II.IV.14c	-ditto-	"	500	43F
212	KQ1(2)II.IV.15a	part of a *Lissodus* Morphotype 1	36755	200	14E
213	KQ1(2)II.IV.15b	-ditto-	"	200	14F
214	KQ1(2)II.IV.15c	-ditto-	"	200	14G
215	KQ1(2)II.IV.16a	*Lissodus* Morphotype 3	36768	200	21D42D

No	Specimen No	Identification	TCD No	Scale µm	Plate & Figure
216	KQ1(2)II.IV.16b	*Lissodus* Morphotype 3	"	200	21E42E
217	KQ1(2)II.IV.16c	-ditto-	"	200	21F42F
218	KQ1(2)II.IV.17a	*Lissodus* Morphotype 1	36756	200	15A
219	KQ1(2)II.IV.17b	-ditto-	"	200	15B
220	KQ1(2)II.IV.17c	-ditto-	"	200	15C
221	KQ1(2)II.IV.17d	-ditto-	"	200	15D
222	KQ1(2)II.IV.18a	*Lissodus* Morphotype 1	36757	200	15E
223	KQ1(2)II.IV.18b	-ditto-	"	200	15F
224	KQ1(2)II.IV.18c	-ditto-	"	200	15G
225	KQ1(2)II.IV.18d	-ditto-	"	200	15H
226	KQ1(2)II.IV.19a	Chond. dent/scale Morphotype1	36810	200	55A
227	KQ1(2)II.IV.19b	-ditto-	"	200	55B
228	KQ1(2)II.IV.20a	Chond. dent/scale Morphotype 2	36811	200	55C
229	KQ1(2)II.IV.20b	-ditto-	"	200	55E
230	KQ1(2)II.IV.20c	-ditto-	"	200	55D
231	KQ1(2)II.IV.20d	-ditto-	"	100	55F
232	KQ1(2)II.IV.21a	*Lissodus* Morphotype 5	36778	200	27E
233	KQ1(2)II.IV.21b	-ditto-	"	200	27F
234	KQ1(2)II.IV.21c	-ditto-	"	200	27G
235	KQ1(2)II.IV.21d	-ditto-	"	100	27H
236	KQ1(2)II.IV.23a	*Lissodus* Morphotype 1	36758	200	16A
237	KQ1(2)II.IV.23b	-ditto-	"	200	16B
238	KQ1(2)II.IV.23c	-ditto-	"	200	16C
239	KQ1(2)II.IV.23d	-ditto-	"	200	16D
240	KQ1(2)II.IV.24a	*Lissodus* Morphotype 1	36759	200	16E
241	KQ1(2)II.IV.24b	-ditto-	"	200	16F
242	KQ1(2)II.IV.24c	-ditto-	"	100	16G
243	KQ1(2)II.IV.25a	*Lissodus* Morphotype 5	36779	200	28A
244	KQ1(2)II.IV.25b	-ditto-	"	200	28B
245	KQ1(2)II.IV.25c	-ditto-	"	200	28C
246	KQ1(2)II.IV.26a	*Lissodus* Morphotype 5	36780	500	28D
247	KQ1(2)II.IV.26b	-ditto-	"	500	28E
248	KQ1(2)II.IV.26c	-ditto-	"	200	28F
249	KQ1(2)II.IV.27a	*Protacrodus* Morphotype 2	36790	200	40C
250	KQ1(2)II.IV.27b	-ditto-	"	200	40D
251	KQ1(2)II.IV.27c	-ditto-	"	200	40E
252	KQ1(2)II.IV.28a	CPD2	36734	200	44A
253	KQ1(2)II.IV.28b	-ditto-	"	200	44B
254	KQ1(2)II.IV.28c	-ditto-	"	200	44C
255	KQ1(2)II.IV.28d	-ditto-	"	200	44D
256	KQ1(2)II.IV.29a	*Lissodus* Morphotype 4	36770	200	23A
257	KQ1(2)II.IV.29b	-ditto-	"	200	23B
258	KQ1(2)II.IV.29c	-ditto-	"	200	23C
259	KQ1(2)II.IV.29d	-ditto-	"	200	23D
260	KQ1(2)II.IV.30a	*Lissodus* Morphotype 4	36771	200	23E
261	KQ1(2)II.IV.30b	-ditto-	"	200	23F
262	KQ1(2)II.IV.30c	-ditto-	"	200	23G
263	KQ1(2)II.IV.30d	-ditto-	"	100	23H
264	KQ1(2)II.IV.31a	*Lissodus* Morphotype 4	36772	200	24A
265	KQ1(2)II.IV.31b	-ditto-	"	200	24B
266	KQ1(2)II.IV.31c	-ditto-	"	200	24C
267	KQ1(2)II.IV.31d	-ditto-	"	200	24D

No	Specimen No	Identification	TCD No	Scale µm	Plate & Figure
268	KQ1(2)II.IV.32a	*Lissodus* Morphotype 1	36781	200	29A
269	KQ1(2)II.IV.32b	-ditto-	"	200	29B
270	KQ1(2)II.IV.32c	-ditto-	"	200	29C
271	KQ1(2)II.IV.32d	-ditto-	"	200	29D
272	KQ1(2)II.IV.33a	*Lissodus* Morphotype 1	36760	200	17A
273	KQ1(2)II.IV.33b	-ditto-	"	200	17B
274	KQ1(2)II.IV.33c	-ditto-	"	200	17C
275	KQ1(2)II.IV.33d	-ditto-	"	100	17D
276	KQ1(2)II.IV.34a	*Lissodus* Morphotype 1	36782	200	29E
277	KQ1(2)II.IV.34b	-ditto-	"	200	29F
278	KQ1(2)II.IV.34c	-ditto-	"	200	29G
279	KQ1(2)II.IV.34d	-ditto-	"	200	29H
280	KQ1(2)II.IV.35a	*Lissodus* Morphotype 2	36766	200	20D
281	KQ1(2)II.IV.35b	-ditto-	"	200	20E
282	KQ1(2)II.IV.36a	*Lissodus* Morphotype 4	36773	200	24E
283	KQ1(2)II.IV.36b	-ditto-	"	200	24F
284	KQ1(2)II.IV.37a	CPD3	36735	200	45A
285	KQ1(2)II.IV.37b	-ditto-	"	200	45B
286	KQ1(2)II.IV.37c	-ditto-	"	200	45C
287	KQ1(2)II.IV.37d	-ditto-	"	200	45D
288	KQ1(2)II.IV.39a	CPD 4	36738	200	46A
289	KQ1(2)II.IV.39b	-ditto-	"	500	46B
290	KQ1(2)II.IV.39c	-ditto-	"	200	45C
291	KQ1(2)II.IV.40a	CPD 4	36739	200	46D
292	KQ1(2)II.IV.40b	-ditto-	"	200	46E
293	KQ1(2)II.IV.40c	-ditto-	"	200	46F
294	KQ1(2)II.IV.40d	-ditto-	"	200	46G
295	KQ1(2)II.IV.41a	*Lissodus* Morphotype 3	36769	200	22A
296	KQ1(2)II.IV.41b	-ditto-	"	200	22B
297	KQ1(2)II.IV.41c	-ditto-	"	200	22C
298	KQ1(2)II.IV.41d	-ditto-		200	22D
299	KQ1(2)II.IV.42a	CPD 5 - part of symphysis	36741	500	48A
300	KQ1(2)II.IV.42b	-ditto-	"	200	48B
301	KQ1(2)II.IV.42c	-ditto-	"	200	48C
302	KQ1(2)II.IV.42d	-ditto-	"	200	48D
303	KQ1(2)II.V.6a	cf. *Denaea*	36744	500	33C
304	KQ1(2)II.V.6b	-ditto-	"	500	33D
305	KQ1(2)II.V.6c	-ditto-	"	200	33A
306	KQ1(2)II.V.6d	-ditto-	"	200	33B
307	KQ1(2)II.V.6e	-ditto-	"	500	33C
308	KQ1(2)II.V.6f	-ditto-	"	200	33D
309	KQ1(2)II.V.8a	cf. *Denaea*	36745	500	34A
310	KQ1(2)II.V.8b	-ditto-	"	500	34B
311	KQ1(2)II.V.8c	-ditto-	"	500	34C
312	KQ1(2)II.V.8d	-ditto-	"	500	34D
313	KQ1(2)II.V.8e	-ditto-	"	200	34E
314	KQ1(2)II.V.8f	-ditto-	"	500	34F
315	KQ1(2)II.V.9a	cf. *Denaea* or dent???	36751	500	not figd
316	KQ1(2)II.V.9b	-ditto-	"	500	not figd
317	KQ1(2)II.V.9c	-ditto-	"	200	not figd
318	KQ1(2)II.V.9d	-ditto-	"	500	not figd
319	KQ1(2)II.V.9e	-ditto-	"	500	not figd

No	Specimen No	Identification	TCD No	Scale µm	Plate & Figure
320	KQ1(2)II.V.10a	cf. *Denaea*	36746	200	35A
321	KQ1(2)II.V.10b	-ditto-	"	500	35B
322	KQ1(2)II.V.10c	-ditto-	"	200	35C
323	KQ1(2)II.V.10e	-ditto-	"	500	35D
324	KQ1(2)II.V.10f	-ditto-	"	500	35E
325	KQ1(2)II.V.12a	cf. *Denaea*	36747	500	36A
326	KQ1(2)II.V.12b	-ditto-	"	500	36E
327	KQ1(2)II.V.12c	-ditto-	"	500	36A
328	KQ1(2)II.V.12d	-ditto-	"	500	36B
329	KQ1(2)II.V.12e	-ditto-	"	500	36C
330	KQ1(2)II.V.12f	-ditto-	"	200	36D
331	KQ1(2)II.V.14a	cf. *Denaea*	36748	500	37D
332	KQ1(2)II.V.14b	-ditto-	"	500	37A
333	KQ1(2)II.V.14c	-ditto-	"	500	37B
334	KQ1(2)II.V.14d	-ditto-	"	500	37C
335	KQ1(2)II.V.14e	-ditto-	"	200	37D
336	KQ1(2)II.V.15a	cf. *Denaea*	36749	500	38A
337	KQ1(2)II.V.15b	-ditto-	"	500	38E
338	KQ1(2)II.V.15c	-ditto-	"	500	38A
339	KQ1(2)II.V.15d	-ditto-	"	500	38B
340	KQ1(2)II.V.15e	-ditto-	"	500	38C
341	KQ1(2)II.V.15f	-ditto-	"	200	38D
342	KQ1(2)II.VIII.1a	Handle-bar moustache denticle 1	36882	200	54A
343	KQ1(2)II.VIII.5a	CPD 1	36733	200	43G
344	KQ1(2)II.VIII.5b	-ditto-	"	200	43H
345	KQ1(2)II.VIII.5c	-ditto-	"	200	43I
346	KQ1(2)II.VIII.7a	Chond. Mucous Membrane Dents.	36829	500	59A
347	KQ1(2)II.VIII.7b	-ditto-	"	500	59B
348	KQ1(2)II.VIII.9a	Tricuspid Tooth	36809	200	42H
349	KQ1(2)II.VIII.9b	-ditto-	"	200	42I
350	KQ1(2)II.VIII.9c	-ditto-	"	200	42J
351	KQ1(2)II.VIII.15a	Poss. Chond. dent 2	36827	200	54B
352	KQ1(2)II.VIII.15b	-ditto-	"	100	54C
353	KQ1(2)II.VIII.25a	CPD6	36742	200	49A
354	KQ1(2)II.VIII.25b	-ditto-	"	500	49B
355	KQ1(2)II.VIII.25c	-ditto-	"	500	49C
356	KQ1(2)II.VIII.25d	-ditto-	"	500	49D
357	KQ1(2)II.VIII.28a	Chond. dent/scale Morphotype 3	36812	200	55G
358	KQ1(2)II.VIII.37a	Actinopterygian jaw	36883	200	52A
359	KQ1(2)II.VIII.37b	-ditto-	"	200	52B
360	KQ1(2)II.VIII.37c	-ditto-	"	200	52C
361	KQ1(2)IV.I.3a	C. Composite dent/scale	36823	500	56A
362	KQ1(2)IV.I.3b	-ditto-	"	500	56B
363	KQ1(2)IV.I.18a	C. Composite dent/scale	36824	500	57A
364	KQ1(2)IV.I.18b	- Ctenacanth like	"	200	57B
365	KQ1(2)IV.I.22a	- ditto -	36825	200	57C
366	KQ1(2)IV.I.27a	Chond. Mucous Membrane M'type 2	36830	200	60A
367	KQ1(2)IV.I.27b	-ditto-		200	60B
368	KQ1(2)IV.I.28a	Hybodont Morphotype 2	36846	500	63A
369	KQ1(2)IV.I.36a	Hybodont Morphotype 2	36813	200	63B
370	KQ1(2)IV.I.39a	?*Thrinacodus incurvus* ferox dent	36845	200	61E
371	KQ1(2)IV.I.39b	-ditto-	"	200	61F

No	Specimen No	Identification	TCD No	Scale µm	Plate & Figure
372	KQ1(2)IV.I.47a	Chond. composite scale/dent.	36826	500	56C
373	KQ1(2)IV.I.63a	Hybondont Morphotype 3	36814	100	63E

I.2.2 Kilbride Quarries - KQ1(5)

No	Specimen No	Identification	TCD No	Scale µm	Plate & Figure
1	KQ1(5)II.20a	*Thrinacodus incurvus* ferox M'type	36801	200	7A
2	KQ1(5)II.20b	-ditto-	"	200	7B
3	KQ1(5)II.20c	-ditto-	"	200	7C
4	KQ1(5)II.20d	-ditto-	"	200	7D
5	KQ1(5)II.21a	*Lissodus* Morphotype 5	36783	200	30A
6	KQ1(5)II.21b	-ditto-	"	200	30B
7	KQ1(5)II.21c	-ditto-	"	200	30C
8	KQ1(5)II.21d	-ditto-	"	100	30D

I.2.3 Kilbride Quarries - KQ2(1)

No	Specimen No	Identification	TCD No	Scale µm	Plate & Figure
1	KQ2(1)I.I.32a	Actinopterygian scale	36864	500	51D
2	KQ2(1)I.I.50a	Actinopterygian scale	36865	200	51E
3	KQ2(1)I.II.34a	Acanthodian scale	36850	200	64D
4	KQ2(1)I.II.34b	-ditto-	"	200	64E
5	KQ2(1)I.II.50aa	Hybodont Morphotype 1	36840	200	62D
6	KQ2(1)I.II.50ab	-ditto-	"	100	62E
7	KQ2(1)I.II.50ba	Hybodont Morphotype 1	36841	100	62F
8	KQ2(1)I.II.50bb	-ditto-	"	100	62G
9	KQ2(1)II.I.4a	Bar - Morphotype G	36728	200	91E
10	KQ2(1)II.I.4b	-ditto-	"	200	91F
11	KQ2(1)II.I.4c	-ditto-	"	200	91G
12	KQ2(1)II.I.4d	-ditto-	"	100	91H
13	KQ2(1)II.I.7a	Bar - Morphotype G	36729	500	92A
14	KQ2(1)II.I.7b	-ditto-	"	500	92B
15	KQ2(1)II.I.7c	-ditto-	"	500	92C
16	KQ2(1)II.I.7d	-ditto-	"	100	92D
17	KQ2(1)II.I.11a	Bar - Morphotype A	36701	200	72E
18	KQ2(1)II.I.11b	-ditto-	"	200	72F
19	KQ2(1)II.I.11c	-ditto-	"	200	72G
20	KQ2(1)II.I.11d	-ditto-	"	100	72H
21	KQ2(1)II.I.21a	*Lissodus* Morphotype 1	36761	200	17E
22	KQ2(1)II.I.21b	-ditto-	"	200	17F
23	KQ2(1)II.I.21c	-ditto-	"	200	17G
24	KQ2(1)II.I.21d	-ditto-	"	100	17H
25	KQ2(1)II.I.22a	*Lissodus* Morphotype 5	36784	200	30E
26	KQ2(1)II.I.22b	-ditto-	"	200	30F
27	KQ2(1)II.I.22c	-ditto-	"	200	30G
28	KQ2(1)II.I.22d	-ditto-	"	200	30H
29	KQ2(1)II.I.23a	Bar - Morphotype A	36702	200	76A
30	KQ2(1)II.I.23b	-ditto-	"	200	76B

No	Specimen No	Identification	TCD No	Scale µm	Plate & Figure
31	KQ2(1)II.I.23c	Bar - Morphotype A	"	200	76C
32	KQ2(1)II.I.23d	-ditto-	"	200	76D
33	KQ2(1)II.I.24a	*Lissodus* Morphotype 4	36774	200	25A
34	KQ2(1)II.I.24b	-ditto-	"	200	25B
35	KQ2(1)II.I.24c	-ditto-	"	200	25C
36	KQ2(1)II.I.24d	-ditto-	"	200	25D
37	KQ2(1)II.I.25a	Hybodont Morphotype 3	36816	200	63F
38	KQ2(1)II.I.25b	-ditto-	"	200	63G
39	KQ2(1)II.I.25c	-ditto-	"	200	63H
40	KQ2(1)II.I.26a	*Lissodus* Morphotype 5	36785	200	31A
41	KQ2(1)II.I.26b	-ditto-	"	200	31B
42	KQ2(1)II.I.26c	-ditto-	"	200	31C
43	KQ2(1)II.I.26d	-ditto-	"	100	31D
44	KQ2(1)II.I.29a	Chond. Mucous Membrane M'type 2	36831	200	60C
45	KQ2(1)II.I.29b	-ditto-	"	200	60D
46	KQ2(1)II.I.29c	-ditto-	"	200	60E
47	KQ2(1)II.I.29d	-ditto-	"	200	60F
48	KQ2(1)II.I.31a	Hybodont Morphotype 2	36817	200	63C
49	KQ2(1)II.I.31b	-ditto-	"	200	63D
50	KQ2(1)II.I.33a	Chond. Mucous Membrane M'type 1	36832	200	59C
51	KQ2(1)II.I.33b	-ditto-	"	500	59D
52	KQ2(1)II.I.39a	Chond. dent. Morphoptype 4	36818	500	55H
53	KQ2(1)II.I.39b	-ditto-	"	500	55I

I.2.4 Kilbride Quarries - KQ2(2)

No	Specimen No	Identification	TCD No	Scale µm	Plate & Figure
1	KQ2(2)I.II.3a	Acanthodian scale	36851	100	64F
2	KQ2(2)I.II.4a	Hybodont scale Morphotype 1	36842	200	62H
3	KQ2(2)I.II.4ba	Hybodont scale Morphotype 1	36843	200	62I
4	KQ2(2)I.II.6a	Hybodont Morphotype 4	36819	200	63I
5	KQ2(2)I.II.6b	-ditto-	"	200	63J
6	KQ2(2)I.II.10a	Actinopterygian scale	36867	200	51F
7	KQ2(2)II.I.1a	*Lissodus* Morphotype 1	36762	200	18A
8	KQ2(2)II.I.1b	-ditto-	"	200	18B
9	KQ2(2)II.I.1c	-ditto-	"	200	18C
10	KQ2(2)II.I.1d	-ditto-	"	200	18D
11	KQ2(2)II.I.2a	*Lissodus* Morphotype 5	36786	500	31E
12	KQ2(2)II.I.2b	-ditto-	"	500	31F
13	KQ2(2)II.I.2c	-ditto-	"	200	31G
14	KQ2(2)II.I.2d	-ditto-	"	500	31H
15	KQ2(2)II.I.6a	Chond. Dent Morphotype 5	36820	200	55J
16	KQ2(2)II.I.6b	-ditto-	"	200	55K
17	KQ2(2)II.I.6c	-ditto-	"	200	55L

I.2.5 Kilbride Quarries - KQ2(3)

No	Specimen No	Identification	TCD No	Scale µm	Plate & Figure
1	KQ2(3)I.II.1a	Acanthodian scale	36852	200	not figd
2	KQ2(3)I.II.6a	Hybodont scale Morphotype 1	36844	200	62J
3	KQ2(3)I.II.7a	Hybodont scale Morphotype 1	36815	200	62K
4	KQ2(3)I.II.14a	Actinopterygian scale	36868	500	51G
5	KQ2(3)I.II.18a	Actinopterygian scale	36869	200	51H
6	KQ2(3)I.II.19a	Actinopterygian scale	36870	200	51I
7	KQ2(3)I.II.20a	Actinopterygian scale	36871	200	51J
8	KQ2(3)II.I.9a	Bar - Morphotype B	36707	200	78E
9	KQ2(3)II.I.9b	-ditto-	"	200	78F
10	KQ2(3)II.I.9c	-ditto-	"	200	78G
11	KQ2(3)II.I.9d	-ditto-	"	200	78H
12	KQ2(3)II.I.13a	Bar - Morphotype F	36723	200	89A
13	KQ2(3)II.I.13b	-ditto-	"	200	89B
14	KQ2(3)II.I.13c	-ditto-	"	200	89C
15	KQ2(3)II.I.18a	Bar - Morphotype D	36716	200	84A
16	KQ2(3)II.I.18b	-ditto-	"	200	84B
17	KQ2(3)II.I.18c	-ditto-	"	200	84C
18	KQ2(3)II.I.23a	Bar - Morphotype A	36703	200	76E
19	KQ2(3)II.I.23b	-ditto-	"	200	76F
20	KQ2(3)II.I.24a	Bar - Morphotype F	36724	200	89D
21	KQ2(3)II.I.24b	-ditto-	"	200	89E
22	KQ2(3)II.I.24c	-ditto-	"	200	89F
23	KQ2(3)II.I.24d	-ditto-	"	200	89G
24	KQ2(3)II.I.27a	Bar - Morphotype D	36717	200	85A
25	KQ2(3)II.I.27b	-ditto-	"	200	85B
26	KQ2(3)II.I.27c	-ditto-	"	100	85C
27	KQ2(3)II.I.27d	-ditto-	"	200	85D
28	KQ2(3)II.II.1a	*Lissodus* Morphotype 5	36787	200	32A
29	KQ2(3)II.II.1b	-ditto-	"	200	32B
30	KQ2(3)II.II.1c	-ditto-	"	200	32C
31	KQ2(3)II.II.1d	-ditto-	"	200	32D
32	KQ2(3)II.II.2a	*Lissodus* Morphotype 1	36763	200	18E
33	KQ2(3)II.II.2b	-ditto-	"	200	18F
34	KQ2(3)II.II.2c	-ditto-	"	200	18G
35	KQ2(3)II.II.2d	-ditto-	"	100	18H
36	KQ2(3)II.II.4a	*Lissodus* Morphotype 5	36788	200	32E
37	KQ2(3)II.II.4b	-ditto-	"	200	32F
38	KQ2(3)II.II.4c	-ditto-	"	200	32G
39	KQ2(3)II.II.4d	-ditto-	"	200	32H
40	KQ2(3)II.II.17a	cf. *Denaea*	36750	500	39A
41	KQ2(3)II.II.17b	-ditto-	"	200	39B
42	KQ2(3)II.II.17c	-ditto-	"	200	39C
43	KQ2(3)II.II.17d	-ditto-	"	200	39D
44	KQ2(3)II.II.17e	-ditto-	"	500	39E
45	KQ2(3)II.II.17f	-ditto-	"	200	39F
46	KQ2(3)II.II.17g	-ditto-	"	200	39C
47	KQ2(3)II.II.17h	-ditto-	"	200	39D
48	KQ2(3)II.II.20a	*Thrinacodus incurvus* ferox M'type	36807	500	not figd
49	KQ2(3)II.II.20b	- cusp	"	500	not figd

I.3 Urlingford Specimens (URL 226 etc. are depths in the borehole)

No	Specimen No	Identification	TCD No	Scale µm	Plate & Figure
1	URL226-35.43a	CPD 4	36740	200	47A
2	URL226-35.43b	-ditto-	"	200	47B
3	URL226-35.43c	-ditto-	"	200	47C
4	URL226-35.43d	-ditto-	"	200	47D
5	URL226-35.44a	*Lissodus* Morphotype 1	36764	200	19A
6	URL226-35.44b	-ditto-	"	200	19B
7	URL226-35.44c	-ditto-	"	200	19C
8	URL226-35.44d	-ditto-	"	200	19D
9	URL226-35.45a	*Thrinacodus incurvus* ferox M'type	36804	200	10A
10	URL226-35.45b	-ditto-	"	200	10B
11	URL226-35.45c	-ditto-	"	200	10C
12	URL226-35.45d	-ditto-	"	200	10D
13	URL226-35.45e	-ditto-	"	200	10E
14	URL219-10.57a	Acanthodian scale	36856	100	65E
15	URL219-10.57b	-ditto-	"	100	65F
16	URL219-10.58a	Bar - Morphotype D	36718	100	85E
17	URL219-10.58b	-ditto-	"	20	85F
18	URL219-10.58c	-ditto-	"	100	85G
19	URL219-10.58c	-ditto-	"	50	85H
20	URL219-10.59a	*Protacrodus* Morphotype 3	36791	200	41A
21	URL219-10.59b	-ditto-	"	200	41B
22	URL219-10.59c	-ditto-	"	200	41C
23	URL219-10.59d	-ditto-	"	200	41D
24	URL219-10.60a	Actinopterygian scale	36874	200	50D
25	URL219-10.60b	-ditto-	"	200	50E
26	URL219-10.62a	Actinopterygian scale	36875	200	50F
27	URL196-00.34a	Chond. composite scale/dent.	36828	200	56D
28	URL196-00.34b	-ditto-	"	200	56E
29	URL196-00.35a	*Thrinacodus incurvus* ferox M'type	36805	200	9A
30	URL196-00.35b	-ditto-	"	200	9B
31	URL196-00.35c	-ditto-	"	200	9C
32	URL196-00.35d	-ditto-	"	200	9D
33	URL196-00.35e	-ditto-	"	200	9E
34	URL196-00.36a	Actinopterygian scale	36876	200	50G
35	URL196-00.37a	Acanthodian scale	36857	100	65G
36	URL196-00.38a	*Thrinacodus i.* [f] cusp (probably)	36806	200	not figd
37	URL182-10.49a	Poss. Chond. dent 3	36821	200	54D
38	URL182-10.49b	-ditto-	"	200	54E
39	URL182-10.49c	-ditto-	"	200	54F
40	URL182-10.50a	Chond. Composite scale/d	36822	200	57D
41	URL182-10.50b	- Ctenacanth-like dent	"	200	57E
42	URL182-10.50c	-ditto-	"	200	57F
43	URL182-10.51a	Bar - Morphotype G	36730	500	92E
44	URL182-10.51b	-ditto-	"	500	92F
45	URL182-10.52a	Actinopterygian scale	36877	200	50H

I.4 Moyola River

No	Specimen No	Identification	UM No	Scale µm	Plate & Figure
1	MRI.24a	Actinopterygian scale	K28701	500	66A
2	MRI.45a	Actinopterygian scale	K28702	1mm	66B
3	MRI.45b	-ditto-		500	66D
4	MRI.46a	Actinopterygian scale	K28703	500	66C
5	MRI.46b	-ditto-		500	66E
6	MRI.56a	Actinopterygian scale	K28704	200	66F
7	MRI.56b	-ditto-		200	66G
8	MRI.56c	-ditto-		200	66H
9	MRI.II.10a	Actinopterygian scale	K28705	1mm	67A
10	MRI.II.10b	-ditto-		1mm	67B
11	MRI.II.26a	Actinopterygian scale	K28706	500	67C
12	MRI.II.36a	Actinopterygian scale	K28707	500	67D
13	MRI.II.36b	-ditto-		500	67E
14	MRI.II.47a	Actinopterygian scale	K28708	200	67F
15	MRI.III.33a	Actinopterygian scale	K28709	500	67G
16	MRI.III.33b	-ditto-		500	67H
17	MRI.IV.14a	Actinopterygian scale	K28710	200	68A
18	MRI.IV.14b	-ditto-		200	68B
19	MRI.IV.18a	Hybodont Morphotype 3	K28711	100	68C
20	MRI.IV.18b	-ditto-		200	68D
21	MRI.IV.19a	Hybodont Morphotype 3	K28712	200	68E
22	MRI.IV.19b	-ditto-		200	68F
23	MRI.IV.19c	-ditto-		200	68G
24	MRI.IV.35a	Two - Actinopterygian scale	K28713	200	69A
25	MRI.IV.35b	-ditto-		200	69B
26	MRI.IV.39a	Actinopterygian scale	K28714	200	69C
27	MRI.V.5a	Unknown	K28715	100	69D
28	MRI.V.10a	Hybodont Morphotype 2	K28716	500	69E
29	MRII.1a	Sarcopterygian tooth	K28717	1mm	70A
30	MRII.1b	-ditto-		500	70B
31	MRII.1c	-ditto-		200	70C
32	MRII.2a	Sarcopterygian tooth	K28718	500	70D
33	MRII.2b	-ditto-		500	70E
34	MRII.17a	Sarcopterygian tooth	K28719	200	70F
35	MRII.17b	-ditto-		200	70G
36	MRII.19a	Sarcopterygian tooth	K28720	200	71A
37	MRII.19b	-ditto-		200	71B
38	MRII.26a	Tooth of unknown affinity	K28721	500	71C
39	MRII.27a	Tooth of unknown affinity	K28722	200	71D
40	MRII.27b	-ditto-		200	71E

APPENDIX II

Curation of Samples

Microvertebrate (ichthyolith) specimens used in this work have been lodged in the Geological Museum, Trinity College Dublin, except those lent by the Ulster Museum, Belfast, Northern Ireland which have been returned to the Ulster Museum. Specimens lodged in Trinity College have been allocated TCD numbers while those returned to the Ulster Museum have been allocated numbers relating to their collections.

Those macrovertebrate samples and rock samples containing invertebrate fauna (that are illustrated within this work) together with thin sections pertaining to rock samples have been lodged in the Geological Museum, Trinity College Dublin and allocated TCD numbers. Illustrated macrovertebrate samples and rock thin sections on loan from the Ulster Museum have been allocated Ulster Museum numbers and lodged with the Ulster Museum, Belfast, Northern Ireland.

Picked residues from bulk sample collection have been allocated TCD numbers and lodged in the Geological Museum, Trinity College Dublin or allocated Ulster Museum numbers and lodged in the Ulster Museum, Belfast, Northern Ireland.

This appendix gives the TCD or Ulster Museum number; specimen type, lithology, location; collector, collectors sample number.

Microvertebrates illustrated within this work have been allocated specific collection numbers and paced in individual cavity slides (those illustrated are also indicated in Appendix I), all other microvertebrates have been sorted according to suggested type and placed within cavity slides each of which has been allocated a collection number.

Under collector/code number the following abbreviations have been used:

md	Bulk sample collected and picked from residues by the author
md/dag	Bulk sample collected by Davida Geraghty [Geraghty, 1996]
md/UM	Bulk sample donated by the Ulster Museum, processed and picked by residues obtained by the author
md/GDS/3246/4	Bulk sample from core 3246/4, processed by George Sevastopulo, with residues obtained 'picked' by the author

All catalogue numbers are TCD numbers accept where specifically indicated; all Sheet numbers relate to GSI sheet for the Republic of Ireland unless denoted GSNI (Northern Ireland)

TCD No:	Specimen, lithology, location:	Collector/ Collectors Code
35864	**Cavity slide of microvertebrates (not illus.)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(1)I.II Scales
35865	**Cavity slide of microvertebrates (not illus.)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(1)II.I Teeth
35866	**Cavity slide of microvertebrates (not illus.)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(1)II.II Teeth
35867	**Cavity slide of microvertebrates (not illus.)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(1)II.III Teeth
35868	**Cavity slide of microvertebrates (not illus.)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(1)III Oddments
35869	**Cavity slide of microvertebrates (not illus.)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(2)I.I Scales
35870	**Cavity slide of microvertebrates (not illus.)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(2)I.II Scales
35871	**Cavity slide of microvertebrates (not illus.)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(2)II.I Teeth
35872	**Cavity slide of microvertebrates (not illus.)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(2)II.II Teeth
35873	**Cavity slide of microvertebrates (not illus.)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(2)II.III Teeth
35874	**Cavity slide of microvertebrates (not illus.)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(2)III.I Oddments
35875	**Cavity slide of microvertebrates (not illus.)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(3)I.I Scales
35876	**Cavity slide of microvertebrates (not illus.)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(3)I.II Scales
35877	**Cavity slide of microvertebrates (not illus.)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(3)II.I Teeth
35878	**Cavity slide of microvertebrates (not illus.)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(3)II.II Teeth
35879	**Cavity slide of microvertebrates (not illus.)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(3)II.III Teeth
35880	**Cavity slide of microvertebrates (not illus.)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(3)III.I Oddments
35881	**Cavity slide of microvertebrates (not illus.)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(3)III.II Scales
35882	**Rock Sample (not illus.)** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1.1

35883	**Rock Sample (not illus.)** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1.2
35884	**Rock Sample (not illus.)** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1.3
35885	**Rock Sample (not illus.)** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1.4
35886	**Rock Sample (not illus.)** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1.5
35887	**Rock Sample (not illus.)** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1.6
35888	**Rock Sample (not illus.)** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1.7
35889	**Rock Sample (not illus.)** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1.8
35890	**Rock Sample (not illus.)** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1.9
35891	**Rock Sample (not illus.)** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1.10
35892	**Rock Sample (not illus.)** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1.11
35893	**Rock Sample (not illus.)** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1.12
35894	**Rock Sample (not illus.)** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1.13
35895	**Rock Sample (not illus.)** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1.14
35896	**Rock Sample (not illus.)** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1.15
35897	**Rock Sample (not illus.)** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1.16
35898	**Rock Sample (not illus.)** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1.17
35899	**Rock Sample (not illus.)** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1.18
35900	**Rock Sample (not illus.)** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1.19
35901	**Rock Sample (not illus.)** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1.20
35902	**Rock Sample (not illus.)** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1.21
35903	**Rock Sample (not illus.)** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1.22

35904	**Rock Sample (not illus.)** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1.23
35905	**Rock Sample (not illus.)** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1.24
35906	**Rock Sample (not illus.)** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1.25
35907	**Rock Sample (not illus.)** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1.26
35908	**Rock Sample (not illus.)** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1.27
35909	**Rock Sample (not illus.)** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1.28
35910	**Rock Sample (not illus.)** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1.29
35911	**Rock Sample (not illus.)** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1.30
35912	**Rock Sample (not illus.)** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1.31
35913	**Rock Sample (not illus.)** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1.32
35914	**Rock Sample (not illus.)** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1.33
35915	**Rock Sample (not illus.)** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1.34
35916	**Rock Sample (not illus.)** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1.35
35917	**Rock Sample (not illus.)** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1.36
35918	**Rock Sample (not illus.)** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1.37
35919	**Rock Sample (not illus.)** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1.38
35920	**Rock Sample (not illus.)** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1.39
35921	**Rock Sample (not illus.)** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1.40
35922	**Rock Sample (not illus.)** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1.41
35923	**Rock Sample (not illus.)** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1.42
35924	**Rock Sample (not illus.)** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1A.1

35925	**Rock Sample (not illus.)** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1A.2
35926	**Rock Sample (not illus.)** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1A.3
35927	**Rock Sample (not illus.)** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1A.4
36694	**Bar - Morphotype A** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13.	md/dagKQ1(2)
36695	**Bar - Morphotype A** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13.	md/dagKQ1(2)
36696	**Bar - Morphotype A** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13.	md/dagKQ1(2)
36697	**Bar - Morphotype A** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13.	md/dagKQ1(2)
36698	**Bar - Morphotype A** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13.	md/dagKQ1(2)
36699	**Bar - Morphotype A** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13.	md/dagKQ1(2)
36700	**Bar - Morphotype A** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13.	md/dagKQ1(2)
36701	**Bar - Morphotype A** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(1)
36702	**Bar - Morphotype A** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(1)
36703	**Bar - Morphotype A** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(3)
36704	**Bar - Morphotype B** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13.	md/dagKQ1(2)
36705	**Bar - Morphotype B** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13.	md/dagKQ1(2)
36706	**Bar - Morphotype B** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13.	md/dagKQ1(2)
36707	**Bar - Morphotype B** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(3)
36708	**Bar - Morphotype C** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13.	md/dagKQ1(2)
36709	**Bar - type D** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13.	md/dagKQ1(2)
36710	**Bar - Morphotype D** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13.	md/dagKQ1(2)
36711	**Bar - Morphotype D** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13.	md/dagKQ1(2)

36712	**Bar - Morphotype D** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13.	md/dagKQ1(2)
36713	**Bar - Morphotype D** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13.	md/dagKQ1(2)
36714	**Bar - Morphotype D** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36715	**Bar - Morphotype D** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36716	**Bar - Morphotype D** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(3)
36717	**Bar Morphotype D** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(3)
36718	**Bar - Morphotype D** Upper Ballysteen Limestone, Urlingford, Co. Kilkenny	md/GDS/3246/4 218.7-219.1
36719	**Bar - Morphotype E** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13.	md/dagKQ1(2)
36720	**Bar - Morphotype F** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13.	md/dagKQ1(2)
36721	**Bar - Morphotype F** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13.	md/dagKQ1(2)
36722	**Bar - Morphotype F** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13.	md/dagKQ1(2)
36723	**Bar - Morphotype F** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(3)
36724	**Bar - Morphotype F** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(3)
36725	**Bar - Morphotype F** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1A
36726	**Bar - Morphotype F** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1A
36727	**Bar - Morphotype G** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13.	md/dagKQ1(2)
36728	**Bar - Morphotype G** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(1)
36729	**Bar - Morphotype G** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(1)
36730	**Bar - Morphotype G** Upper Ballysteen Limestone, Urlingford, Co. Kilkenny	md/GDS/3246/4 181.6-182
36731	**CPD 1** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36732	**CPD 1** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)

36733	**CPD 1** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36734	**CPD 2** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36735	**CPD 3** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36736	**CPD 3** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1A
36737	**CPD 3** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1A
36738	**CPD 4** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36739	**CPD 4** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36740	**CPD 4** Upper Ballysteen Limestone, Urlingford, Co. Kilkenny	md/GDS/3246/4 226-226.35
36741	**CPD 5 - part of symphysis** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36742	**CPD 6** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36743	**CPD 7** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36744	**cf. *Denaea*** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36745	**cf. *Denaea*** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36746	**cf. *Denaea*** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36747	**cf. *Denaea*** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36748	**cf. *Denaea*** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36749	**cf. *Denaea*** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36750	**cf. *Denaea*** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(3)
36751	**cf. *Denaea*** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36752	***Lissodus* Morphotype 1** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36753	***Lissodus* Morphotype 1** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)

36754	***Lissodus* Morphotype 1** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36755	***Lissodus* Morphotype 1 (incomplete)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36756	***Lissodus* Morphotype 1** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36757	***Lissodus* Morphotype 1** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36758	***Lissodus* Morphotype 1** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36759	***Lissodus* Morphotype 1** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36760	***Lissodus* Morphotype 1** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36761	***Lissodus* Morphotype 1** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(1)
36762	***Lissodus* Morphotype 1** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(2)
36763	***Lissodus* Morphotype 1** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(3)
36764	***Lissodus* Morphotype 1** Upper Ballysteen Limestone, Urlingford, Co. Kilkenny	md/GDS/3246/4 226-226.35
36765	***Lissodus* Morphotype 2** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36766	***Lissodus* Morphotype 2** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36767	***Lissodus* Morphotype 3** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36768	***Lissodus* Morphotype 3** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36769	***Lissodus* Morphotype 3** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36770	***Lissodus* Morphotype 4** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36771	***Lissodus* Morphotype 4** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36772	***Lissodus* Morphotype 4** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36773	***Lissodus* Morphotype 4** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36774	***Lissodus* Morphotype 4** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(1)

36775	***Lissodus* Morphotype 5** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36776	***Lissodus* Morphotype 5** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36777	***Lissodus* Morphotype 5** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36778	***Lissodus* Morphotype 5** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36779	***Lissodus* Morphotype 5** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36780	***Lissodus* Morphotype 5** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36781	***Lissodus* Morphotype 1** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36782	***Lissodus* Morphotype 1** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36783	***Lissodus* Morphotype 5** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(5)
36784	***Lissodus* Morphotype 5** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(1)
36785	***Lissodus* Morphotype 5** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(1)
36786	***Lissodus* Morphotype 5** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(2)
36787	***Lissodus* Morphotype 5** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(3)
36788	***Lissodus* Morphotype 5** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(3)
36789	***Protacrodus* Morphotype 1** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36790	***Protacrodus* Morphotype 2** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36791	***Protacrodus* Morphotype 3** Upper Ballysteen Limestone, Urlingford, Co. Kilkenny	md/GDS/3246/4 218.7-219.1
36792	***Thrinacodus incurvus* ferox morphotype** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36793	***Thrinacodus incurvus* ferox morphotype** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36794	***Thrinacodus incurvus* ferox morphotype** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36795	***Thrinacodus incurvus* ferox morphotype** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)

36796	***Thrinacodus incurvus* ferox morphotype** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36797	***Thrinacodus incurvus* ferox morphotype** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36798	***Thrinacodus incurvus* ferox morphotype** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36799	***Thrinacodus incurvus* ferox morphotype** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36800	***Thrinacodus incurvus* ferox morphotype** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36801	***Thrinacodus incurvus* ferox morphotype** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(5)
36802	***Thrinacodus incurvus* nanus morphotype** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36803	***Thrinacodus incurvus* ferox morphotype** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1A
36804	***Thrinacodus incurvus* ferox morphotype** Upper Ballysteen Limestone, Urlingford, Co. Kilkenny	md/GDS/3246/4 226-226.35
36805	***Thrinacodus incurvus* ferox morphotype** Upper Ballysteen Limestone, Urlingford, Co. Kilkenny	md/GDS/3246/4 195.7-196
36806	***Thrinacodus* cusp** (?) Upper Ballysteen Limestone, Urlingford, Co. Kilkenny	md/GDS/3246/4 195.7-196
36087	**poss *Thrinacodus incurvus* ferox morphotype cusp** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(3)
36808	***Thrinacodus incurvus* nanus morphotype** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36809	**Tricuspid Tooth** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36810	**Chond. dent/scale Morphotype 1** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36811	**Chond. dent/scale Morphotype 2** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36812	**Chond. dent/scale Morphotype 3** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36813	**Hybodont scale Morphotype 2** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36814	**Hybodont scale Morphotype 3** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36815	**Hybodont scale Morphotype 1** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(3)
36816	**Hybodont scale Morphotype 3** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(1)

36817	**Hybodont Scale Morphotype 2** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(1)
36818	**Chond. dent Morphotype 4** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(1)
36819	**Hybodont scale Morphotype 4** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(2)
36820	**Chond. Dent Morphotype 5** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(2)
36821	**Poss. Chond. dent 3** Upper Ballysteen Limestone, Urlingford, Co. Kilkenny	md/GDS/3246/4 181.6-182
36822	**Chond. composite scale/dent** Upper Ballysteen Limestone, Urlingford, Co. Kilkenny	md/GDS/3246/4 181.6-182
36823	**Chond. composite scale/dent** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36824	**Chond. composite scale/dent** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36825	**Chond. composite scale/dent** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36826	**Chond. composite scale/dent** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36827	**Poss. Chond.. Dent. 2** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36828	**Chond. composite scale/dent** Upper Ballysteen Limestone, Urlingford, Co. Kilkenny	md/GDS/3246/4 195.7-196
36829	**Chond. Mucous Membrane Dent.** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36830	**Chond. Mucous Membrane Morphotype 2** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36831	**Chond. Mucous Membrane Morphotype 2** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(1)
36832	**Chond. Mucous Membrane Morphotype 1** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(1)
36833	**Actinopterygian flat scale** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13.	md/dagKQ1(2)
36834	**Actinopterygian flat scale** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13.	md/dagKQ1(2)
36835	**Actinopterygian flat scale** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13.	md/dagKQ1(2)
36836	**Actinopterygian flat scale** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13.	md/dagKQ1(2)
36837	**Chondrichthyan Body Scale** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)

36838	**Hybodont scale Morphotype 1** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13.	md/dagKQ1(2)
36839	**Hybodont scale Morphotype 1** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13.	md/dagKQ1(2)
36840	**Hybodont scale Morphotype 1** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(1)
36841	**Hybodont scale Morphotype 1** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(1)
36842	**Hybodont scale Morphotype 1** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(2)
36843	**Hybodont scale Morphotype 1** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(2)
36844	**Hybodont scale Morphotype 1** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(3)
36845	**? Thrinacodus denticle** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36846	**Hybodont scale Morphotype 2** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36847	**Acanthodian scale** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13.	md/dagKQ1(2)
36848	**Acanthodian scale** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13.	md/dagKQ1(2)
36849	**Acanthodian scale** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13.	md/dagKQ1(2)
36850	**Acanthodian scale** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(1)
36851	**Acanthodian scale** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(2)
36852	**Acanthodian scale** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(3)
36853	**Acanthodian scale** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1
36854	**Acanthodian scale** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1
36855	**Acanthodian scale** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1
36856	**Acanthodian scale** Upper Ballysteen Limestone, Urlingford, Co. Kilkenny	md/GDS/3246/4 218.7-219.1
36857	**Acanthodian scale** Upper Ballysteen Limestone, Urlingford, Co. Kilkenny	md/GDS/3246/4 195.7-196
36858	***Palaeacis* sp.** (Illustrated) Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1

36859	**Actinopterygian scale** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13.	md/dagKQ1(2)
36860	**Actinopterygian scale** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13.	md/dagKQ1(2)
36861	**Actinopterygian scale** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13.	md/dagKQ1(2)
36862	***Vaughania* sp.** (Illustrated) Lyraun Cove Shale Mbr., Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1
36863	**Chondrichthyan crushing tooth** (macro) Lyraun Cove Shale Mbr., Porter's Gate Fm. Hook head, Co. Wexford. S276/100 - sheet 23	md/HHLC1
36864	**Actinopterygian scale** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(1)
36865	**Actinopterygian scale** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(1)
36866	**Rock sample Hook Head** (illustrated) Lyraun Cove Shale Mbr., Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1
36867	**Actinopterygian scale** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(2)
36868	**Actinopterygian scale** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(3)
36869	**Actinopterygian scale** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(3)
36870	**Actinopterygian scale** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(3)
36871	**Actinopterygian scale** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(3)
36872	**Actinopterygian scale** Lyraun Cove Mbr, Porters Gate Fm. Hook Head, Co. Wexford S276/100 - sheet 23	md/HHLC1
36873	**Rock Sample Hook Head (illustrated)** Lyraun Cove Shale Mbr., Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1
36874	**Actinopterygian scale** Upper Ballysteen Limestone, Urlingford, Co. Kilkenny	md/GDS/3246/4 218.7-219.1
36875	**Actinopterygian scale** Upper Ballysteen Limestone, Urlingford, Co. Kilkenny	md/GDS/3246/4 218.7-219.1
36876	**Actinopterygian scale** Upper Ballysteen Limestone, Urlingford, Co. Kilkenny	md/GDS/3246/4 195.7-196
36877	**Actinopterygian scale** Upper Ballysteen Limestone, Urlingford, Co. Kilkenny	md/GDS/3246/4 181.6-182
36878	**Unknown poss gill raker/spine** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13.	md/dagKQ1(2)
36879	**Unknown poss gill raker/spine** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13.	md/dagKQ1(2)

36880	**Unknown poss gill raker/spine** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13.	md/dagKQ1(2)
36881	**Unknown poss gill raker/spine** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13.	md/dagKQ1(2)
36882	**Handle-bar mustache denticle 1** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36883	**Actinopterygian jaw** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36884	**Macro - part of unidentified tooth** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
36885	**Rock thin section KQ1(2)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	dagKQ1(2)
36886	**Rock thin section KQ1(3)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	dagKQ1(3)
36887	**Rock thin section KQ1(4)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	dagKQ1(4)
36888	**Rock thin section KQ1(5)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	dagKQ1(5)
36889	**Rock thin section KQ2(1)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	dagKQ2(1)
36890	**Rock thin section KQ2(3)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	dagKQ2(3)
36891	**Rock thin section KQ2(2)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	dagKQ2(2)
36892	**Rock thin section HHLC1.1** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1
36893	**Rock thin section HHLC1.3** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1
36894	**Rock thin section HHLC1.7** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1
36895	**Rock thin section HHLC1.9** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1
36896	**Rock thin section HHLC1.11** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1
36897	**Rock thin section HHLC1.12** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1
36898	**Rock thin section HHLC1.13** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1
36899	**Rock thin section HHLC1.15** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1
36900	**Rock thin section HHLC1.16** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1

36901	**Rock thin section HHLC1.18** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1
36902	**Rock thin section HHLC1.21** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1
36903	**Rock thin section HHLC1.23** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1
36904	**Rock thin section HHLC1A.1A** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1A
36905	**Rock thin section HHLC1A.1B** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1A
36906	**Rock thin section HHLC1A.2** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1A
36907	**Rock thin section HHLC1A.3** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1A
36908	**Rock thin section HHLC1A.4** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1A
36909	**Picked Residue sample** Upper Ballysteen Limestone, Urlingford, Co. Kilkenny	md/GDS/3246/4 181.6-182
36910	**Picked Residue sample** Upper Ballysteen Limestone, Urlingford, Co. Kilkenny	md/GDS/3246/4 195.7-196
36911	**Picked Residue sample** Upper Ballysteen Limestone, Urlingford, Co. Kilkenny	md/GDS/3246/4 205.6-205.9
36912	**Picked Residue sample** Upper Ballysteen Limestone, Urlingford, Co. Kilkenny	md/GDS/3246/4 218.7-219.1
36813	**Picked Residue sample** Upper Ballysteen Limestone, Urlingford, Co. Kilkenny	md/GDS/3246/4 226-226.35
36914	**Picked Residue sample** Upper Ballysteen Limestone, Urlingford, Co. Kilkenny	md/GDS/3246/4 241.5-241.9
36915	**Picked Residue sample** Upper Ballysteen Limestone, Urlingford, Co. Kilkenny	md/GDS/3246/4 252.3-252.7
36916	**Crinoid** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1A
36917	**Picked Residue sample** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1.1
36918	**Picked Residue sample** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1.2
36919	**Picked Residue sample** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1.3
36920	**Picked Residue sample** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1.4
36921	**Picked Residue sample** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1.6

36922	**Picked Residue sample** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1.7
36923	**Picked Residue sample** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1.9
36924	**Picked Residue sample** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1.15
36925	**Picked Residue sample** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1.20
36926	**Picked Residue sample** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1.21
36927	**Picked Residue sample** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1.23
36928	**Picked Residue sample** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1.27
36929	**Picked Residue sample** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1.28
36930	**Picked Residue sample** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1.30
36931	**Picked Residue sample** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1.31
36932	**Picked Residue sample** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1A.1
36933	**Picked Residue sample** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1A.2
36934	**Picked Residue sample** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1A.3
36935	**Picked Residue sample** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1A.4
36936	**Cavity slide of microvertebrates (not illus.)** Upper Ballysteen Limestone, Urlingford, Co. Kilkenny	md/GDS/3246/4 181.6-182
36937	**Cavity slide of microvertebrates (not illus.)** Upper Ballysteen Limestone, Urlingford, Co. Kilkenny	md/GDS/3246/4 195.7-196
36938	**Cavity slide of microvertebrates (not illus.)** Upper Ballysteen Limestone, Urlingford, Co. Kilkenny	md/GDS/3246/4 205.6-205.9
36939	**Cavity slide of microvertebrates (not illus.)** Upper Ballysteen Limestone, Urlingford, Co. Kilkenny	md/GDS/3246/4 218.7-219.1
36940	**Cavity slide of microvertebrates (not illus.)** Upper Ballysteen Limestone, Urlingford, Co. Kilkenny	md/GDS/3246/4 226-226.35
36941	**Cavity slide of microvertebrates (not illus.)** Upper Ballysteen Limestone, Urlingford, Co. Kilkenny	md/GDS/3246/4 226-226.35
36942	**Cavity slide of microvertebrates (not illus.)** Upper Ballysteen Limestone, Urlingford, Co. Kilkenny	md/GDS/3246/4 241.5-241.9

36943	**Cavity slide of microvertebrates (not illus.)** Upper Ballysteen Limestone, Urlingford, Co. Kilkenny	md/GDS/3246/4 252.3-252.7
36944	**Cavity slide of microvertebrates (not illus.)** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1.3
36945	**Cavity slide of microvertebrates (not illus.)** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1.6
36946	**Cavity slide of microvertebrates (not illus.)** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1.7-B-1
36947	**Cavity slide of microvertebrates (not illus.)** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1.7-B-2
36948	**Cavity slide of microvertebrates (not illus.)** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1.15
36949	**Cavity slide of conodonts (not illus.)** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1.21
36950	**Cavity slide of oddments (not illus.)** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1.21.D.3
36951	**Cavity slide of oddments (not illus.)** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 231	md/HHLC1.21.D.2
36952	**Cavity slide of oddments (not illus.)** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1.21.D.3
36953	**Cavity slide of microvertebrates (not illus.)** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1.21.C.1
36954	**Cavity slide of microvertebrates (not illus.)** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1.21.C.2
36955	**Cavity slide of microvertebrates (not illus.)** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1.21.B.1
36956	**Cavity slide of microvertebrates (not illus.)** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1.23
36957	**Cavity slide of microvertebrates (not illus.)** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1.27
36958	**Cavity slide of microvertebrates (not illus.)** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1.28
36959	**Cavity slide of microvertebrates (not illus.)** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1A.1
36960	**Cavity slide of microvertebrates (not illus.)** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1A.1.2
36961	**Cavity slide of microvertebrates (not illus.)** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1A.2
36962	**Cavity slide of microvertebrates (not illus.)** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1A.3
36963	**Cavity slide of microvertebrates (not illus.)** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1A.4

36964	**Petrie dish of macrovertebrates (not illus.)** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1.21.A (1-4)
36965	**Petrie dish of oddments (not illus.)** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1A.4
36966	**Petrie dish of oddments (not illus.)** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1.21.A.3
36967	**Petrie dish of oddments (not illus.)** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1.21.A.2
36968	**Petrie dish of oddments (not illus.)** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1.20
36969	**Petrie dish of oddments (not illus.)** Lyraun Cove Shale Mbr, Porter's Gate Fm. Hook Head, Co. Wexford. S276/100 - sheet 23	md/HHLC1.7.A.2
36970	**Cavity slide of microvertebrates (not illus.)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)I.II scales
36971	**Cavity slide of microvertebrates (not illus.)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)I.III scales
36972	**Cavity slide of microvertebrates (not illus.)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)I.IV scales
36973	**Cavity slide of microvertebrates (not illus.)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)I.V scales
36974	**Cavity slide of microvertebrates (not illus.)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)I.VI scales
36975	**Cavity slide of microvertebrates (not illus.)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)I.VII scales
36976	**Cavity slide of microvertebrates** (not illus.) Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)I.VIII scales
36977	**Cavity slide of microvertebrates (not illus.)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)I.IX scales
36978	**Cavity slide of microvertebrates (not illus.)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)I.X scales
36979	**Cavity slide of microvertebrates (not illus.)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)I.XI scales
36980	**Cavity slide of microvertebrates (not illus.)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)II.I teeth
36981	**Cavity slide of microvertebrates (not illus.)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)II.II teeth
36982	**Cavity slide of microvertebrates (not illus.)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)II.III teeth
36983	**Cavity slide of microvertebrates (not illus.)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)II.IV teeth
36984	**Cavity slide of microvertebrates (not illus.)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)II.V teeth

36985	**Cavity slide of microvertebrates (not illus.)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)II.VI teeth
36986	**Cavity slide of microvertebrates (not illus.)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)II.VII teeth
36987	**Cavity slide of microvertebrates (not illus.)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)II.VIII teeth
36988	**Cavity slide of microvertebrates (not illus.)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)III.I Oddments
36989	**Cavity slide of microvertebrates (not illus.)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)III.II Oddments
36990	**Cavity slide of microvertebrates (not illus.)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)III.III Oddments
36991	**Cavity slide of microvertebrates (not illus.)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)III.IV Oddments
36992	**Cavity slide of microvertebrates (not illus.)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)III.V Oddments
36993	**Cavity slide of microvertebrates (not illus.)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)IV.I Denticles
36994	**Cavity slide of microvertebrates (not illus.)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)IV.II Denticles
36995	**Cavity slide of microvertebrates (not illus.)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(4) Oddments
36996	**Cavity slide of microvertebrates (not illus.)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(5)I Scales
36997	**Cavity slide of microvertebrates (not illus.)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(5)II Teeth
36998	**Cavity slide of microvertebrates (not illus.)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(5)III Oddments
36999	**Cavity slide of microvertebrates (not illus.)** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(1)I.I Scales
49091	**Picked Residue sample** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(2)
49092	**Picked Residue sample** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(4)
49093	**Picked Residue sample** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ1(5)
49094	**Picked Residue sample** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(1)
49095	**Picked Residue sample** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(2)
49096	**Picked Residue sample** Kilbride Limestone Formation Kilbride Quarries, Co. Meath N845/848 - sheet 13	md/dagKQ2(3)

31087	**Collection of Petalodont Teeth** upper Corgrig Lodge Formation Quarry at south point of Doon, nr Ballybunion, Co. Kerry.	
K28701	**Actinopterygian scale** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MRI
K28702	**Actinopterygian scale** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MRI
K28703	**Actinopterygian scale** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MRI
K28704	**Actinopterygian scale** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MRI
K28705	**Actinopterygian scale** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MRI.II
K28706	**Actinopterygian scale** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MRI.II
K28707	**Actinopterygian scale** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MRI.II
K28708	**Actinopterygian scale** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MRI.II
K28709	**Actinopterygian scale** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MRI.III
K28710	**Actinopterygian scale** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MRI.IV
K28711	**Chond. Hybodont scale Morphotype 3** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MRI.IV
K28712	**Chond. Hybodont scale Morphotype 3** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MRI.IV
K28713	**Two Actinopterygian scales** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MRI.IV
K28714	**Actinopterygian scale** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MRI.IV
K28715	**Unknown affinity** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MRI.V
K28716	**Hybodont scale Morphotype 2** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MRI.V
K28717	**Sarcopterygian tooth** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MRII
K28718	**Sarcopterygian tooth** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MRII
K28719	**Sarcopterygian tooth** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MRII

K28720	**Sarcopterygian tooth** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MRII
K28721	**Tooth of unknown affinity** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MRII
K28722	**Tooth of unknown affinity** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MRII
K28723	**Sarcopterygian - isolated dentary fragment** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM
K28724	**Palynology slide** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM
K28725	**Palynology slide** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM
K28726	**Rock Thin Section** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM
K28727	**Rock Thin Section** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM
K28728	**Picked Residue Sample** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MR
K28729	**Picked Residue Sample** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MR
K28730	**Picked Residue Sample** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MR
K28731	**Picked Residue Sample** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MR
K28732	**Picked Residue Sample** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MR
K28733	**Picked Residue Sample** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MR
K28734	**Picked Residue Sample** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MR
K28735	**Picked Residue Sample** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MR
K28736	**Picked Residue Sample** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MR
K28737	**Picked Residue Sample** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MR
K28738	**Picked Residue Sample** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MR
K28739	**Picked Residue Sample** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MR
K28740	**Picked Residue Sample** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MR

K28741	**Picked Residue Sample** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MR
K28742	**Picked Residue Sample** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MR
K28743	**Picked Residue Sample** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MR
K28744	**Picked Residue Sample** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MR
K28745	**Picked Residue Sample** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MR
K28746	**Picked Residue Sample** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MR
K28747	**Picked Residue Sample** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MR
K28748	**Picked Residue Sample** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MR
K28749	**Picked Residue Sample** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MR
K28750	**Picked Residue Sample** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MR
K28751	**Picked Residue Sample** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MR
K28752	**Picked Residue Sample** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MR
K28753	**Picked Residue Sample** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MR
K28754	**Picked Residue Sample** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MR
K28755	**Picked Residue Sample** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MR
K28756	**Picked Residue Sample** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MR
K28757	**Picked Residue Sample** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MR
K28758	**Picked Residue Sample** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MR
K28759	**Picked Residue Sample** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MR
K28760	**Picked Residue Sample** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MR
K28761	**Picked Residue Sample** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MR

K28762	**Picked Residue Sample** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MR
K28763	**Picked Residue Sample** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MR
K28764	**Picked Residue Sample** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MR
K28765	**Picked Residue Sample** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MR
K28766	**Picked Residue Sample** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MR
K28767	**Picked Residue Sample** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MR
K28768	**Picked Residue Sample** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MR
K28769	**Picked Residue Sample** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MR
K28770	**Large picked sample (Petrie dish)** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MRbig a
K28771	**Large picked sample (Petrie dish)** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MRbig b
K28772	**Cavity Slide - scales** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MRI.I
K28773	**Cavity slide - scales** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MRI.II
K28774	**Cavity slide - scales** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MRI.III
K28775	**Cavity slide - scales** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MRI.IV
K28776	**Cavity slide - scales** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MRI.VI
K28777	**Cavity slide - denticles** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MRI.V
K28778	**Cavity slide - teeth** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MR.II
K28779	**Cavity slide - bone etc. fragments** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MRIII
K28780	**Cavity slide - bone etc. fragments** Mormeal Member, Altagoan Formation, Draperstown, Co. Derry. H792/974 - sheet 19 GSNI	md/UM/MRIII.II

APPENDIX III

III.1 FISH MATERIAL NOTED IN THE MEMOIRS OF THE GEOLOGICAL SURVEY OF IRELAND

The memoirs to accompany Sheets 1-205 of the one-inch-to-mile geological survey of the thirty-two counties of Ireland were published in the late nineteenth and early twentieth century. Detailed locality information can be obtained from the six-inch-to-one-mile field sheets referred to in the individual memoirs. Location numbers quoted below are those from the Memoirs.

Sheet 8, Co. Antrim - Location 3

Broughanlea. On shore road, a little east of Bath Lodge 1.25 miles north east of Ballycastle; dark grey shales. **Fish Remains.** (Published in 1888; palaeontological notes by W.H. Baily, collector Richard Clark)

- Location 10

Cross. East side of Fair Head, c.1.25 miles west of Portdoo. 500' over sea level; red shales. **Fish Remains.** (Published in 1888; palaeontological notes by W.H. Baily, collector Richard Clark)

- Location ?

Ballyreach Lower. Just above coast road, 300 yards east of Bath Lodge. Ministry for Munitions Borehole 1. **Fish scales and tooth.** (Published in 1924; palaeontological notes by E.A. Newell Arber and L.B. Smyth)

Sheet 18, Co. Londonderry - Location 5

Hass. In stream a little east of Hass Lower and half a mile east of Dungiven.
***Palaeoniscus* (scales).** (Published in 1884; palaeontological notes by W.H. Baily, collector - not recorded)

Sheet 24, Co. Donegal - Location 8

?Greenan. Road cutting west shore of Lough Eask, crossing the Eglish Road; "yellow sandstone" (Harte's); light brown calc. grit. ***Psammodus porosus.*** (Published in 1888; palaeontological notes by W.H. Baily, collector William Harte)

Sheet 25, Co. Tyrone - Location 10

Lisnagirr. Quarry 0.75 mile west of Mountjoy Bridge. 5 miles south of Newtownstewart; dark grey compact limestone. ***Helodus*** (fish palate). (Published in 1887; palaeontological notes by W.H. Baily, collector Richard Clark)

Sheet 27, Co. Londonderry - Location 3

Knocknagin. Quarry at village of Desertmartin; compact red limestone. ***Psephodus magnus*** (Palatal tooth). (Published in 1881; palaeontological notes by W.H. Baily, collector - not recorded)

- Location 6

Trial shaft of iron ore. 1.25 miles south west of Cookstown; purple shale. ***Helodus laevissimus*** (palatal tooth). (Published in 1881; palaeontological notes by W.H. Baily, collector- not recorded)

Sheet 30, Donegal - Muckross Point

7 miles south west of Killybegs; dark grey shale. ***Cochliodus deltoideus.*** (Published in 1881; palaeontological notes by W.H. Baily, collector - not recorded)

Sheet 31, Co. Donegal

Along St. John's Point shore line. ***Helodus; Psammodus rugosa.*** (Published in 1891; palaeontological notes by W.H. Baily, collector - R. Clark & W.H. Baily)

- Location 1

Muckross. Rocks on shore at Muckross Point. c. 7 miles south west of Killybegs; lower limestone dark grey shale. ***Cochliodus deltoideus.*** (Published in 1891; palaeontological notes by W.H. Baily, collector - R. Clark & W.H. Baily)

- Location 3

Killulton and Point. Rocks at various places on seashore of the Peninsula leading to St. John's Point; dark grey limestone and shale; lower limestone share. ***Helodus*** sp.; ***Psammodus rugosus.*** (Published in 1891; palaeontological notes by W.H. Baily, collector - R. Clark & W.H. Baily)

- Location 19

Finner. Rocks on seashore, a little south of Aughrus Point, 0.5 mile N of Bundoran Church, 4 miles south west of Ballyshannon; dark grey crinoidal limestone and shale, lower limestone shale. ***Helodus*** sp.; ***Palaeoniscus*** sp. (fin ray); ***Palaeoniscus*** sp. (spine ichthyodorulite); ***Psammodus porosus.*** (Published in 1891; palaeontological notes by W.H. Baily, collector - R. Clark & W.H. Baily)

- Location 20

Magheracar. Cliffs on shore, under Rockfort Lodge, 1 mile west of Bundoran, 5 miles south west of Ballyshannon; dark grey crinoidal limestone and shale, lower limestone shale. ***Helodus gibberulus*** (Published in 1891; palaeontological notes by W.H. Baily, collector - R. Clark & W.H. Baily)

- Location 24

Sheegys. Rocks on west shore of River Erne at Abbey Bay, a little north of Whitehall Point, 1 mile west of Ballyshannon; dark grey shales, lower limestone shale. ***Psammodus*** ? fishbone. (Published in 1891; palaeontological notes by W.H. Baily, collector - R. Clark & W.H. Baily)

Sheet 32, Co. Donegal - Location 43

Tober or Ballymagroarty. Rocks in small stream, 0.25 mile west of Lough Gologh, a little east of National School, 5 miles north of Belleek; light grey limestone. ***Deltodus sublaevis*** . (Published in 1891; palaeontological notes by W.H. Baily, collector - not recorded)

- Location 53

Dreenan. Rocks on shore at west end Boa Island Lough Erne; light grey micaceous sandstone decomposing to ochrey. ***Cladodus mirabilis.*** (Published in 1891; palaeontological notes by W.H. Baily, collector - not recorded)

- Location 64

Tieveolough Glebe. Old quarry, south side of Keenaghan Lough close to Abbey, about 2.25 miles north east of Belleek; dark grey limestone and shales, lower limestone shale. ***Cochliodus contortus; Deltodus*** sp. (Published in 1891; palaeontological notes by W.H. Baily, collector - not recorded)

Sheet 33, Co. Tyrone - Location 4

Billary. 0.25 miles north west of Carrickaness Bridge. 2 miles west of Drumquin; dark grey limestone "upper limestone" on map. ***Helodus planus.*** (Published in 1886; palaeontological notes by W.H. Baily, collector - R. Clark)

Sheet 34, Co. Tyrone - Location 11

Annaghmakeown. Quarry at an outlier of limestone in a bog about 1.5 miles north west of Castlecaulfield; grey compact limestone. ***Palaeoniscus*** ? (scale). (Published in 1878; palaeontological notes by W.H. Baily, collector - not recorded)

- Location 13

Legilly. Old quarry close to stream, about 1.5 miles north west of Derrygortey Glebe House and 2 miles south of Castlecaulfield; dark grey limestone and shale. ***Chomatodus linearis*** (palatal tooth). (Published in 1878; palaeontological notes by W.H. Baily, collector - not recorded)

Sheet 35, Co. Tyrone - Location 2

Castle Farm. A little east of Stewartstown Castle; dove coloured and pinkish limestone. ***Psammodus porosus*** (Published in 1877; palaeontological notes by W.H. Baily, collector - not recorded)

- Location 12

Liskettle. 1.5 miles south west of Stewartstown; dove coloured limestone. ***Chomatodus linearis*** (Published in 1877; palaeontological notes by W.H. Baily, collector- not recorded)

- Location 21

Drumreagh Etra . A little east of Drumreagh House, c. .75 of a mile north west of Coal Island and 1.5 miles south east New Mills. Grey sandstone and shale and black fissile shales. **Caelacanthus ? tooth and scales.** (Published in 1877; palaeontological notes by W.H. Baily, collector - not recorded)

- Location 30

Brackaville. Old Colliery a little north of Coal Island. Black laminated shales. **Caelacanthus ? tooth and scales, *Helodus laevissimus*** palatal tooth, ***Rhizodus Portlocki,*** teeth and scales. (Published in 1877; palaeontological notes by W.H. Baily, collector - not recorded)

- Location 31

Brackaville. A little east Brackaville, c. .25 of a mile north of Coal Island; grey shale. ***Rhizodus Portlocki,*** teeth and scales. (Published in 1877; palaeontological notes by W.H. Baily, collector - not recorded)

- Location 33

Gortnaskea. Clay pit colliery, 1 mile south west Coal Island. Light grey micaceous shale. ***Palaeoniscus*** scales and bone. (Published in 1877; palaeontological notes by W.H. Baily, collector - not recorded)

- Location 34

Gortnaskea. Pit a little north of location 33. Black shales. ***Palaeoniscus*** scales and bone. (Published in 1877; palaeontological notes by W.H. Baily, collector - not recorded)

Sheet 35, Belfast Area

Lower limestone shales. ***Palaeoniscus Robisoni*** ?; ***Palaeoniscus*** sp.; ***Amblypterus punctatus; Psammodus rugosus;*** (Published in 1877; palaeontological notes by W.H. Baily, revised 1904 collector J.A. Wright) ***Ctenacanthus denticulatis.*** (Published in 1877; palaeontological notes by W.H. Baily, revised 1904, collector S.A. Stewart)

Sheet 42, Co. Sligo

A very large palatal tooth of ***Psammodus rugosus*** in a dark grey Carboniferous shale, said to be found by Capt. Jones somewhere near Easkey. (Published in 1880; palaeontological notes by W.H. Baily, collector - given to Enniskillen by Agassiz Recherches sue les Poissons Vol 3, p. 11 plate xix, figure 15)

Sheet 46, Co. Tyrone - Location 7

Boundary of townlands of Bernabane and Glack. Rocks in stream about 1 mile north of Aughnacloy; dark grey limestone and shale. ***Palaeoniscus*** ? fish scale. (Published in 1886; palaeontological notes by W.H. Baily, collector- not recorded.

Sheet 47, Co. Armagh - Location 17

Castlerain. 1 mile east of Loughgall on north side of road to Portadown. Carboniferous limestone. ***Paecilodus Jonesii***. (Published in 1873; palaeontological notes by W.H. Baily, collector - not recorded)

- Location 26

Tullary. 0.5 mile west of Wilson's Bridge - Ulster Railway, 1.5 miles north of Armagh; Carboniferous limestone. ***Ctenacanthus tenuistraitus*** defence spine. (Published in 1873; palaeontological notes by W.H. Baily, collector -many specimens by Admiral Jones and Enniskillen)

- Location 27

Tullyard. A little south west of Wilson's Bridge 1.5 miles north east of Armagh. Carboniferous limestone. ***Ctenopetalus serratus*** (Published in 1873; palaeontological notes by W.H. Baily, collector -many specimens by Admiral Jones and Enniskillen)

- Location 35

Aghamoat. About .25 mile north east of Red Barn, 1 mile south of Armagh. Carboniferous limestone. ***Psephodus magnus; Cochliodus contortus.*** (Published in 1873; palaeontological notes by W.H. Baily, collector -many specimens by Admiral Jones and Enniskillen)

- Location 36

Aghamoat. A little east of "location 35", about 1 mile south of Armagh. Carboniferous limestone. ***Psephodus magnus*** (Published in 1873; palaeontological notes by W.H. Baily, collector -many specimens by Admiral Jones and Enniskillen)

- Location 38

Ballyheridan. A little south west of (north east of Red Barn 1 mile south of Armagh). Carboniferous limestone. ***Psephodus magnus.*** (Published in 1873; palaeontological notes by W.H. Baily, collector - many specimens by Admiral Jones and Enniskillen)

- Location 39

Farmacaffly. A little north east ***mirabilis; Cladodus striatus; Deltophychius acutus; Helodus didymus*** or ***gibberulus; Helodus laevissimus; Paecilodus Jonesii; Psammodus porosus; Psammodus rugosus; Psephodus magnus; Streblodus Colai; Streblodus oblongus*** (Published in 1873; palaeontological notes by W.H. Baily, collector -many specimens by Admiral Jones and Enniskillen)

- Location 42

Navan. Navan quarry 1.5 miles west of Armagh. Carboniferous limestone. ***Cladodus striatus; Cladodus contortus; Petalodus laevissimus; Psammodus porosus; Helodus*** sp. indet. (Published in 1873; palaeontological notes by W.H. Baily, collector - many specimens by Admiral Jones and Enniskillen)

Sheet 53, Co. Mayo - Location 38

Ballina, A little north west of Ballina close to workhouse; dark grey earthy limestone. ***Petalodus Hastingsiae*** (Published in 1879; palaeontological notes by W.H. Baily, collector - not recorded)

- Location 41

Lackan. On seashore, 1 mile south of Pollacheeny Harbour, a little north of road; dark grey compact limestone. ***Labodus prototypus.*** (Published in 1879; palaeontological notes by W.H. Baily, collector - not recorded)

Sheet 54, Co. Sligo

Palatal tooth ***Psammodus porosus*** obtained by Capt. W.R. Dover from Carboniferous shale in river 0.5 mile west of Coolaney. (Published in 1880; palaeontological notes by W.H. Baily, collector - given to Enniskillen)

Sheet 58, Co. Monaghan - Location 4

Hillhall quarry a little north east Faulkland Bridge. Dark blueish limestone and black shale. **Palatal Teeth.** (Published in 1914; palaeontological notes by Dr. G.W. Lee, Geological Survey of Great Britain, collector -not recorded)

- Location 9

Telayden quarry in a field near Lamb's Lough. 1.5 miles north Monaghan. Light grey limestone. (Published in 1914; palaeontological notes by Dr. G.W. Lee, Geological Survey of Great Britain, collector - not recorded)

Sheet 66, Co. Sligo - Location 22

? Quarry 1 mile south-south west of Kilfree 3 miles south-south west of Gorteen; lower limestone. ***Helodus*** etc. (palatal tooth) (Published in 1878; palaeontological notes by W.H. Baily, collector - not recorded)

- Location 29

Doogary. Old quarry south side of road, 0.5 mile west of Drumcurry Lough, about 2 miles north east of Coothall. Lower Carboniferous sandstone. ***Helodus*** etc. (palatal tooth) (Published in 1878; palaeontological notes by W.H. Baily, collector - not recorded)

- Location 31

Breandrum. South side of Boyle River, 1 mile west of Boyle. Lower limestone. ***Helodus*** etc. (palatal tooth) (Published in 1878; palaeontological notes by W.H. Baily, collector - not recorded)

- Location 35

Warren or Drum. A little south west of Drum Lodge 0.5 mile east of Boyle; lower limestone. ***Ctenodus*** (Published in 1878; palaeontological notes by W.H. Baily, collector - not recorded)

- Location 40

? Quarry at Old Church, near west entrance gate of Rockingham Demesne; lower limestone. ***Helodus*** etc. (palatal teeth) (Published in 1878; palaeontological notes by W.H. Baily, collector - not recorded)

- Location 51

Cuiltygower. Rocks in stream 1 mile east of Ballyfornan pits on bottom coal; grey sandstone (coal measures) described as 'Millstone grit' on map. ***Coelacanthus*** bones and scales. - identical with that figured in Explan to Sheet 142 p19 figure 10a (Published in 1878; palaeontological notes by W.H. Baily, collector - not recorded)

- Location 55

Boundary of Carrownault and Derreenavoggy. 1 mile west of Arigna works; dark grey shales, described as 'lower coal measures' on map. ***Palaeoniscus*** scales. (Published in 1878; palaeontological notes by W.H. Baily, collector - not recorded)

Sheet 67, Co. Leitrim - Location 60

Cornashamsoge. At coat pit a little south of Glen Bridge, 3 miles north of Drumshambo; black shales (coal measures) "yaredale" on map. ***Coelacanthus*** bones and scales. (Published in 1878; palaeontological notes by W.H. Baily, collector - not recorded)

Sheet 68, Co. Cavan - Location 32

Derrygeeraghan. 0.5 miles north of Milltown; black limestone and shale. ***Heoldus*** ? (Published in 1878; palaeontological notes by W.H. Baily, collector - not recorded)

- Location 40

Countenan. 0.5 miles south of Courtenan House, about 4 miles east of Cavan; dark grey limestone and shales. ***Helodus gibberulus*** (Published in 1878; palaeontological notes by W.H. Baily, collector - not recorded)

- Location 41

Coolnagor or Rice Hill. A little south of Rice Hill 2.5 miles south west of Cavan; dark grey limestone and shales. ***Paecilodus transversus*** (Published in 1878; palaeontological notes by W.H. Baily, collector - not recorded)

Sheet 70, Co. Louth - Location 17

Knockagh. Quarry north side of river, 0.25 miles west of Ford's Bridge, 3 miles north west of Dundalk. Carboniferous limestone. ***Psephodus magnus*** (Published in 1877; palaeontological notes by W.H. Baily, collector - not recorded)

Sheet 74, Co. Mayo - Location 3

Cloonmonad. 1 miles north east of Kinlovey Lake about 2 miles south west of Westport; limestone. ***Psammodus porosus*** palatal tooth. (Published in 1876; palaeontological notes by W.H. Baily, collector - not recorded)

Sheet 75, Co. Mayo - Location 6

Annagh. 0.5 miles north of Cloonkeen, 4 miles south west of Castlebar; Carboniferous limestone. ***Helodus laevissimus*** (Published in 1872; palaeontological notes by W.H. Baily, collector - not recorded)

Sheet 78, Co. Leitrim - Location 17

Killamaun at Lough Errill Bridge north side of road from Mohill to Drumsna, 2 miles west of Mohill; black limestone and shales. ***Helodus laevissimus*** Palatal teeth. (Published in 1873; palaeontological notes by W.H. Baily, collector - not recorded)

Sheet 80, Co. Meath - Location 33

Crossdrum lower. Quarry on branch road from Castlecor to Roman Catholic Chapel; moat 1.5 miles west of Oldcastle; grey crinoidal limestone. ***Helodus laevissimus*** palatal teeth and undetermined fish palates and fragments. (Published in 1873; palaeontological notes by W.H. Baily, collector - not recorded)

Sheet 90, Co. Meath - Location 26

Mullaghstares. Quarry on north side of road about 0.5 miles east of Athboy; dark grey limestone and shales; ? junction beds lower coal measures and Carboniferous limestone. ?? fish scale. (Published in 1872; palaeontological notes by W.H. Baily, collector - not recorded)

Sheet 91, Co. Meath - Location 39

Knowth. north side River Boyne near Knowth House, 2 miles south east of Slane; black splintery shale. ***Coelacanthus*** ? fish bones and impression of scales. (Published in 1871; palaeontological notes by W.H. Baily, collector - not recorded)

- Location 46

Stalleen. South side of River Boyne, close to 'The Collage' 3 miles south west of Drogheda; black shales. ***Coelacanthus*** ? opercular bone. (Published in 1871; palaeontological notes by W.H. Baily, collector - not recorded)

- Location 47

Stalleen. Road cutting about 0.5 miles south west of Darone. ***Coelacanthus*** ? fish remains. (Published in 1871; palaeontological notes by W.H. Baily, collector - not recorded)

- Location 43

Roughgrange. South side of River Boyne cutting in old road to Duleek. 3.5 miles south east of Slane; black shales. ? fish (Published in 1871; palaeontological notes by W.H. Baily, collector - J. Flanagan)

Sheet 102, Co. Dublin - Location 3

Tobergreggan. 1.5 miles west-south west of Garristown, coal measures. Fish bones and scales. (Published in 1865; palaeontological notes by W.H. Baily, collector - not recorded)

- Location 6

Westown. In bed of River Devlin at Ford of Fine. Upper limestone. Fish bones and scales. (Published in 1865; palaeontological notes by W.H. Baily, collector - not recorded)

- Location 7

Knockbrack. Small quarry in the glen. Coal measures. Fish bones and scales. (Published in 1865; palaeontological notes by W.H. Baily, collector - not recorded)

- Location 9

Belgee. Quarry a little south of cross roads. Coal measures. Fish bones and scales. (Published in 1865; palaeontological notes by W.H. Baily, collector - not recorded)

- Location 10

Courtlough. Quarry close to road about 0.75 miles north west of Man of War. Upper part of coal measures. Fish defence spine? (Published in 1865; palaeontological notes by W.H. Baily, collector - not recorded)

- Location 12

Holmpatrick. On shore a little north of townland boundary; lower limestone. ***Chomtodus*** palatal tooth. (Published in 1865; palaeontological notes by W.H. Baily, collector - not recorded)

- Location 18

Malahide. Seamount quarries; lower limestone. ***Psammodus*** ? palatal tooth. (Published in 1865; palaeontological notes by W.H. Baily, collector - not recorded)

- Location 19

Robbswalls and Carrickhill. The Malahide shore; lower limestone. ***Psammodus*** ? palatal tooth. (Published in 1865; palaeontological notes by W.H. Baily, collector - not recorded)

Sheet 111, Co. Dublin - Location 46

Brownsbarn. Road cutting and quarries south of Corkagh; upper limestone. Fish scales ? (Published in 1860; palaeontological notes by W.H. Baily, collector - not recorded)

Sheet 112, Co. Dublin - Location 57

Roebuck, part of Crumlin. Quarry south east of Cromwells Fort; upper limestone. ***Cochliodus*** ? palatal tooth. (Published in 1860; palaeontological notes by W.H. Baily, collector - not recorded)

Sheet 127, Co. Laois

Mountrath quarry. West of the town beds of black impure limestone. ***Orodus ramosus*** large palatal tooth, purchased at the quarry said to have been obtained from the black limestone at the lowest part of the quarry. Same teeth occur in the Lower Carboniferous limestone at Hook Point, Co. Wexford. (Published in 1881; palaeontological notes by W.H. Baily, collector - not recorded)

Sheet 128, Co. Kilkenny - Location 7

Skehana, Skehana Colliery about 2 miles north west of Castlecomer. Dark grey and micaceous shales. Lower Coal Measures. ***Rhizodus* (Holoptychius) Portlocki,** opercular bone of fish. (Published in 1881; palaeontological notes by W.H. Baily, collector - not recorded).

Sheet 142, Co. Clare

Rossduff. Coal measures of Co. Clare. 1 mile south of Foynes at a cutting in the old road. Fish bones and scales. (Published in 1860; palaeontological notes by W.H. Baily, collector - G.H. Kinahan, F.J. Foot and Baily)

Sheet 147, Co. Kilkenny - Location 19

Cloneen. Jarrow Colliery. 1 mile south east of Clough, 4 miles north east of Castlecomer. Dark grey shale. Middle Coal Measures. ***Campylopleuron*** **sp. (Huxley).,** ***Ctenodus*** **sp. (palatal tooth),** ***Gyracanthus formosus, Palaeoniscus ?, Rhizodus*** **(Megalithys) Hibberti.** (Published in 1881; palaeontological notes by W.H. Baily, collector - not recorded)

- Location 20

Clonbrook. Geneva Colliery. Near Castlebrook House, c. 4.5 miles north east of Castlecomber. Dark grey shales. Middle Coal Meaures. Unidentified fish shales and bones. (Published in 1881; palaeontological notes by W.H. Baily, collector - Benjamin Edge)

- Location 23

Farnham at 'Englishmans Pit'. near Holly Park Colliery, c. 1.5 miles east-north east of New Coal Pit, c. 6.25 miles north east of Castlecomer. Middle Coal Measures. ***Hewlodus laevissimus***. (Published in 1881; palaeontological notes by W.H. Baily, collector - not recorded)

Sheet 153, Co. Limerick - Location 16

Croagh Commons? ***Holoptychius Portlockii*** (Published in 1861; palaeontological notes by W.H. Baily, collector - not recorded. GSI NO. F 22925)

Sheet 168, Co. Wexford - Location 28

Porters Gate, Loftus Hall, Churchtown and Slade. Various localities around Hook Head from Lumsdin's Bay to the Lighthouse and Warwoy Bay; lower limestone. ***Cochliodus (Psammodus) contortus, Chomatodus (Psammodus) linceris, Helodus (Psammodus) laevissimus, Helodus*** ? ***(Psammodus) cinctus, Oroodus ramosus, Oroodus cenctus*** ?, ***Psammodus porosus*** all palatal teeth***, Palaeoniscus Egertoni*** scales. (Published in 1865; palaeontological notes by W.H. Baily, collector - not recorded)

Sheet 169, Co. Wexford - Location 9

Kerloge. About 1.5 mile south of Wexford; dark grey limestone with decomposing arenaceous beds.. ***Helodus*** sp. indet. (Published in 1879; palaeontological notes by W.H. Baily, collector - not recorded)

- Location 13

Scar. Quarry on boundary of townlands of Scar and Knocktown a little south west of Knocktown Crossroads and 2 miles N of Duncormick; dary earthy shales. ***Cochliodus obliquus*** (Published in 1879; palaeontological notes by W.H. Baily, collector - not recorded)

Sheet 177, Co. Waterford - Location 6 (ORS)

Tallowbridgelands. Tallowbridge upper ORS. Fish scales ***Glyptolepis*** ?? (Published in 1864; palaeontological notes by W.H. Baily, collector - not recorded)

Sheet 191, Co. Kerry - Location 23

Collorus. Shore opposite Black Island on east side of Ardgroom Harbour. Scale of ***Holoptychius*** (Published in 1864; palaeontological notes by W.H. Baily, collector - not recorded)

Sheet 194, Co. Cork - Location 54

Ballyheedy. Halfway between Priest's Bridge and Ballyheedy; coal measure shales? ***Coelacanthus*** sp. (Published in 1864; palaeontological notes by W.H. Baily, collector - not recorded)

- Location 55

Skehanagh. West of Ballyheedy Roman Catholic Chapel; coal measure shales. ***Coelacanthus*** sp; ***Palaeoniscus*** sp. (Published in 1864; palaeontological notes by W.H. Baily, collector - not recorded. Updated 1905)

Sheet 195, Co. Cork - Location 71b

Meadtown. In lane 500 yards west of Meadstown ?coal measure shales. Fish scales. (Published in 1864; palaeontological notes by W.H. Baily, collector - not recorded)

III.2 National Museum of Ireland Collection of Fossil Fish Teeth from the Armagh Limestone

Catalogue No:	**Museum Identification:**
F15114 - F15158	*Psammodus rugosus* Agassiz
F15159 - F15163	UK and no locality
F15164	*Streblodus oblongus* Agassiz
F15165 - F15166	*Streblodus colei* Agassiz
F15167	*Helodus turgidus*
F15168 - F15172	*Helodus obliquus*
F15173 - 15180	*Xystrodus striatus* Agassiz
F15181	*Xystrodus angustus* Agassiz
F15182	*Xystrodus striatus* Agassiz
F15183	not named
F15184 - F15204	*Phsephodus magnus* Agassiz
F15205 - F15213	*Ctenopetalus serratus* Agassiz
F15214 - F15215	*Poecilodus jonsesi* Agassiz
F15216 - F15218	*Helodus*
F15219	*Polyrhizodus colei* Davis
F15220 - F15222	not named
F15223 - F15231	*Copodus prototypus* (? = *Labodus prototupus*) Agassiz
F15232 - F15235	*Petalorhynchus psittoacinus* Agassiz
F15236 - F15238	*Polyrhizodus sinautus* (? = *P. sinuosus* Davis
F15239 - F15240	*Orodus gibbus* Agassiz
F15241	*Lophodus bifurcatuss* Davis
F15242	*Lophodus laevissimus* Agassiz
F15243	*Helodus laevissimus*
F15244- F15278	*Poecilodus jonesi* Agassiz
F15279	*Poecilodus transversus*
F15280	*Poecilodus*
F15281	*Streblodus oblongus* Agassiz
F15282 - F15283	*Orodus catenatus* Agassiz
F15284 - F152304	*Psephodus magnus* Agassiz
F15305	not named
F15306	*Polyrhizodus elongatus* Davis
F15307	*Chomatodus*
F15308 - F15310	*Ctenoptychius dentatus*

F15311 - F15312	*Pleuroplax woodi*
F15313	*Cladodus mirabilis* Agassiz
F15314 - F15316	*Cladodus striatus* Agassiz
F15317	*Petalodus hastingsiae* Owen
F15318 - F15319	*Petalodus acuminatus* Agassiz
F15320 - F15322	*Petalodus hastingsiae* Owen
F15323	*Petalodus radicans* (? = *Polyrhyizodus radicans* Agassiz)
F15324 - F15327	*Petalodus*
F15328 - F15349	*Copodus cornutus* Agassiz
F15350 - F15351	*Comatodus truncatus* ? (?spelt *Chomatodus*)
F15352 (Silurian)	
F15353 - F15361	*Ctencanthus heterogyrus* Agassiz
F15362	*Ctencanthus dubius* Davis
F15363 - F15365	*Psammodus rugosus* Agassiz
F15366	*Streblodus oblongus* Agassiz
F15367 - F15369	*Cochliodus contortus* Agassiz
F15370	not named
F15371 - F15373	*Acondylacanthus colei* Davis
F15374	*Acondylacanthus attenuatus* Davis
F15375	*Lophodus mammilaris* Agassiz
F15376 - F15387	*Polyrhizodus magnus*
F15388	*Orodus moniliformis* Davis
F15389	*Erismacanthus jonesi*
F15390	*Cosmacanthus priscus*
F15391 - F15393	*Asterroptychius ornatus*
F15394 - F15395	*Ctenoptychius dentatus*
F15396 - F15401	*Oracanthus milleri*
F16999 - F17089	not named

This information was kindly supplied by N. Monaghan, Curator-Geology, National History of Ireland, Dublin.

III.3 TRINITY COLLEGE DUBLIN - CARBONIFEROUS MACROFISH COLLECTION

TCD No:	Specimen, lithology, location	Collector:
{**Armagh**}		
F4	Fish Tooth (museum spec.) Carb. Limestone. Armagh.	
17993	*Polyrhizodus elongatus* (museum spec.) Dinantian, Carboniferous. Armagh.	
17994	*Orodus ramosus* Agassiz Armagh Limestone. Red Barn. Armagh.	
24713	*Oracanthus* Carb. Limestone assumed to be Armagh	
23825	Unidentified Carb. Limestone assumed to be Armagh.	
23837	Unidentified Carb. Limestone Armagh	

24686	*Psammodus* Carb. Limestone Armagh	
24695	*Psammodus* Carb. Limestone Armagh	
36530	Unidentified Carb. Limestone Index 2. Armagh	
36531	Unidentified Carb. Limestone Index 2. Armagh	
36532	Unidentified Carb. Limestone Index 2. Armagh	
36533	Unidentified Carb. Limestone Index 2. Armagh	
36534	Unidentified Carb. Limestone Index 2. Armagh	
36535	Unidentified Carb. Limestone Index 2. Armagh	
36536	Unidentified Carb. Limestone Index 2. Armagh	
36537	*Psammodus Way.. rugosus* ? allied to Carb. Limestone Co. Armagh	Dr. Porter
36538	Unidentified Carb. Limestone Index 3. Armagh	
36539	Unidentified Carb. Limestone Index 4. Armagh	
36540	Unidentified Carb. Limestone Index 4. Armagh	
36541	? *Coochliodus* Carb. Limestone Armagh	
36542	Unidentified Carb. Limestone Index 2. Co. Armagh	
36543	Unidentified Carb. Limestone "Hut"? 15.2. Armagh	

36544 Unidentified
Carb. Limestone
Index ?. Armagh

36545 *Petalodus m..i.us* (rest of label illegible)
Lower Limestone
assumed to be Armagh

36546 *Psammodus ramosus*
Carb. Limestone
Armagh

36547 Tooth of Fish (Ray)
Carb. Limestone
assumed to be Armagh

36548 label illegible
Carb Limestone
assumed to be Armagh

36549 *Cochliodus magmus*
Carb. Limestone
Armagh

36550 Unidentified
Armagh Limestone
Red Barn. Armagh.

36551 *Paecilodus oublaevis*
Armagh Limestone.
Red Barn. Armagh.

36552 Unidentified
Armagh Limestone.
Red Barn. Armagh.

36553 *Psammodus rugosus*
Armagh Limestone.
Red Barn 3. Armagh.

36554 *Psammodus rugosus*
Lower Limestone
Red Barn. Armagh.

36555 Unidentified
Armagh Limestone
Red Barn. Armagh.

36556 *Cochliodus contortus*
Armagh Limestone
Red Barn. Armagh.

36557 (fragment of broken tooth)
Armagh Limestone
Red Barn. Armagh.

36558 *Cochliodus magnus*
Armagh Limestone
Red Barn. Armagh

36559 Unidentified
Armagh Limestone
Red Barn. Armagh

36560 *? Cochliodus contortus*
Armagh Limestone
Red Barn. Armagh

36561 *Helodus*
Armagh Limestone
Red Barn. Armagh

36562 Unidentified
Carb. Limestone
assumed to be Armagh

36563 Unidentified
Carb. Limestone
assumed to be Armagh

36564 Unidentified
Carb. Limestone
assumed to be Armagh

36565 tooth
Carb. Limestone
assumed to be Armagh

36566 tooth
Carb. Limestone
assumed to be Armagh

36567 Unidentified
Carb. Limestone
assumed to be Armagh

36568 Unidentified
Carb. Limestone
assumed to be Armagh

36569 tooth
Carb. Limestone
assumed to be Armagh

36570 tooth
Carb. Limestone
assumed to be Armagh

36571 Unidentified
Carb. Limestone
assumed to be Armagh

36572 Unidentified
Carb. Limestone
assumed to be Armagh

36573 Unidentified
Carb. Limestone
assumed to be Armagh

36574 Unidentified
Carb. Limestone
assumed to be Armagh

36575 Unidentified
Carb. Limestone
assumed to be Armagh

36576 Unidentified
Carb. Limestone
assumed to be Armagh

36577 Unidentified
Carb. Limestone
assumed to be Armagh

36578 Spine
Carb. Limestone
assumed to be Armagh

36585 *Psammodus rugosus*
Armagh Limestone.
Red Barn, Armagh

36586 Unidentified
Carb. Limestone
assumed to be Armagh

36587 *Cochliodus*
Armagh Limestone.
Armagh, Tynan or Tynam

36588 Unidentified
Carb. Limestone
Index 3, Armagh

36589 Unidentified
Carb. Limestone
Index 2. Armagh

36590 Unidentified
Carb. Limestone (label missing)
assumed to be Armagh.

36591 Unidentified
Carb. Limestone
assumed to be Armagh.

36592 Unidentified
Carb. Limestone,
Red Barn, Armagh

36593 Unidentified
Carb. Limestone.
Index 4, Armagh

36594 Unidentified
Carb. Limestone
Index 4, Armagh

36595 *Helodus planus*
Carb. Limestone
Red Barn, Armagh

36596 Unidentified
Carb. Limestone
assumed to be Armagh

36598 Unidentified
Carb. Limestone
assumed to be Armagh.

36599 Unidentified
Carb. Limestone
assumed to be Armagh. "5"

36600 Unidentified
Carb. Limestone
assumed to be Armagh. "17"

36601 Unidentified
Carb. Limestone
assumed to be Armagh. "20"

36602 Unidentified
Carb. Limestone
assumed to be Armagh. "5"

36603 *Petalodus radicans & rectus*
Carb. Limestone
assumed to be Armagh

36604 *Cocoliodus contortus*
Carb. Limestone
assumed to be Armagh.

36605 *Psammodus rugosus*
Carb. Limestone
assumed to be Armagh.

36606 *Cochliodus*
Carb. Limestone
assumed to be Armagh.

36607 *Helodus turgidus*
Carb. Limestone
assumed to be Armagh.

36609 *Paecilodus*
Carb. Limestone
assumed to be Armagh.

36610 *Paecilodus sublaevis*
Carb. Limestone
assumed to be Armagh.

36612 *Cochliodus magnus*
Carb. Limestone
assumed to be Armagh.

36613 Unidentified
Carb. Limestone
assumed to be Armagh.

36614 Unidentified
Carb. Limestone
assumed to be Armagh.

36615 Unidentified
Carb. Limestone
assumed to be Armagh.

36616 Unidentified
Carb. Limestone
assumed to be Armagh.

36617	Unidentified Carb. Limestone assumed to be Armagh.
36618	Unidentified Carb. Limestone assumed to be Armagh.
36619	Unidentified Carb. Limestone assumed to be Armagh.
36620	Unidentified Carb. Limestone assumed to be Armagh.
36621	Unidentified Carb. Limestone assumed to be Armagh.
36622	Unidentified Carb. Limestone assumed to be Armagh
36623	Unidentified Carb. Limestone assumed to be Armagh
36624	Unidentified Carb. Limestone assumed to be Armagh.
36625	Unidentified Carb. Limestone assumed to be Armagh.
36626	Unidentified Carb. Limestone assumed to be Armagh.
36627	Unidentified Carb. Limestone assumed to be Armagh.
36628	Unidentified Carb. Limestone assumed to be Armagh.
36629	Unidentified Carb. Limestone assumed to be Armagh.
36630	Unidentified Carb. Limestone assumed to be Armagh.
36631	Unidentified Carb. Limestone assumed to be Armagh.
36632	Unidentified Carb. Limestone assumed to be Armagh.

36633	Unidentified Carb. Limestone assumed to be Armagh
36634	Unidentified Carb. Limestone assumed to be Armagh
36635	Unidentified Carb. Limestone assumed to be Armagh
36636	Unidentified Carb. Limestone assumed to be Armagh
36637	Unidentified Carb. Limestone assumed to be Armagh
36638	Unidentified Carb. Limestone assumed to be Armagh.
36639	Unidentified Carb. Limestone assumed to be Armagh
36640	Unidentified Carb. Limestone assumed to be Armagh.
36641	Unidentified Carb. Limestone assumed to be Armagh.
36642	Unidentified Carb. Limstone assumed to be Armagh
36643	Unidentified Carb. Limestone assumed to be Armagh
36644	Unidentified Carb. Limestone assumed to be Armagh.
36645	Unidentified Carb. Limestone assumed to be Armagh.
36646	Unidentified Carb. Limestone assumed to be Armagh.
36647	Unidentified Carb. Limestone assumed to be Armagh.
36648	Unidentified Carb. Limestone assumed to be Armagh.

36649 Unidentified
Carb. Limestone
assumed to be Armagh.

36650 Unidentified
Carb. Limestone
assumed to be Armagh.

36651 *Psammodus* sp?
Carb. Limestone
assumed to be Armagh.

36652 Unidentified
Carb. Limestone
assumed to be Armagh

36653 *Ptenacanthus ? onchus?*
L. Limestone
Ballygally, Loughgall, Armagh

36654 Unidentified
Carb. Limestone
assumed to be Armagh. "101"

36655 Unidentified
Carb. Limestone
assumed to be Armagh.

36656 Unidentified
Carb. Limestone
assumed to be Armagh.

36657 Unidentified
Carb. Limestone
assumed to be Armagh.

36658 Unidentified
Carb. Limestone
assumed to be Armagh.

36659 *Asteroptychius ornatus*
L. Limestone
Ballygally, Loughgall, Armagh.

36661 Unidentified
Carb. Limestone
assumed to be Armagh

36662 Unidentified
Carb. Limestone
assumed to be Armagh.

36663 Unidentified
Carb. Limestone
assumed to be Armagh.

36664 Unidentified
Carb. Limestone
assumed to be Armagh.

36665 Unidentified
Carb. Limestone
assumed to be Armagh.

36666 Unidentified
Carb. Limestone
assumed to be Armagh.

36667 Unidentified
Carb. Limestone.
assumed to be Armagh. "11"

36668 Unidentified
Carb. Limestone
assumed to be Armagh.

36669 Unidentified
Carb. Limestone
assumed to be Armagh.

36670 Unidentified
Carb. Limestone
assumed to be Armagh.

36671 Unidentified
Carb. Limestone
assumed to be Armagh.

36672 Unidentified
Carb. Limestone
assumed to be Armagh.

36673 *Psammodus rugosus*
L. Limestone
Ballygally, Loughgall, Armagh. 6.

36674 Unidentified
Carb. Limestone
assumed to be Armagh.

36675 Unidentified
Carb. Limestone
assumed to be Armagh.

36676 Unidentified
Carb. Limestone.
Armagh. Tynan or Tynam

36677 Unidentified
Carb. Limestone,
Red Barn, Armagh.

36678 Unidentified
Carb. Limestone
assumed to be Armagh

36679 Unidentified
Carb. Limestone
Red Barn, Armagh.

36680 Unidentified
Carb. Limestone
assumed to be Armagh.

36579 Spine
?
? Armagh?

36580 Spine
?
? Armagh

36581 Spine
?
? Armagh?

36582 tooth
?
?

36583 tooth
?
? Armagh?

24714 *Cosmacanthus marginalis* Davis
Carb. Limestone
Red Barn, Armagh

{**Hook Head**}

05569 fish fragment
Lower Carboniferous
Hk 3h 7, Lyraun, Hook Head, Co. Wexford
L.B. Smyth Coll.

05570 fish debris
Lower Carboniferous
Hk 3h, Hook Head, Co. Wexford.
L.B. Smyth Coll.

05571 fish debris
Lower Carboniferous
Hk 3h, Hook Head, Co. Wexford.
L.B. Smyth Coll.

05572 fish debris
Lower Carboniferous
Hk 3h, Hook Head, Co. Wexford.
L.B. Smyth Coll.

05573 fish debris
Lower Carboniferous
Hk 3h, Hook Head, Co. Wexford.
L.B. Smyth Coll.

05574 fish debris
Lower Carboniferous
Hk 17 w, Hook Head, Co. Wexford.
L.B. Smyth Coll.

05575 *Deltodus sublaevis* Agassiz
Lower Carboniferous
Hk 18w 4, Hook Head, Co. Wexford.
L.B. Smyth Coll.

05576 fish debris
Lower Carboniferous
Hk 19d 2, Hook Head, Co. Wexford.
L.B. Smyth Coll.

05577 fish debris
Lower Carboniferous
Hk 23a, Hook Head, Co. Wexford.
L.B. Smyth Coll.

05578	fish debris Lower Carboniferous Hk 30c, Hook Head, Co. Wexford.	L.B. Smyth Coll.
05579	fish debris ? *Deltodus* spine 2 pieces Lower Carboniferous Hk 13b 27	L.B. Smyth Coll.
05580	fish debris Lower Carboniferous Hk 30c, Hook Head, Co. Wexford.	L.B. Smyth Coll.
05581	fish debris Lower Carboniferous Hk 30c 9, Hook Head, Co. Wexford.	L.B. Smyth Coll.
05582	fish debris Lower Carboniferous Hk 32m, Hook Head, Co. Wexford.	L.B. Smyth Coll.
05583	fish debris Lower Carboniferous Hk 32s, Hook Head, Co. Wexford	L.B. Smyth Coll.
05584	fish debris Lower Carboniferous Hk 31 1 Hook Head, Co. Wexford.	L.B. Smyth Coll.
05585	fish debris Lower Carboniferous Hk 31, Hook Head, Co. Wexford.	L.B. Smyth Coll.
05586	fish debris Lower Carboniferous Hk 31 2, Hook Head, Co. Wexford.	L.B. Smyth Coll.
05587	fish debris Lower Carboniferous Hook Head, Co. Wexford.	L.B. Smyth Coll.
05588	fish debris Lower Carboniferous Hook Head, Co. Wexford.	L.B. Smyth Coll.
05589	fish debris Lower Carboniferous Hook Head, Co. Wexford.	L.B. Smyth Coll.
05590	fish debris Lower Carboniferous Hook Head, Co. Wexford.	L.B. Smyth Coll.
05591	fish debris Lower Carboniferous Hook Head, Co. Wexford.	L.B. Smyth Coll.
05592	fish debris Lower Carboniferous Hook Head, Co. Wexford.	L.B. Smyth Coll.
05593	fish debris Lower Carboniferous Hook Head, Co. Wexford.	L.B. Smyth Coll.

05594	fish debris Lower Carboniferous Hook Head, Co. Wexford.	L.B. Smyth Coll.
05595	fish debris Lower Carboniferous Hook Head, Co. Wexford.	L.B. Smyth Coll.
05596	fish debris Lower Carboniferous Hook Head, Co. Wexford.	L.B. Smyth Coll.
05597	fish debris Lower Carboniferous Hook Head, Co. Wexford.	L.B. Smyth Coll.
05598	fish debris Lower Carboniferous Hook Head, Co. Wexford.	L.B. Smyth Coll.
05599	fish debris Lower Carboniferous Hook Head, Co. Wexford.	L.B. Smyth Coll.
05600	fish debris Lower Carboniferous Hook Head, Co. Wexford.	L.B. Smyth Coll.
05601	fish debris Lower Carboniferous Hook Head, Co. Wexford.	L.B. Smyth Coll.
05602	fish debris Lower Carboniferous Hook Head, Co. Wexford.	L.B. Smyth Coll.
05603	fish debris Lower Carboniferous Hook Head, Co. Wexford.	L.B. Smyth Coll.
05604	fish debris Lower Carboniferous Hook Head, Co. Wexford.	L.B. Smyth Coll.
05605	fish debris Lower Carboniferous Hook Head, Co. Wexford.	L.B. Smyth Coll.
05606	fish debris Lower Carboniferous Hook Head, Co. Wexford.	L.B. Smyth Coll.
05607	fish debris Lower Carboniferous Hook Head, Co. Wexford.	L.B. Smyth Coll.
05608	fish debris Lower Carboniferous Hook Head, Co. Wexford.	L.B. Smyth Coll.
05609	fish debris Lower Carboniferous Hook Head, Co. Wexford.	L.B. Smyth Coll.

05610	fish debris Lower Carboniferous Hook Head, Co. Wexford.	L.B. Smyth Coll.
05611	fish debris Lower Carboniferous Hook Head, Co. Wexford.	L.B. Smyth Coll.
05612	fish debris Lower Carboniferous Hook Head, Co. Wexford.	L.B. Smyth Coll.
05613	fish debris Lower Carboniferous Hook Head, Co. Wexford.	L.B. Smyth Coll.
05614	fish debris Lower Carboniferous Hook Head, Co. Wexford.	L.B. Smyth Coll.
05615	fish debris Lower Carboniferous Hook Head, Co. Wexford.	L.B. Smyth Coll.
05616	fish debris Lower Carboniferous Hook Head, Co. Wexford.	L.B. Smyth Coll.
05617	fish debris Lower Carboniferous Hook Head, Co. Wexford.	L.B. Smyth Coll.
05618	fish debris Lower Carboniferous Hook Head, Co. Wexford.	L.B. Smyth Coll.
05619	fish debris Lower Carboniferous Hook Head, Co. Wexford.	L.B. Smyth Coll.
05620	fish debris Lower Carboniferous Hook Head, Co. Wexford.	L.B. Smyth Coll.
05621	fish debris Lower Carboniferous Hook Head, Co. Wexford.	L.B. Smyth Coll.
05622	fish debris Lower Carboniferous Hook Head, Co. Wexford.	L.B. Smyth Coll.
05623	fish debris Lower Carboniferous Hook Head, Co. Wexford.	L.B. Smyth Coll.
05624	fish debris Lower Carboniferous Hook Head, Co. Wexford.	L.B. Smyth Coll.
05625	fish debris Lower Carboniferous Hook Head, Co. Wexford.	L.B. Smyth Coll.

05626	fish debris Lower Carboniferous Hook Head, Co. Wexford.	L.B. Smyth Coll.
05627	fish debris Lower Carboniferous Hook Head, Co. Wexford.	L.B. Smyth Coll.
05628	fish debris Lower Carboniferous Hook Head, Co. Wexford.	L.B. Smyth Coll.
05629	fish debris Lower Carboniferous Hook Head, Co. Wexford.	L.B. Smyth Coll.
05630	fish debris (30 pieces) Lower Carboniferous Hk 3h, Hook Head, Co. Wexford.	L.B. Smyth Coll.
23867	*Orodus ramosus* Agassiz Lr. Carb (C2) Hook Head, Co. Wexford.	
24150	tooth Courceyan (Carb) Hook Head, Co. Wexford	
36584	fish debris Lower Carboniferous Hk 30 e 2, Hook Head, Co. Wexford.	L.B. Smyth Coll.
36597	*Psammodus* sp. Carboniferous assumed to be Hook Head 268	
36660	*Psammodus porosus* Lower Carboniferous Limestone Hook Head, Co. Wexford	
36681	Unidentified Carboniferous possibly Hook Head, Co. Wexford.	
36683	Unidentified ?'fish shales' possibly Hook Head, Co. Wexford	
36684	Unidentified ?'fish shales' possibly Hook Head, Co. Wexford	
36685	Unidentified ?'Michelinia beds' poss. Hook Head, Co. Wexford	
36686	*Psammodus porosus* Lower Carboniferous Doornage Bay, Hook Head, Co. Wexford.	L.B. Smyth Coll.