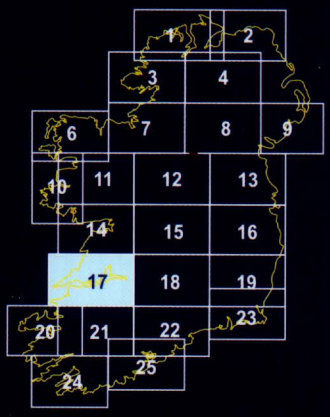
GEOLOGY OF THE SHANNON ESTUARY



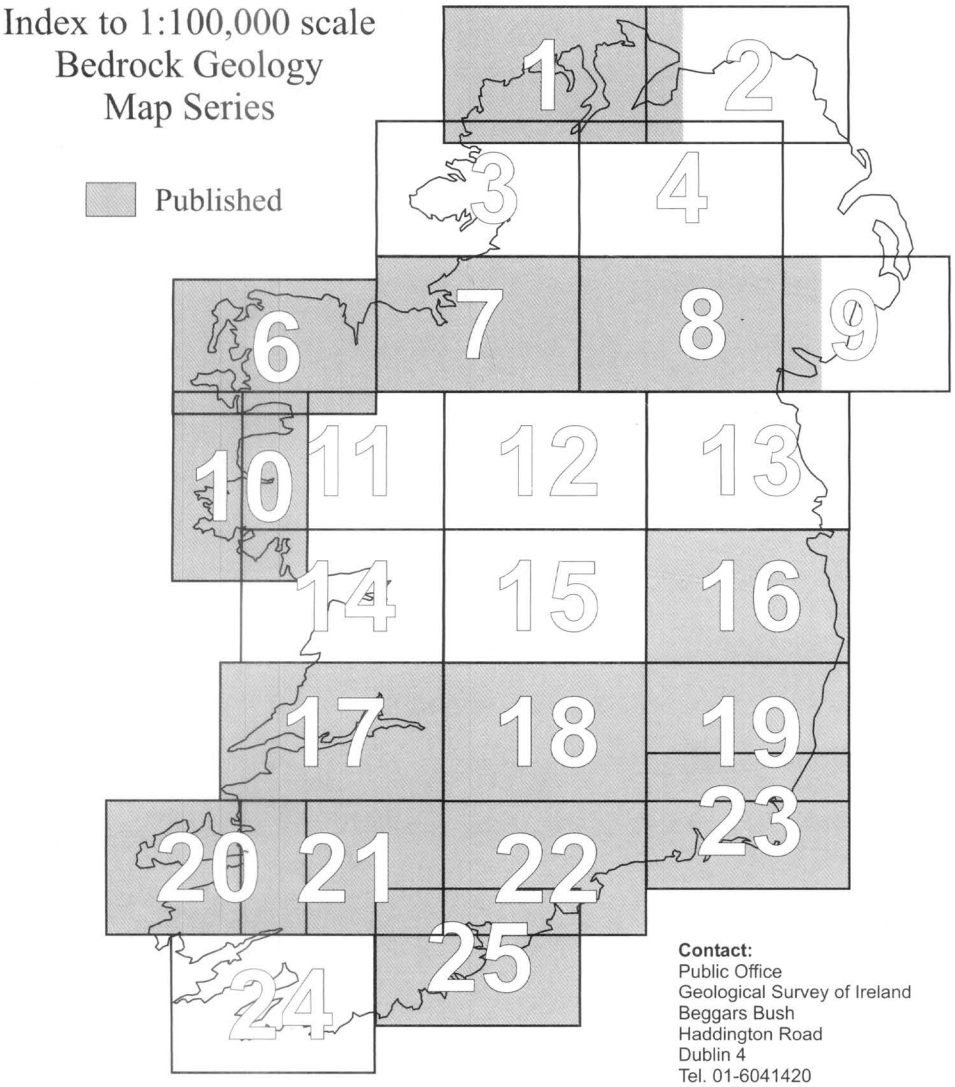


1:100,000 scale, Bedrock Geology Map Series,
Sheet 17, **ENCLOSED**

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Front Cover: The tranquil waters of Cloondorney Lough, north of Tulla village nestling among Carboniferous limestones and shales. (photo by Patrick Maher)

Back Cover: The nautiloid *Triboloceras formosum* Foord, from the Waulsortian Limestones at Lisbane, near Shanagolden, Co. Limerick.

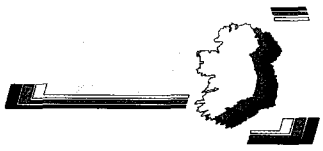
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GEOLOGY OF THE SHANNON ESTUARY

A GEOLOGICAL DESCRIPTION OF THE SHANNON ESTUARY REGION INCLUDING PARTS OF CLARE, LIMERICK AND KERRY, TO ACCOMPANY THE BEDROCK GEOLOGY 1:100,000 SCALE MAP SERIES, SHEET 17, SHANNON ESTUARY

A.G. Sleeman and M. Pracht

with contributions by
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J. Deakin and G. Wright (Groundwater),
O. Bloetjes and R. Creighton (Quaternary).



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CONTENTS

PREFACE vii

INTRODUCTION 1

READING THE GEOLOGICAL MAP 4

A SUMMARY OF THE ROCK TYPES AND GEOLOGICAL HISTORY OF THE SHANNON ESTUARY REGION 7
Lower Palaeozoic Rocks 7
Upper Palaeozoic Rocks 10
Post (Namurian) Carboniferous Geology 12
Quaternary Geology 12

BEDROCK GEOLOGY OF THE SHANNON ESTUARY REGION 15
The Lower Palaeozoic Rocks 15
The Old Red Sandstone (Uppermost Devonian and early Carboniferous) 17
OLD RED SANDSTONE SURROUNDING THE LOWER PALAEOZOIC INLIERS 17
OLD RED SANDSTONE OF KERRY HEAD 17
Dinantian Rocks - the Lower Carboniferous 19
COURCEYAN ROCKS 19
VISEAN LIMESTONES - EAST CLARE SYNCLINE 24
VISEAN LIMESTONES - NORTHWEST LIMERICK 28
VISEAN LIMESTONES - FERGUS ESTUARY 30
VISEAN LIMESTONES - NORTH KERRY 33
VISEAN LIMESTONES - SOUTH OF LIMERICK CITY 34
Namurian Rocks - Upper Carboniferous 36
SHANNON GROUP 36
CENTRAL CLARE GROUP 40
ENVIRONMENTAL INTERPRETATION OF THE NAMURIAN 41
Post-Carboniferous Geology 42
Igneous Rocks 42
VOLCANICLASTIC LITHOLOGIES 43
MASSIVE IGNEOUS ROCKS 44
Tectonics 44
CALEDONIAN TECTONICS 44
The Iapetus Suture 44
VARISCAN TECTONICS 45
Shortening 45
Fold Style 45
Fergus Shear Zone 47
Quinn Shear Zone 47
Magnetic Anomalies 47
Upper Palaeozoic Shelf and Basin Development 47
SHANNON TROUGH 48
THE LIMERICK RAMP 48
THE NORTHERN MARGIN OF THE SHANNON TROUGH 49
THE SHANNON TROUGH IN POST DINANTIAN TIMES 50

HYDROGEOLOGY 51
Introduction 51
Regionally Important Bedrock Aquifers 51
Locally Important Bedrock Aquifers 51
Poor Bedrock Aquifers 52
Quaternary Sand and Gravel Aquifers 52
Warm Springs 52

MINERAL RESOURCES 53
Metallic deposits 53
Coal deposits 55
Industrial mineral and rocks 55
Mineralogical note 57

REFERENCES AND ADDITIONAL READING LIST 59

APPENDIX 1 - Brief lithological descriptions of all units
appearing on the accompanying geological map. 70

APPENDIX 2 - Glossary 74

FIGURES

1. Geological timescale. vi

2. Topography of the Shannon region. 2

3. Simplified geology of the Shannon Estuary Region. 6

4. The world 450 million years ago: mid-Ordovician tectonic plate reconstruction for the time of the Taconic orogeny. 8

5. The world 370 million years ago: a Devonian tectonic plate reconstruction. 9

6. Terrane map of Ireland. 10

7. The outcrop of Lower Palaeozoic rocks. 16

8. The outcrop of the Old Red Sandstone. 18

9. The outcrop of Dinantian rocks. 20

10. The outcrop of Namurian and igneous rocks. 37

11. The trend of major structural lineaments and geophysical features 46

TABLES

1. Comparative, interpretative and schematic stratigraphic successions from the Namurianrocks of the Shannon Trough. 39

2. The location of igneous rocks in the Shannon region. 43

3. Active quarries extracting limestone for aggregate. 56

PLATES

1. Folded sandstones of Namurian age near Loop Head, Co. Clare (photo by A.G. Sleeman). 11

2. Spar-filled cavities in Waulsortian Limestone at Ballybunnion, Co. Kerry (photo by M. Pracht). 23

3. Clay way-board resting on a palaeokarstic surface, Burren Formation, at Whelan's Quarry, Co. Clare (photo by A.G. Sleeman). 26

4. Striped limestones from the Parsonage Formation at Ballybunnion, Co. Kerry (photo by A.G. Sleeman). 33

5. Interbedded basinal limestones and shales of the Corgrig Lodge Formation at Ballybunnion, Co. Kerry (photo by A.G. Sleeman). 33

6. Pale weathering, large scale cross- bedded oolitic/skeletal grainstones overlying dark, thin-bedded grainstones,packstones and interbedded shales at Mungret Quarry, Co. Limerick (photo by A.G. Sleeman). 35

7. Intraformational slumping of interbedded sandstones and mudstones in the Gull Island Formation south of Tullig Point (photo by C. MacDermot). 38

8. The old mine chimney at Kilbreckan Mine, Co. Clare (photo by C. MacDermot). 57

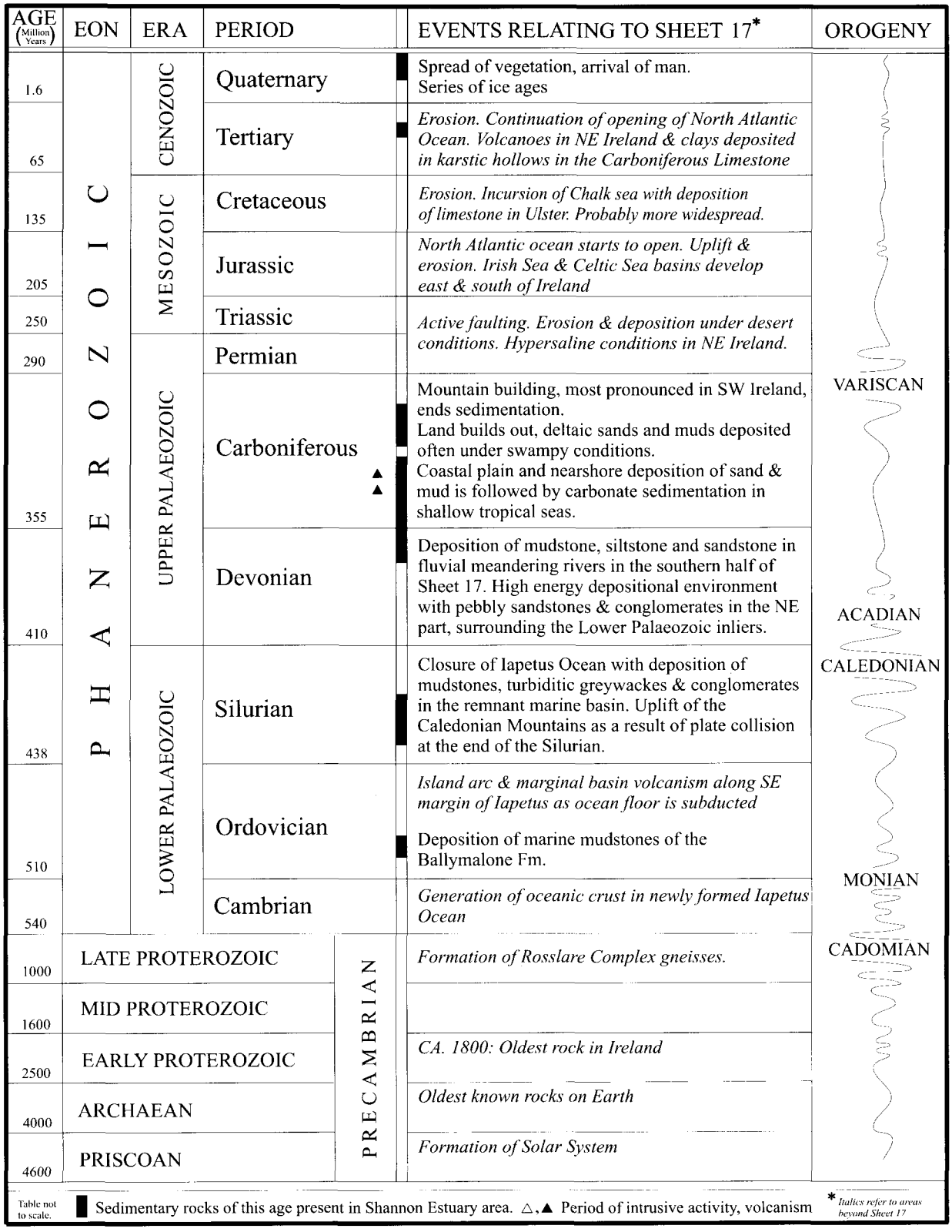


Figure 1. Geological Time Scale

PREFACE

This booklet is written to accompany the 1:100,000 scale Bedrock Geological Map of the Shannon Estuary region, Sheet 17, which includes parts of Counties Clare, Limerick and Kerry. The booklet is aimed at both the general reader who has an interest in earth science and the geologist or other professional who has a specific interest in the earth resources of the area.

The introduction gives a brief overview of some geological concepts and how the underlying geology has influenced the form of the present day landscape. The summary provides a short description of the geology for the general reader and also an image of the ancient environments in which the rocks formed. This is followed by a more detailed technical description of the geology and then by summaries of the hydrogeology, and the industrial and metallic minerals of the area. The final sections of the booklet include, a reading and cited reference list, a list of lithological descriptions for each of the stratigraphical units and a glossary of geological terms used in the introductory and summary geology sections.

This booklet and the accompanying geological map are not the last word on the geology or earth resources of the region, quite the reverse. Compilation of the geology of this area has in many ways highlighted how little we know about some of the area. Much more detailed mapping and drilling still needs to be done to help us understand and interpret the geology. We have attempted to indicate where there is uncertainty on the map as to the geological interpretation, in this booklet.

INTRODUCTION

The evolution of the landscape

The Shannon Estuary is a region of considerable landscape diversity and potential attraction to the visitor. The highest hills in the east (e.g. Woodcock Hill, 1010 feet) are an extension of Slieve Bernagh. Most of the remaining high ground runs in a central north - south belt between Abbeyfeale in the south and Miltown Malbay in the north. Knockanimpaha (1132 feet) is the highest point to the south of the River Shannon and Slievecallan (1284 feet) is the highest point to the north.

Each of the landscapes owes its form to the geological materials from which it has been carved, and they, in turn, owe their character to long vanished ancient environments. The story of the area and its geological foundations extend back not just thousands of years, but through hundreds of millions of years. We hope this introduction to the geological foundations of the Shannon Estuary region will stimulate interest in an all too easily overlooked component of our natural heritage, the landscape and the rocks from which it is formed.

Before we begin our journey back into the geological past we will pause to consider the three principal kinds of topography formed by the region's rocks.

First, there are the undulating lowlands, floored by **limestone** of lower Carboniferous (Dinantian) age in East Clare, West Limerick and North Kerry (Figs 2, 3) which are generally covered by glacially deposited sediments and alluvium.

Secondly, rising from the lowlands, west of the Fergus Estuary in West Clare, and south of the Shannon in North Kerry and West Limerick (Figs 2, 3) are the low hills formed of upper Carboniferous (Namurian) **shales** and **sandstones**.

Thirdly, there are the mountains and hills of Slieve Bernagh, the Broadford Mountains and the Cratloe Hills in the east of the map area (Figs 2, 3), composed of rocks of various ages which are older then the Carboniferous limestones. The Old Red Sandstone is generally found around the perimeter of the hills, the interior of each of which is underlain by a core of much older, Lower Palaeozoic rocks (Fig. 1), consisting largely of **greywackes** and **mudstone**, or **slate**, its **low-grade metamorphic** equivalent.

Older Lower Palaeozoic rocks are exposed in the deeply eroded cores of large **anticlinal** folds which were formed during late Carboniferous to Permian earth movements (Fig. 1). The Lower Palaeozoic rocks commonly form rounded hills which are covered by thin soils supporting natural scrub or are under forestry.

Limestone is readily dissolved by rainwater. It is often highly permeable, which sometimes results in bare limestone (**karst**) areas, such as the Burren, with no surface waters. In East Clare much of the land is near sea-level and the water table is near ground level with the result that there are many lakes.

South of Limerick City, volcanic rocks were erupted more than 325 million years ago, during the Lower Carboniferous (Dinantian) (Fig. 1) and are now found interbedded with or cross-cutting the limestones.

In West Clare and North Kerry, Upper Carboniferous shales and sandstones which originally buried Ireland's limestone to a depth of several hundred metres are extensively exposed.

The countryside represented on Sheet 17 contains a number of linear features represented on the map as major **faults** parallel to the grain of the rocks or cross-cutting them. One such feature forms the faulted northern boundary of the Cratloe Hills (the continuation of the Silvermines Fault on the adjacent Sheet 18). Most of the faults cannot be seen directly on the ground but are inferred from apparent displacement of rock types on either side of the fault. Other linear features not depicted on the map are major joints, generally north - south trending fractures in the limestone along which marshy or boggy areas are aligned.

Glacial erosion and glacial deposition were both important in the shaping of the landscape. The typically undulating lowlands owe their appearance to the deposition, from ice sheets, of jumbled masses

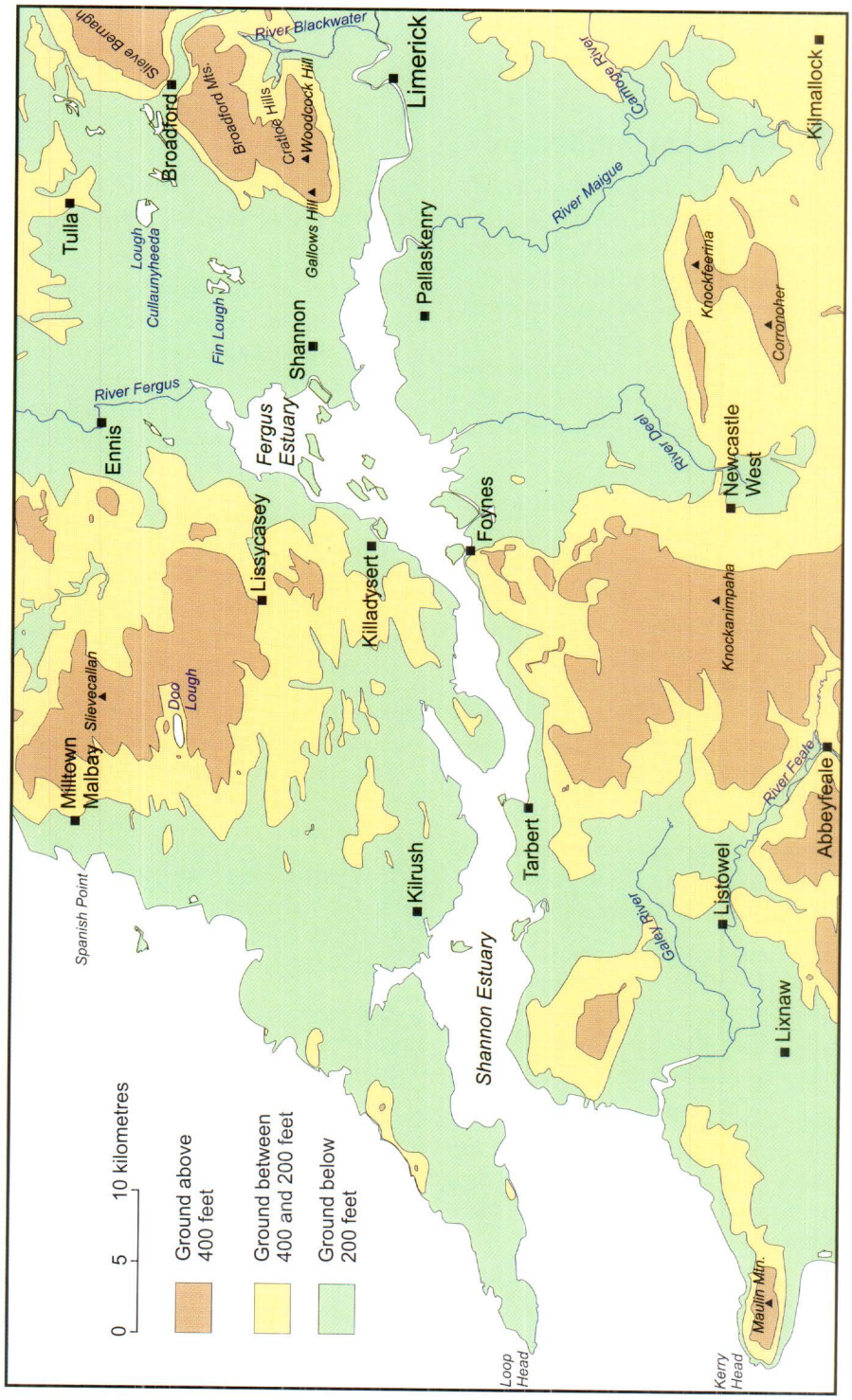


Figure 2. Topography of the Shannon Region

of boulders, pebbles, sand and mud and to the rounding of these deposits by over-riding ice.

Evolution of the landscape by natural forces is a never ending process. Rain and rivers gradually wash away the hills, shaping valleys and filling lakes. Since the end of the Ice Age, about 10,000 years ago, natural processes have been joined by another agent of environmental change - people.

Over the centuries use of natural resources has left an indelible mark on the cultural landscape from which, to some extent, the geology of the area can be deduced. The recent "Celtic Tiger" economy has resulted in frenetic building activity in much of East Clare, only a few minutes commuting time from Limerick, Shannon and Ennis. This activity does not always plan adequately for the forces of nature where speculative housing developments have been sited in areas subject to flooding. An understanding of the relationship between rainfall, groundwater, and the rocks through which it flows, could assist in better planning and also help to avoid groundwater pollution in such vulnerable areas. Huge quarries supply the building and road building industries with cement, concrete, and aggregates. Most larger rock quarries now worked are in limestone, but slate, volcanics, shale, sandstone and clay have been used extensively in the past. Many sand and gravel workings continue to be major geological resources from the ice-sheet generated terrain. Field stone walls show the varied bedrock and glacial drift characters of the landscapes, while cut-stone masonry is of special interest in townscapes such as Ennis, Limerick and Listowel.

"The present is the key to the past"

To begin to understand the events that have contributed to the shaping of the landscape, we try to recognise features in the rocks caused by processes which can be seen at work in the world today.

Sedimentary rocks, for example, sandstone and limestone, which are found widely in Ireland, are familiar to us as building materials, whether as cut stone or further processed materials such as concrete. Some structures, such as **ripple marks**, preserved in sedimentary rocks were formed when the rocks were soft sand and mud on the sea-bed, in rivers, or in shifting desert dunes. By comparing such features in these rocks with those in sediments being laid down today, we apply the principle that "the present is the key to the past", and so build up a picture of the likely conditions under which the ancient sediments were deposited (the palaeo-environment). We can form an idea of the palaeo-geography by looking at rocks laid down as sediments at about the same time in different areas.

The same principle applies to **igneous** rocks and in fact to many other geological features. In studying the mechanism of emplacement of **dykes** and **sills** or the outpouring of lava onto the land surface, in modern day volcanic environments, such as southern Italy or Iceland, we can make comparisons with igneous rocks deposited millions of years ago as, for example, at Carrigogunnel.

"Missing Rocks"

In any one region, as elsewhere, we see only a partial record of the Earth's long history. Some of the geological **succession** (Fig. 1) is not seen, because it was never deposited (because the area was land at the time), or because destructive processes such as erosion have removed parts of the sequence, or because it is buried deep beneath the rocks we can see. Periodic earth movements throughout geological time have led to great thicknesses of rock being eroded, and deposited as new sediment elsewhere.

All of the Precambrian, most of the Cambrian and Ordovician, some of the Silurian, most of the Devonian, the uppermost Upper Carboniferous and rocks of Mesozoic and Tertiary age are absent from the geological succession exposed in the Shannon region (Fig. 1).

READING THE GEOLOGICAL MAP

The Rock Units

Of the kinds of rock which form the earth's surface, sedimentary rocks are by far the most widespread in the area represented on the accompanying map. Igneous rocks are mainly represented by volcanic rocks which outcrop south of Limerick city. **Metamorphic** rocks are confined to the slates of the Slieve Bernagh and Broadford Mountains.

Sedimentary rocks are deposited in individual layers called **beds** which can accumulate to form enormous thicknesses of rock. However, in nature, neither sedimentary rocks nor their metamorphic equivalents (meta-sedimentary rocks) occur in single kinds. Two, or usually more, kinds of sedimentary rock are almost invariably inter-layered with each other: limestone with shale and/or **chert;** sandstone with **conglomerate** and/or **siltstone** and/or mudstone.

To facilitate description and representation on maps, we group associated rocks together into formal hierarchical sequences of units, called members, formations and groups. The formation is the most fundamental of these units, consisting of a sequence of related or similar rock types which can be mapped at the surface or underground. The formation is normally applied to units of at least several tens of metres in thickness and, in plan view, extending for considerable distances. An exception to this is the extremely thin Ballyvergin Formation, shown on the map and described in this booklet. It is only about 5m thick, and therefore too thin to show at the scale of the map, but which is regionally a very extensive marker bed. Smaller-scale, but distinct rock packages are frequently defined within formations and these are called members. Groups are made up of related formations.

A formal **lithostratigraphical** unit is named after the district from where the unit was first described (e.g. Ballysteen Formation), or, after the place where it is best exposed (e.g. Burren Formation. A few units depicted on the map are informally named (e.g. Waulsortian Limestones - after a similar type of limestone described from Belgium.

Formations and members are indicated on the map by a combination of colours and code letters - two capitals for a formation (e.g. BA for Ballysteen Formation) with the addition of two lower case letters for a member, e.g. BAbn for the Ballynash Member of the Ballysteen Formation). The explanation of the colours and codes used to identify each rock unit are shown in the legend to the left of the map, as are their relative positions in the **stratigraphical** succession. Similar codes are applied to **intrusive** and **extrusive** igneous rocks. Distinctive mappable rock types found within formations are shown as a two letter code (e.g. cg - conglomerates within the Slieve Bernagh Formation). Note that in the figures the youngest units are shown up the page, while the text describes the oldest rocks first.

How rock units come to lie side by side

The rocks represented on Sheet 17, like all rocks, ultimately owe their character and distribution to movement of the earth's **lithospheric plates (plate tectonics)**. Earth movements, during the distant geological past, have folded, faulted, and uplifted the rocks. so that rock units which originally were stacked one on top of another are now situated side-by-side (see the cross-sections below the map). Folding corrugates the rock and repeats the outcrop of individual units. On the eroded crest of the ridges (**anticlines**) older rocks are flanked by younger ones and, conversely, the younger rocks in the troughs (**synclines**) are flanked by older rocks.

Boundaries between rock units

There are three principal kinds of geological boundaries: stratigraphical, **unconformable** and faulted. Stratigraphical boundaries are the contacts between different rock units and include contacts

between beds, members, formations and groups, so long as these contacts have not been modified in any way since the rocks were first laid down. In reality, these contacts are often gradational rather than sharp differences between rock types. The placing of a boundary is often arbitrary, particularly where outcrops (not shown on the accompanying map) are far apart. Igneous extrusive contacts fall into the same general category. Intrusive rock contacts cross-cut other stratigraphical contacts. Each stratigraphical contact is depicted on the map by a thin black line.

Unconformable contacts are similar to normal stratigraphical boundaries but, very importantly, they represent a time interval between when the rocks above and below the **unconformity** were deposited. Unconformities represent a break or gap in the rock sequence, often, but not always, with an angular discordance between the units, due to earth movements which folded the older rocks before the younger ones were deposited. Unconformities are shown on the map by a thick black line with dots on the side of the younger rocks.

Faults represent fractures which cut through rock sequences and displace the rocks on either side of the fracture. Displacement of rocks on one side of a fault plane (the plane of fracture) is relative to that on the other side and may be up, down, horizontal or, commonly, oblique. An observer standing on one side of a fault, the surface of which dips away from the observer, will in a **normal** fault, notice that the rocks on the far side of the plane have moved down in relation to the near side. In contrast, the opposite sense of movement will be observed in the case of **reverse**, or **thrust** faults (distinguished on the basis of the steepness of the fault plane, high angles for reverse faults, low angels for thrusts): the rocks on the far side of the fault plane will have moved upward towards the observer's side. Normal faults reflect extension in the earth's crust whereas reverse and thrust faults reflect compression (shortening). Lateral displacement faults are called either **wrench** faults, or **"strike-slip"**) faults, and oblique sense faults are simply called **oblique** faults. The scale of movement on faults is extremely variable, ranging from a few metres or so to tens, hundreds, and even thousands of kilometres. On our 1:100,000 scale maps faults are indicated by thick black lines. Rarely are the faults interpreted on the map to be seen in the field. The faults shown are generally placed on the basis of a non-matching sequence on either side of the fault shown, or the absence of a part of the sequence known elsewhere. Faults may sometimes appear to be more common where there are numerous **boreholes** or abundant outcrop. In reality, however, faults are probably more common than can be identified from the usually scattered outcrops or boreholes.

What the map does and does not show

The map shows an interpretation of the distribution of the various geological formations which make up the bedrock foundation of the area. The formations are depicted as they would appear if they were stripped bare of vegetation, soils and glacial deposits, but the whereabouts of actual exposures of rock is not shown.

Viewing the rocks

Throughout this booklet the whereabouts of specific sites of interest are indicated by the national grid reference (GR). Grid references in the text are 10 figure references, the first figures for the easting and northing replacing the grid square letter shown on the Ordnance Survey half inch to the mile series of topographical maps. Sheet 17 is situated within the grid sub-zones Q and R.

Should you choose to visit any site on private land, you must obtain permission from the owner before going to the site.

If more detailed information about the location of individual rock outcrops is required, then the original Geological Survey of Ireland (GSI) field maps and other GSI sources should be consulted. The original nineteenth century GSI field sheets, on the scale of six inches to one mile (1:10,560), show the precise position of most rock outcrops within the map area and can be viewed in the Geological Survey. More recent geological field sheets on the same scale, and unpublished compilation geological maps on the 1:25,000 scale, may be consulted by prior arrangement. Other mineral exploration company data used in the compilation are available in Minerals Exploration Assessment Reports in the GSI (Open File) Mineral Exploration Records Databank.

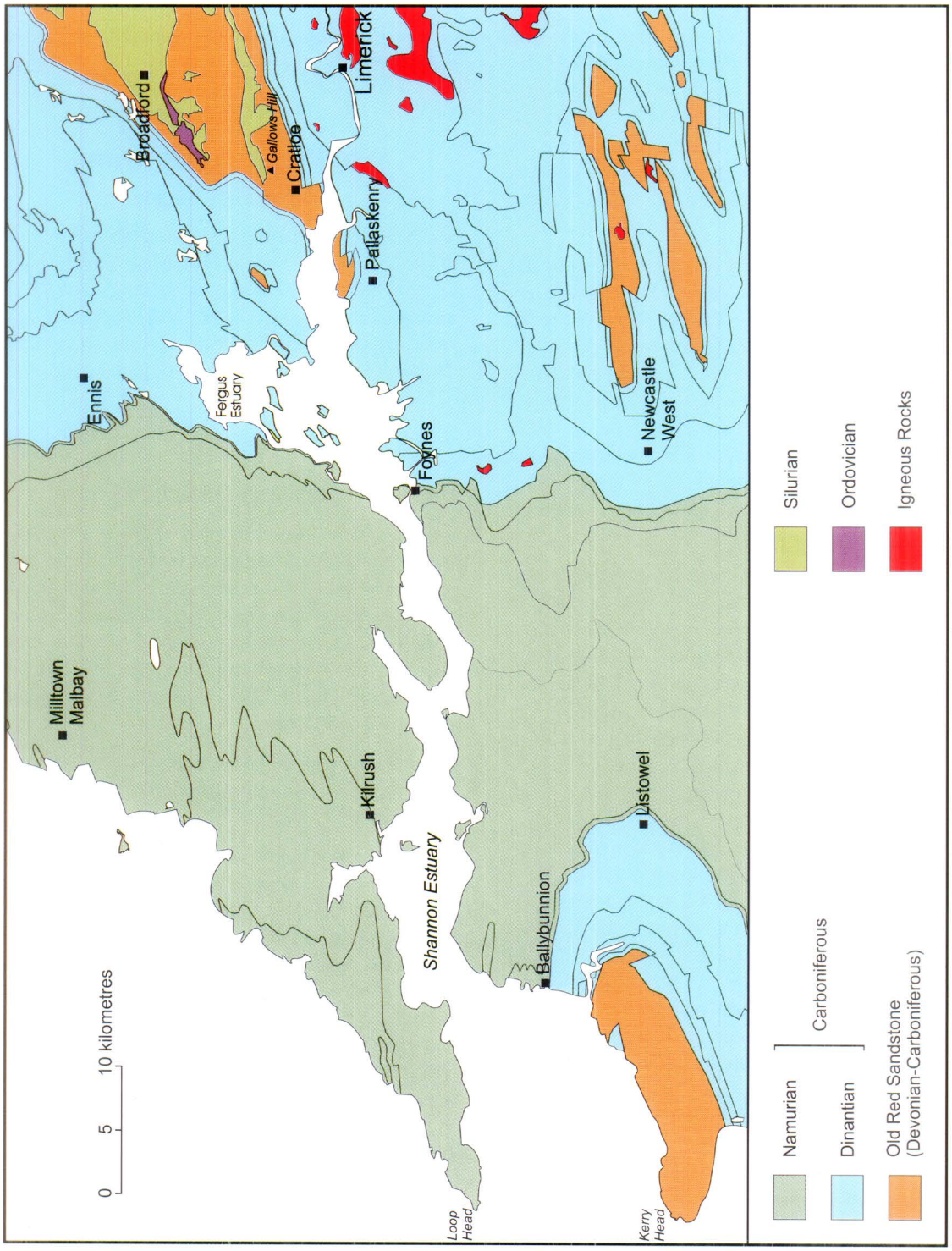


Figure 3. Simplified geology of the Shannon Estuary Region.

A SUMMARY OF THE ROCK TYPES AND GEOLOGICAL HISTORY OF THE SHANNON ESTUARY REGION

Lower Palaeozoic Rocks

The oldest rocks, Lower Palaeozoic in age, form the core of Slieve Bernagh, the Broadford Mountains and the Cratloe Hills (Fig. 3). These rocks originated in a long vanished ocean, the story of which has been unravelled from the Lower Palaeozoic rocks now exposed on both sides of today's Atlantic Ocean.

THE IAPETUS OCEAN: 600 - 400 MILLION YEARS AGO

The Iapetus Ocean opened about 600 million years ago, between what are now North and South America. At its peak, about 510 million years ago, the ocean may have been as wide as the modern Atlantic. Traces of the former Iapetus Ocean are to be found today in rocks exposed along the eastern seaboard of North America, through eastern Greenland, into Scandinavia, Scotland, northern England, Wales and Ireland.

The distribution of distinctive fossils and other evidence indicates that the axis of the Iapetus ran through central Ireland, roughly from the present day Shannon Estuary to Clogher Head, in Co. Louth, and across the Irish Sea along the border between Scotland and England. It is difficult now to imagine that during the Ordovician Period, northwestern and southeastern Ireland were situated on different sides of an ocean several thousands of kilometres wide, but that is precisely what happened (Fig. 4).

The Ordovician and Silurian rocks exposed on Sheet 17 originated on the northwest side of the Iapetus Ocean (Fig. 4). Lithospheric plate movements during late Ordovician and early Silurian times led to progressive diminution in the width of the Iapetus Ocean. By the time most of the Silurian rocks represented here were deposited, about 425 million years ago, the ocean had largely contracted. The Silurian rocks of Central Ireland accumulated in a residual marine basin, perhaps no wider than the present day Irish Sea.

ORDOVICIAN

The Ordovician rocks (Ballymalone Formation), exposed at the eastern edge of the map, lie to the north of the Shannon Estuary - Clogher Head axial line of the former Iapetus Ocean, but almost certainly accumulated far from either shore.

The Ballymalone Formation consists of black, **pyritous** shales. These shales represent the type of fine-grained sediment which settles out of suspension on the ocean floor and which consists largely of siliceous matter. During accumulation of the formation this sediment included large numbers of **graptolites**. The fossil remains of these extinct **pelagic** creatures are sometimes crowded on **bedding** surfaces. The graptolites present show it to be of mid-Ordovician age, that is, about 450 million years old.

LOWER SILURIAN

The earliest Silurian rocks (Cornagnoe Formation) are faulted alongside the Ordovician Ballymalone Formation, but they are more than ten million years younger. During the time between deposition of these two formations, the Iapetus Ocean contracted.

In the lower Silurian Cornagnoe Formation, land influence is to be found in layers of fine-grained sandstone which are interbedded with mudstone. This sediment was delivered episodically to the sea-floor which, also, continued to receive organic sediment. Thin layers of black mudstone contain rare graptolites, which have been used to determine the age of these rocks.

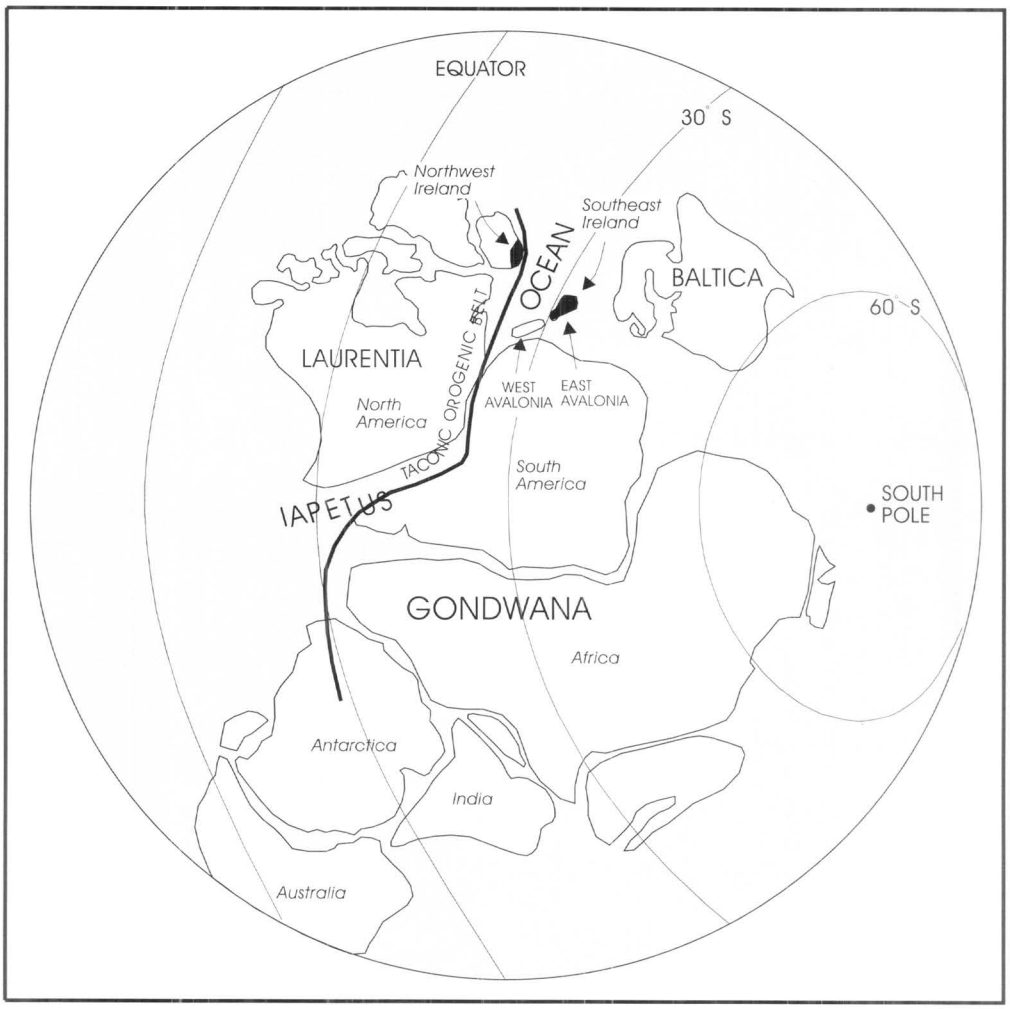


Figure 4. The world 450 million years ago: mid-Ordovician tectonic plate reconstruction for the time of the Taconic **orogeny** (based on Dalziel *et al.* 1994). The areas of present day northwest and southeast Ireland are shown in black and these have been exaggerated for clarity: other present day landmasses are indicated by names in italics.

MID-SILURIAN

Rocks of mid-Silurian age are much the most widespread of all the Lower Palaeozoic rocks within the area, comprising the Broadford, Slieve Bernagh, and Cratloes Formations (see map).

During the few million years between deposition of the youngest lower Silurian rocks and the oldest middle Silurian rocks enormous quantities of land-derived sediment was deposited into the remnant Iapetus Ocean.

These sediments, which accumulated on the floor of the ocean, now form enormous thicknesses (perhaps thousands of metres) of blue-grey mudstone interlayered with thin (a few centimetres, or less) beds of black siltstone, or thin beds of **turbiditic** siltstone (Slieve Bernagh Formation). Similar mudstones and siltstones are inter-layered with beds of **greywacke** sandstone which individually range in thickness from a few centimetres up to a few tens of centimetres (Cratloes and Broadford Formations).

Other mid-Silurian rocks occur locally. Rocks in the first of these categories include conglomerates within the Slieve Bernagh Formation (see map). These consist of very small pebbles of white **vein quartz**, red **jasper** and drab coloured pieces of metamorphic and igneous rocks all set in a deep

greenish-grey, sandstone **matrix**. In addition to the pebbles, the matrix commonly contains lumps of mudstone. These mudstone lumps were ripped-up from the sea-bed by powerful submarine currents which transported the pebbles and lumps into deeper water and were deposited, when each current slackened and dumped its load of sediment out of suspension on the seabed.

While the conglomerates described above represent almost instantaneous events "frozen" in time, the second category of middle Silurian rock to be singled out from the others, owes its development to events spread over tens of millions of years. These are the slates which have been quarried over the centuries in the Killaloe area (Sheet 18) and are commonly referred to as the "Killaloe Slates". They occur within the Slieve Bernagh Formation and to a lesser extent in the Broadford Formation (see map) and originated as interbedded layers of mud and silt on the floor of the Iapetus Ocean. During the powerful earth movements which terminated the existence of this ocean, parts of the Broadford Formation were subject to intense deformation, accompanied by metamorphism, which acted on the soft mudstones to develop a sheet like **cleavage** along which the rocks can now be split to form roofing slates.

DESTRUCTION OF THE IAPETUS OCEAN: 440 - 390 MILLION YEARS AGO

By the end of the Silurian Period, the existence of the Iapetus Ocean was nearly gone. During the 80 million years between the mid-Ordovician and the mid-Devonian, lithospheric plate movements effected large-scale changes in the disposition of the

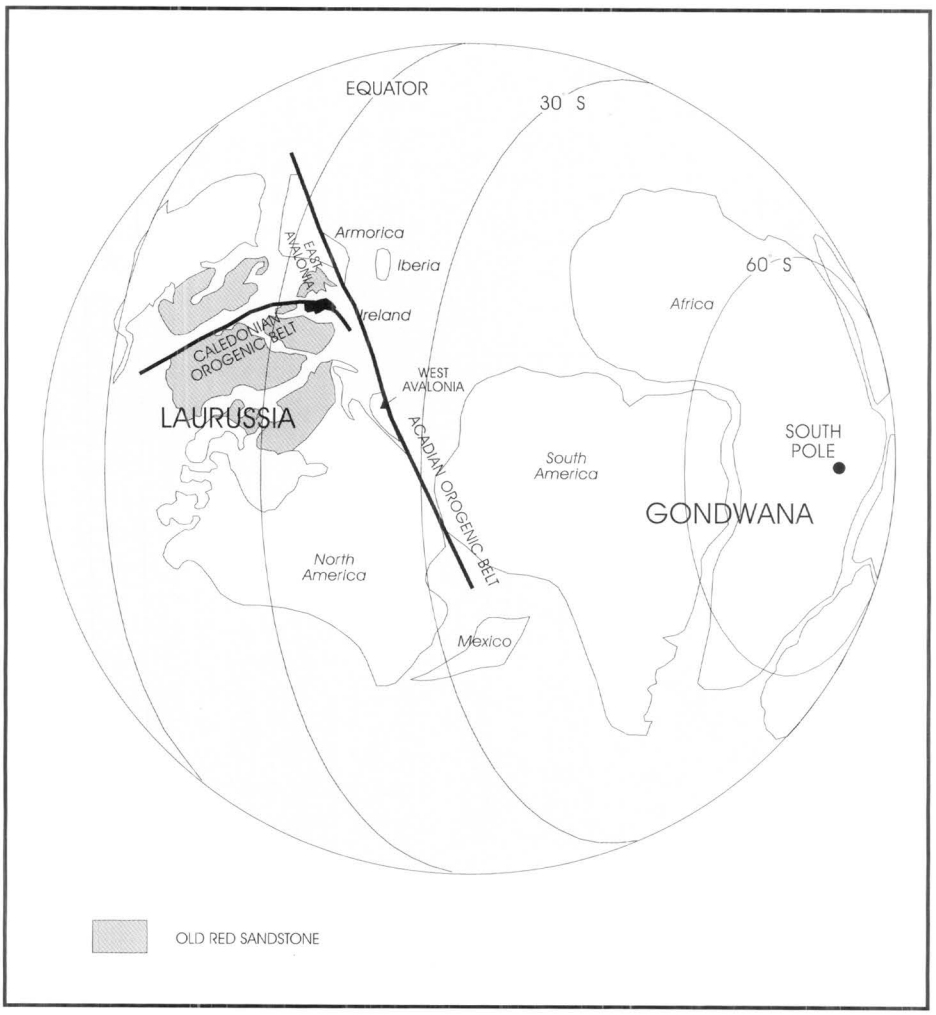


Figure 5. The world 370 million years ago: a Devonian tectonic plate reconstruction, based on Dalziel *et al.* (1994).

worlds continental masses (compare Figure 4 with Figure 5), and brought about the closure of the Iapetus Ocean.

Throughout the late Ordovician and the whole of the Silurian Period the continents on either side of the Iapetus Ocean moved towards each other at a rate of a centimetre or so a year, that is, at a similar rate to the present day widening of the Atlantic Ocean. Modern day comparison also serves to illustrate one effect of the late Silurian oceanic closure. Just as the collision between India and Eurasia, in geologically recent times, has formed the mighty Himalayan chain of mountains, so, too, the end Silurian collision of the continents bordering the Iapetus Ocean formed a range of lofty mountains (Caledonian **orogenic belt** of Figure 5).

Rocks formed on both sides of the Iapetus Ocean occur deep beneath the surface, in the various blocks of rock (**terranes**) which form Ireland's Lower Palaeozoic foundations (Fig. 6). These terranes were brought together by great earth movements involving hundreds, or perhaps, thousands of kilometres of displacement along northeast - southwest fractures of the Earth's crust. Part of one of these fractures crosses Sheet 17, the Gallows Hill - Silvermines Fault which forms the northern boundary of the Cratloes Formation and which is a branch of the Navan - Silvermines Fault (Sheet 18).

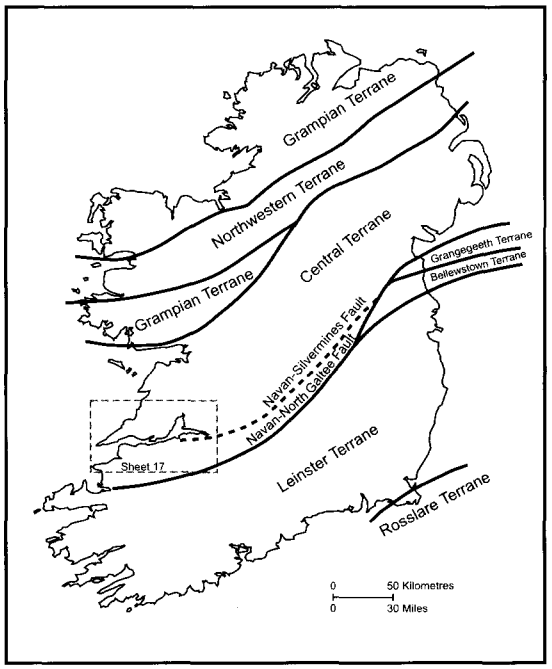


Figure 6. Terrane map of Ireland.

In this great fracture, events of 400 million years ago impact directly upon our modern economy, because the fractures acted as conduits for the fluids from which were precipitated the huge metallic mineral deposits until recently worked at Silvermines, currently being mined at Galmoy and under investigation at Lisheen (Sheet 18, Archer *et al.* 1996).

Upper Palaeozoic Rocks

THE OLD RED SANDSTONE

Deposition of the Old Red Sandstone rocks took place during the Devonian Period (410 - 355 million years ago) in a sub-equatorial arid environment (Fig. 5) when the Caledonian Mountains were subject to intensive erosion. As time went on, and the mountains were worn away by erosion the gravels and sands left behind by rivers formed what were to become the conglomerates and the sandstones which make up most of the Old Red Sandstone. The fine-grained red sandstones, siltstones and mudstones which are associated with these conglomerates and sandstones derived from sediments which accumulated on the floodplains of the meandering rivers, the red colouration reflecting the arid, sub-aerial **oxidising** conditions under which these rocks formed.

The wearing away of the Caledonian Mountains is reflected by the gradual disappearance of conglomerates and coarse sandstones higher in the sequence. Evidence of climatic change can be detected in the upper levels of the Old Red Sandstone succession. Wetter conditions resulted in the replacement of the **redbeds** by greenish-grey siltstones, which occasionally contain fossil plants. Evidence from fossil plant spores shows that at least the topmost beds of the Old Red Sandstone were deposited in earliest Carboniferous times. Climatic change was followed by radical environmental change, as the Lower Carboniferous sea encroached upon the Old Red Sandstone continent. The gradual change from coastal plain conditions to a marine environment is recorded in the rocks which form the top of the Old Red Sandstone succession and the overlying marine Lower Limestone Shales.

LOWER LIMESTONE SHALES

The "Lower Limestone Shales" are represented by the Mellon House, Ringmoylan and Ballyvergin Formations in the Pallaskenry district of West

Limerick. Due to their poor exposure in most places, these three formations are depicted together as Lower Limestone Shale (LLS) on the rest of the map. Nowhere do they exceed about 100m thickness. These beds represent the start of the Carboniferous marine flooding of the Old Red Sandstone continent. They are shallow water sandstones and mudstones.

CARBONIFEROUS LIMESTONE

The Lower Limestone Shales are followed by dark-grey muddy limestones and interbedded thin **calcareous** shales of the Ballymartin Formation deposited in somewhat deeper water (below **wave-base**). This passes up to the less muddy limestones of the Ballysteen Formation. The Ballymartin Formation, like the Lower Limestone Shales is poorly exposed and away from the Pallaskenry area it is not shown separately from the Ballysteen Formation.

As the shoreline retreated, in the face of the northward advancing sea, less clay was transported into the area, allowing **carbonate** accumulation in cleaner and more energetic depositional conditions as the **crinoidal** limestones of the Ballysteen Formation. These were deposited in a warm tropical sea. The Ballysteen Formation was succeeded by the growth of carbonate mudmounds, the Waulsortian Limestones, sometimes referred to as the "reef". However, there are no similar mudmounds being deposited today and they are quite unlike coral reefs found in modern tropical seas. These mudmounds or "banks" probably first developed as individual mounds on the sea-floor at a depth of at least 200m surrounded by the more muddy limestones of Ballysteen type. The mounds contained abundant life-forms, notably crinoids and **bryozoa**, and maintained high depositional slopes due partly to microbial activity. Through time the mounds in the area coalesced to form a continuous mass of limestone. The general **macrofauna** of the banks and their surrounds is similar. Corals are rare, except for a few specialised species.

In most places the Waulsortian limestones are overlain by a thin sequence of cherty crinoidal limestones (Lough Gur and Ballycar Formations and the Cregmahon Member of the Tubber Formation).

Younger Visean limestones are found in East Clare, West and South Limerick, and North Kerry. Each area has a different succession (see successions inset map on main map) but in general they record a progression from shallow-water continental shelf limestones down a gentle slope (ramp) to deep-water limestones deposited in a basin (the Shannon Trough). Some of these limestones were deposited in very shallow conditions such that grains were washed to and fro on carbonate sand-banks. As a result, **oolitic** limestones formed (e.g. "oo" within the Burren Formation). In other places there is evidence that the limestones were exposed above sea-level periodically. This is shown by "**clay wayboards**" within the upper part of the Burren Formation.

These thin clays represent fossil soils which formed on a karstified land surface, within the top layers of which is sometimes preserved evidence of plant life. However, deeper water muddy limestones (Rathkeale Formation, Finlough Formation) are found in West Limerick and East Clare and later in the succession more deep water limestones, represented by the Parsonage and Corgrig Lodge Formations, were deposited.

UPPER CARBONIFEROUS TURBIDITES AND DELTAS

Over 1.5km of Upper Carboniferous (Namurian) sediments were deposited in the Shannon Trough, of which only the eastern part reaches onshore Ireland. It covers a large area on the western half of the map (West Clare and North Kerry/West Limerick). This basin was gradually filled, first by

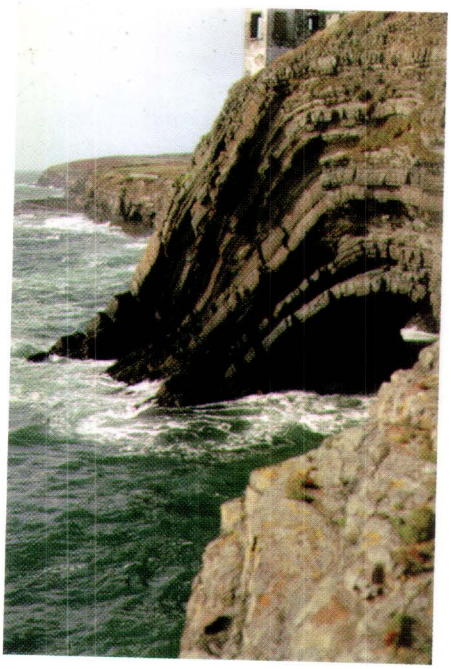


Plate 1. Folded sandstones of Namurian age near Loop Head, Co. Clare (photo by A.G. Sleeman).

deep-water marine shales, the Clare Shales. These were followed by, and cut into by, turbidites which formed sub-marine fans. The turbidites were in turn covered by slumped continental slope and shelf siltstones and mudstones and finally topped by deltaic sandstones and siltstones. The deltaic deposits form repeated cycles of sediments which mirror the ups and downs of relative sea-level over a considerably length of time.

The oldest Namurian sediments, the black pyritic marine Clare Shales were deposited under quiet deep-water conditions in a basin with its axis running approximately along the trend of the present day River Shannon. The sea gradually moved north and southwards, which can be demonstrated by the increasingly younger goniatite faunas found in the basal beds of the Clare Shales moving away from the basin axis. Additionally the formation is consistently thicker along the axis than further north and south. The laterally equivalent Ross Sandstone Formation, which crops out along the coast near the Bridges of Ross in Co. Clare, consists of horizontally bedded sandstones with thin shale and siltstone partings deposited close to the inferred basin margin. The turbidites have a westerly provenance (Rider 1974).

Both formations are overlain by finer-grained siltstones and sandstones of the Gull Island Formation, which are often slumped and whose overall sandstone contents decreases upwards. Within this unit channels with turbiditic sandstone fills are common. The channels were up to 6m deep and several 100m wide (Hopkins 1962). The slumped nature of many horizons, the abundance of turbidites and the occurrence of dewatering structures such as **sand-volcanoes,** indicate a high subsidence and deposition rate during sedimentation.

By latest Namurian times deposition of silts and sands outpaced subsidence which resulted in the expansion and progradation of river deltas into the sea. Rootlet horizons and coal seams are typical remnants of the swampy deltaic environments. A good analogy for the Namurian deltas would be today's birds-foot delta of the Mississippi. However, the advance of the deltas was repeatedly interrupted by sea-level rises and flooding of the delta plains which resulted in deposition of marine shales containing goniatites, marine organisms which floated freely in the water-column and which can be used for correlation basin-wide. The repeated occurrence of goniatite bearing marine beds are interpreted to be due to sea-level changes arising from the Carboniferous glaciation. The glaciation, which started in the early Namurian, covered large parts of the Gondwana supercontinent.

Post (Namurian) Carboniferous Geology

After the formation of the Namurian rocks shown on the map, deposition of sands and muds and coals probably continued through the remainder of Upper Carboniferous times, although we no longer have any record of these rocks on the ground. At the end of the Carboniferous Period, the rocks of the area were uplifted, folded into a series of very broad shallow folds, and faulted during the Variscan Orogeny (mountain building episode, Fig. 1). This Orogeny affected rocks from Ireland to central and eastern Europe.

There is little direct evidence of what happened in the area following the Variscan Orogeny until the Quaternary Period. However, there is indirect evidence that substantial thicknesses of rock were deposited, buried, and later removed by erosion, suggested by, for example, the high rank of coals, indicating high temperatures partly due to burial in the crust. The area was probably land during much of the time represented by the Mesozoic and Tertiary Eras (Fig. 1). Non-marine Tertiary clays, however, have been discovered in pockets within the Carboniferous limestone at Aughinish. It is likely, however, that the late Cretaceous chalk sea covered the area. The chalk, like the Westphalian rocks, if they were deposited, have now been removed by erosion.

Quaternary Geology

The Quaternary Period (Fig. 1) is the final one of the geological time scale and began some 1.6 million years ago when there was a significant cooling of the Earth's climate. It is subdivided into the Pleistocene Epoch, which was the time of the Ice Age lasting until 10,000 years ago, and the Holocene Epoch which covers the Postglacial period up to the present day. The Pleistocene in Ireland was characterised by alternating cold stages during which much of the country was covered by great ice sheets, and warmer interglacial stages, during which climatic conditions were much as they are today.

More than 90% of the bedrock of the country is covered by the unlithified sediments of the Quaternary Period. The sediments and the associated landscape morphology seen today are largely the result of the last glaciation and of processes occurring during Postglacial times. There is, as yet, a very poor record of glaciations prior to the last one.

The Irish ice sheet was formed by a number of coalescing ice domes (Warren 1992) from which ice flowed radially outwards. As it moved over the ground the ice sheet eroded the underlying bedrock and formed, within and beneath the ice, a sediment made up of particles of all sizes from boulder down to clay size. This is called **till** (boulder clay) and is the most widespread sediment type, varying widely in its characteristic according to its component bedrock material and how fine that material is. In addition sediment was carried away from the ice by glacial meltwaters, sorted and deposited as sand and gravel. Finer sediments of **silt and clay** were deposited in lakes or in the sea. The sediments contain important indicators as to the conditions in which they were deposited, whether underneath or on the margins of the ice sheet.

The combined action of ice and water has produced a highly varied landscape. Tills can take the form of extensive sheets or be moulded in the form of **drumlins**. Alternatively, there are the sinuous sand and gravel ridges called **eskers.** Huge accumulations of sands and gravels, often complex in origin, take the form of **moraines**, **deltas**, **fans** and **kames** among others. Depressions may be filled with finer lacustrine sediments. During the Postglacial there was considerable reworking of some of the earlier glacial deposits and the deposition of river alluvium and postglacial lake sediments. Peat bogs started growing on high ground or in poorly drained basins. There is great variation in the surface distribution of these glacial and postglacial deposits. They can also vary greatly in type with depth. In thickness they can range from less than a metre to tens of metres.

The area of this map was glaciated on at least two occasions but the majority of the sediments we see today are the result of the last glaciation which was at its maximum some 24,000 years ago. There is sedimentological and morphological evidence of a standstill of the ice sheet, that is, an ice front, running across Co. Limerick from southeast to northwest to meet the Shannon Estuary just west of Tarbert (Synge 1970). However, it has not been finally resolved as to whether this was a halt stage in the retreat of the ice sheet or in fact the maximum limit of the last glaciation. If it was in fact the limit, it would mean that much of west Co. Limerick and north Co. Kerry was unglaciated during the last glaciation.

The map area was dominated by an ice dome, the Central Dome, centred in Co. Galway, north Co. Clare and Co. Tipperary (Warren and Ashley 1994). The general direction of ice flow was towards the south and southwest across the map area away from the southern margin of this ice dome. There were local variations in direction within the map area. In the Fergus estuary area between Ennis and Shannon town there was a strong north/south component of flow. This was continued across the estuary where, between Patrickswell and Foynes, it flowed more or less due south overtopping the sandstone inliers around Ballingarry. To the east, ice overtopped the higher ground of the Cratloe Hills and the Slieve Bernagh Mountains but was also diverted around these hills to subsequently expand southeastwards into the east Co. Limerick lowlands. In west Co. Limerick and north Co. Kerry the ice flow was towards the southwest. Evidence of these ice flow directions is provided by the orientation of the drumlins in the river Fergus valley and in north Co. Limerick, as well as the orientation of glacial **striae** and the distribution of **erratics.** Galway granite erratics have a widespread distribution in Co. Clare and are also found in Co. Limerick.

Although the glaciation had a major impact on the landscape by the widespread deposition of glacial till, there are significant areas where the till cover is generally very thin or absent, and bedrock is exposed at the surface. This is the case on the limestone terrain to the east and northeast of the Fergus estuary, and between Mungret and Aughinish on the Co. Limerick shore of the estuary as far south as Adare and Rathkeale. In these areas there is also a significant number of drumlins with thick sequences of till. The glacial sediment cover is also generally thin on the higher ground of west Co. Clare and Co. Limerick, and in the hills north of Limerick City. By contrast, thick deposits occur in south-central Co. Limerick in the valleys of the rivers Deel and Maigue, and also on the Loop Head peninsula in southwest Co. Clare.

The stone content of the sediments generally reflects the rock type over which the ice has passed. The two main types are therefore a limestone-dominated till and a till containing mainly Namurian shales and

sandstones. There are examples of carry-over of one rock type on to a different bedrock type. Around Loghill and Ballynahill in Co. Limerick limestone clasts have been deposited in the till up on the higher ground underlain by shale and sandstone bedrock. Other till types to note are the sandstone-dominated tills fringing the south side of the inliers in the Ballingarry area, and also in the environs of the Cratloe Hills and Slieve Bernagh Mountains. On the Limerick Volcanics around Herbertstown and Kilteely there is a predominance of volcanic clasts in the tills. The matrix of the tills also reflects the dominant stone content and the underlying bedrock type. Limestone tills tend to have a sandy and/or silty matrix, while tills dominated by shales have a clayey or silty clay matrix and are more poorly drained. The amount of stones in the tills can vary widely. It can be quite high where the tills are thin and the ice has simply ripped up the underlying bedrock. The stone content can also be high in ice marginal or "morainic" areas where it can sometimes be difficult to classify the sediment as a till or a gravel.

Evidence of ice front positions and the pattern of deglaciation, or break-up and retreat of the ice sheet, is provided by the distribution of sands, gravels and fines and the associated landform assemblages. These are very complex environments and involve deposition by ice and meltwater underneath the ice, subaerially in front of the ice, and in standing water bodies or lakes. In general it can be said that the ice sheet retreated to the north and northeast, disappearing from the higher ground first. In the part of Co. Clare covered by this map there are few sand and gravel deposits, perhaps indicating substantial removal of sediment into the Fergus and Shannon estuaries. After vacating the hills of southwest Co. Clare the ice retreated north along the valley of the River Fergus.

South of the Shannon the ice retreated from west Co. Limerick with little resultant sand and gravel deposition. On the limestone lowlands east of Foynes there are morainic sediments, evidence of standstill positions of the ice front. An undulating terrain of sands, gravels and gravelly tills extends southwards from Shanagolden to Newcastle West along the foot of the escarpment defining the junction between the Carboniferous limestones and the Namurian shales. East of Newcastle West these sediments are dissected by the River Deel. There are also suites of morainic sands, gravels and gravelly tills around the sandstone inliers at Ballingarry and Castletown. A fine example of hummocky moraine can be seen a few kilometres to the southeast of Ballingarry, on the lowland south of Knockfeerina Hill. At Granagh there is a fine meltwater channel through which meltwater drained to the west, indicating that the ice retreated eastwards in this area. There is evidence from boreholes of thick lacustrine deposits formed in proglacial lakes beyond the ice margin. Elsewhere within the map area there are only isolated low hills of sands and gravels.

In the Postglacial period there has been extensive deposition of alluvium along the major rivers, that is, the Fergus, Maigue, Deel and Feale, and their tributaries. In places these alluvial flats are very extensive. Along the Shannon Estuary there are expanses of estuarine muds found both on the Co. Clare and Co. Limerick shores. There has been extensive growth of blanket bog on the higher ground in west Co. Clare, and in west Co. Limerick and north Co. Kerry. Much of this has been stripped away completely or leaving a thin veneer of peat only. In recent years there has been much afforestation in these areas. On the Carboniferous plain there was growth of peat in low-lying areas or inter-drumlin hollows. Again many of these have been cleared of peat and drained.

BEDROCK GEOLOGY OF THE SHANNON ESTUARY REGION

The Lower Palaeozoic Rocks

Rocks of Lower Palaeozoic age (Fig. 7) are located to the north of Limerick city in Co. Clare. The northernmost outcrop comprises the western part of Slieve Bernagh where rocks of Silurian age are folded into the major Slieve Bernagh Syncline. This area is separated from the Broadford Mountains by the valley of the Broadford River which is incised into rocks of Silurian age. The Broadford Mountains, with Knockanuarha Mountain as its highest peak (1017 feet), form a major anticline, the Broadford Anticline, with Ordovician rocks in its core. The Broadford Mountains are separated from the Cratloe Hills by a morphologically less well expressed valley, followed by the road from Sixmilebridge via Oatfield to Cloghera, carved in rocks of the Old Red Sandstone. The Silurian Cratloe Hills inlier is thought to represent an upfaulted extension of the southern limb of the Broadford Mountain Anticline (Weir 1962). In the Cratloe Hills various lithological units of Lower Palaeozoic age have been correlated with the Slieve Bernagh succession by Weir (1962) but subsequently amalgamated into one unit, the Cratloes Formation, by Holland *et al.* (1988).

Extensive faunal lists have been produced since the first survey of the area was carried out (Jukes *et al.* 1860, Kinahan *et al.* 1862, Harper 1939, Weir 1962, Weir 1975, Holland *et al.* 1988) to which the reader is referred.

The stratigraphical boundaries shown on Sheet 17 are based largely on Weir (1962), modified to correlate with the stratigraphical nomenclature adopted from Geological Survey mapping by A.M. Flegg (1968 - 1972), and as compiled on the adjacent Sheet 18 (Smith and Sleeman 1996).

BALLYMALONE FORMATION (BO)

The Ordovician Ballymalone Formation consists of red to black coloured shales and buff grey coloured cherts. The shales locally contain graptolites. The formation crops out in the high ground southwest of Broadford and is approximately equivalent to Weir's (1962) Belvoir and Ballyvorgal Group. It ranges in age from gracilis to peltifer graptolite biozones (Rushton 1993).

CORNAGNOE FORMATION (CE)

The Silurian Cornagnoe Formation contains two principal lithologies, grey mudstones and mottled siltstones/mudstones. Both lithologies include thin beds of graptolitic mudstones from which graptolites of Llandovery age were collected (Rickards and Archer 1969, Archer *et al.* 1996).

Purple grits (pg) recorded by Weir (1962) on the southern flank of the Broadford Anticline, Weir's Cloontra Group, are assigned here to the Cornagnoe Formation.

BROADFORD FORMATION (BF)

The Broadford Formation is dominated by grey banded mudstones but also contains abundant arenaceous horizons (Weir 1962). The formation, as described here, is equivalent to the Broadford Group and parts of the Craglea Group of Weir (1962). The base of the formation is nowhere exposed. The fossil contents of Weir's (1962) Broadford Group at Ballycar (see below) indicate that the formation spans most of the Wenlock stage (Weir 1975, Archer *et al.* 1996).

SLIEVE BERNAGH FORMATION (SB)

There are mappable horizons of conglomerate near the base of the Slieve Bernagh Formation which are equivalent to Weir's (1962, 1975) conglomerate at the top of the Craglea Group. The remainder of the Slieve Bernagh Formation is equivalent to Weir's (1962) Moylussa Group and consists largely of laminated siltstones and mudstones. The contact between the Broadford Formation and the overlying Slieve Bernagh Formation is strike-faulted.



Figure 7. The outcrop of Lower Palaeozoic rocks

CRATLOES FORMATION (CR)

The Cratloes Formation occupies the ground north of Woodcock Hill. The Formation is approximately equivalent to the Broadford Formation *sensu* Archer *et al.* (1996). The Cratloes Formation consists of about 300m of thin to medium bedded, laminated, grey to green siltstones which are occasionally calcareous and grade up to fine-sand size. When decalcified, they are yellow/brown in colour. Nodules, sometimes associated with iron oxide, up to 0.5m in diameter, are characteristic of the formation (Holland *et al.* 1988). Two members were mapped by Holland *et al.* (1988).

The Ballycar South Member (Broadford Group of Weir 1962) is a fossiliferous conglomeratic sandstone of upper Silurian age (Baily 1859, Harper 1939, Weir 1975). A shelly fauna occurring at Ballycar in the Cratloe Hills has been correlated with a fauna found in the Arra Mountains and assigned to the upper Wenlock (Homerian) *C. lundgreni* Biozone (Holland *et al.* 1988, Weir 1975). The faunas are considered to have been derived from a shelf area to the southeast and transported northwestwards towards the basin, whose southeastern and southern boundary was controlled by the Nenagh - Navan Line and by the Gallowhill - Silvermines Fault.

The Glennagross Member also consists of a lithic conglomerate interpreted as a submarine channel deposit (Holland *et al.* 1988). Although the Glennagross Member has a similar lithology to the Ballycar South Member, the lack of fossiliferous material and its geographical separation make a direct correlation uncertain.

The Old Red Sandstone (Uppermost Devonian and early Carboniferous)

To the north of the River Shannon Old Red Sandstone surrounds the Lower Palaeozoic inliers of the Cratloe Hills, Broadford Mountains and Slieve Bernagh (Fig. 8). To the south of the River Shannon, Old Red Sandstone crops out in the Kerry Head Anticline and in several poorly known inliers on the southern side of the Limerick Basin, to the east of Newcastle West. Volcanic rocks are interbedded with the Old Red Sandstone at Knockfeerina and Ballinleeny near Ballingarry (One Inch Sheet 153, Jukes *et al.* 1861). In addition a small inlier of Old Red Sandstone crops out north of Pallaskenry.

Little work has been done on the Old Red Sandstone of these areas, with the exception of Kerry Head (Khan 1955, Diemer *et al.* 1987), with the result that most of the Old Red Sandstone is shown as undifferentiated (ORS) on the map. The nineteenth century Geological Survey maps did not differentiate these rocks and referred to them variously as "Old Red Sandstone", "Upper Old Red Sandstone", or "Kiltorcan Beds". While the term "Kiltorcan Beds", was used as a synonym for Upper Old Red Sandstone in the past we follow the definition of Colthurst (1978) and restrict its use to the area in southeast Ireland around Slievenamon.

OLD RED SANDSTONE SURROUNDING THE LOWER PALAEOZOIC INLIERS

Little is known about the sedimentology and architecture of the Old Red Sandstone surrounding the Lower Palaeozoic inliers of Slieve Bernagh, the Broadford Mountains, and the Cratloe Hills. In general the Old Red Sandstone rests unconformably on the Lower Palaeozoic rocks and is gently folded along east - west axes. Locally, e.g. near Ballycullen Castle (GR 15027 16830), there is a basal breccia which contains clasts of the underlying Ordovician cherts and also Silurian grits (Harper 1939).

In general, the Lower Palaeozoic inliers on Sheet 17 consist of yellow to brown coarse-grained sandstone, pebbly sandstone and conglomerate. The clasts are dominated by well-rounded quartz pebbles, in places estimated to comprise over 90% of the assemblage giving the conglomerates a high degree of maturity. Jasper pebbles are found occasionally. Large-scale cross-bedding is common. Plant remains are locally abundant in the lower part of the Old Red Sandstone (e.g. southwest of Gallows Hill).

The lithology of the Old Red Sandstone here indicates a high energy depositional environment in rivers with considerable bed-load. The sandstones and conglomerates were deposited close to the source area. The bi-modality of the sediments indicates that some of them may have been reworked.

OLD RED SANDSTONE OF KERRY HEAD

The Kerry Head succession represents the products of meandering rivers. Lithologically the succession closely resembles the sequence on Slieve Mish in Co. Kerry (Capewell 1965) and may be compared with the Slieve Mish Group (Pracht 1996).

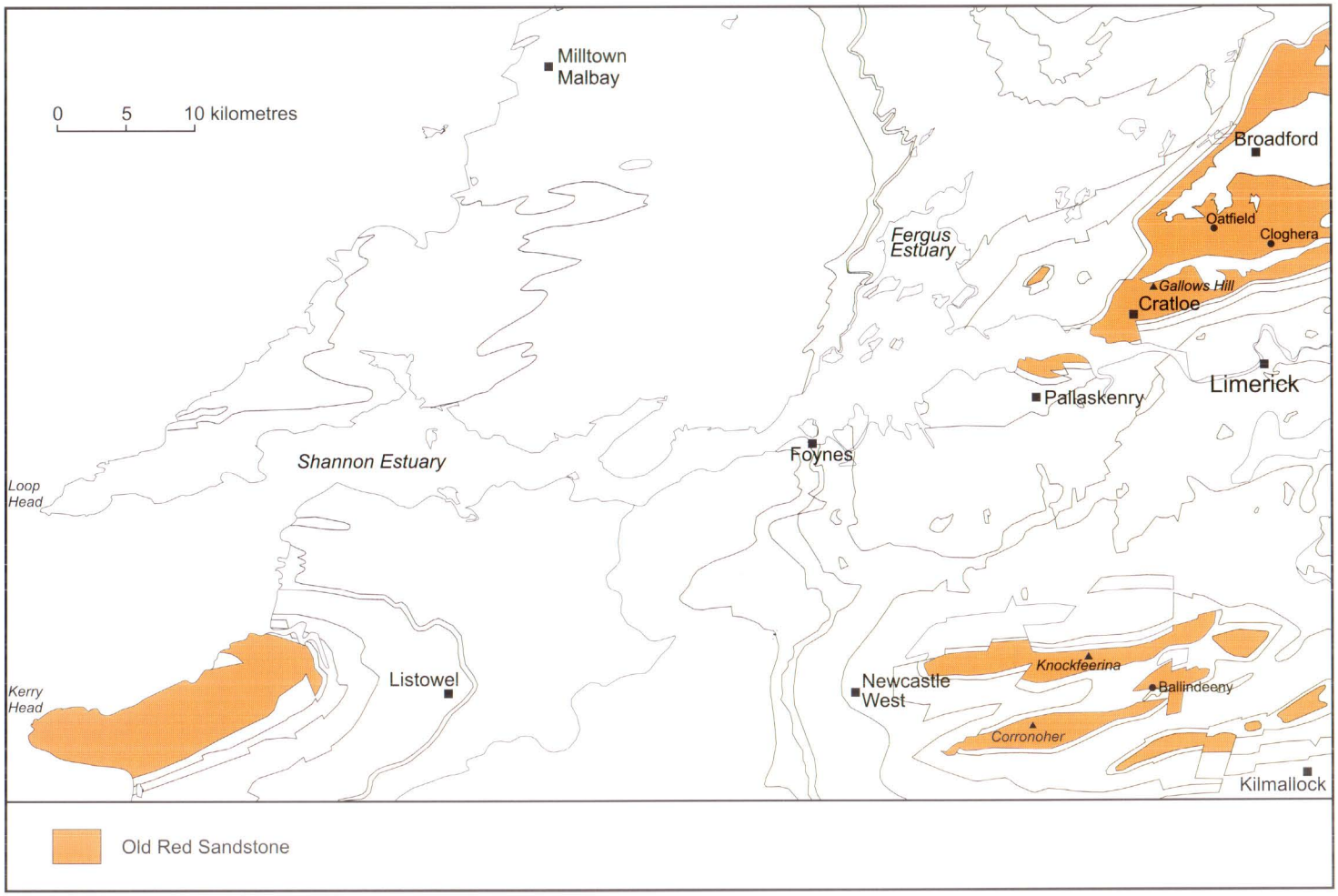


Figure 8. The outcrop of the Old Red Sandstone

Glandahalin Formation (GH)

This is the lowest formation in the sequence and is composed of olive, olive-grey, brown and red trough cross-stratified and planar-stratified, medium to fine-grained sandstones and red and yellow cross-laminated bioturbated siltstones. Sandstone bodies comprise over 60% of the formation.

Inshaboy Formation (IY)

The formation consists of red, olive to grey, and yellow trough cross-stratified and planar-stratified fine to medium grained sandstones and red, green, and yellow cross-laminated siltstones. Yellow colours predominate upwards. Plant remains are locally abundant. Sandstone bodies comprise 34% of the formation. The formation contains miospores belonging to the LL and LE Biozones, indicating a late Devonian (Famennian) age (Bridge *et al.* 1980).

Kilmore Formation (KM)

The formation is made up of yellow, olive, and brown fine-grained sandstones and yellow and green siltstones. The uppermost few metres contain bioturbated structureless olive-grey and dark-grey mudstones as channel fills. Sandstone bodies attain thicknesses up to 55m and comprise about half of the formation. The formation is latest Devonian and early Carboniferous in age based on the presence of miospores belonging to the LN and VI Biozones (Bridge *et al.* 1980).

Dinantian Rocks - the Lower Carboniferous

COURCEYAN ROCKS

Lower Limestone Shales (LLS)

The standard Lower Limestone Shale succession for the Limerick Province (Philcox 1984) is based on coast sections and borehole LI-68-10 (GR 14150 15340) from the Pallaskenry area of Co. Limerick (Shephard-Thorn 1963; Somerville and Jones 1985). The succession succeeding the Old Red Sandstone here comprises the Mellon House (MH), Ringmoylan (RM), and Ballyvergin Formations (BV) and is described in some detail below. Over most of the map, however, these three formations are grouped together as one unit (LLS) for convenience, as the combined thickness amounts to only 73.6m (Somerville and Jones 1985) and the formations are very poorly exposed (Fig. 9).

The base of the Mellon House Formation is marked by a sharp change from white calcareous sandstones with black specks and rip-up clasts (uppermost Old Red Sandstone lithologies) to mainly dark-grey, laminated siltstones and fine-grained sandstones, alternating with calcareous shales (Somerville and Jones 1985). Bioturbation (*Chondrites*) is commonly developed in the darker laminated calcareous beds, and rare flaser-bedded sandstones and small-scale cross-stratification is seen together with desiccation cracks. Shephard-Thorn (1963) recorded the bivalve *Modiolopsis* cf. *lata* (Portlock) from outcrop and Somerville and Jones (1985) record conodonts, gastropods, bivalves, crinoids, and the algae *Ortonella sp.* from a thin limestone, the first skeletal limestone in the succession above the Old Red Sandstone at 353.6m in borehole LI-68-10. The formation is 34.4m thick in borehole LI-68-10 (Somerville and Jones 1985). It thickens to 45.7m in borehole S-4 at Shannon Town (M.E. Philcox *pers. comm.* 1998), then thins northeastwards to 16.5m in the area west of Tulla (Central Mining Finance Borehole 3788/2 at Carahan, J. Colthurst *pers. comm.* 1998) and to 12.5m in the Ballyvergin Borehole (BV-14; GR 14210 18180). Lewis (1986) records two outcrops near Sixmilebridge at Ballyroe Bridge (GR 14980 16623) and at Gourtnacool (GR 14905 16435). At Ballyroe Bridge yellow, non-calcareous mudrocks with dark-grey wisps and bands in flaggy planar-bedded units pass up to dark blue-grey calcareous, unfossiliferous mudstones and siltstones. Some 14m are sporadically exposed. At Gourtnacool 10m of flaggy, thinly laminated, yellow and black siltstones pass up to platy, blue-black, calcareous shales with thin siltstone bands and dark mud-wisps overlain by calcareous mudstones. Thinly bedded slightly calcareous yellow siltstones with dark blue-grey calcareous wisps are found at Drumline (GR 14220 16411; Lewis 1986).

The Ringmoylan Formation is dominated by dark-grey to black calcareous shales with thin bands of bioclastic limestones. The base is marked by a scoured surface in borehole LI-68-10. The formation marks the change to predominantly calcareous beds. Limestones, however, form only 20 - 30% of the 31m total thickness (Somerville and Jones 1985). The formation, like the underlying Mellon House Formation, thickens northwards to Shannon Town where 47m is recorded in Riofinex borehole S 2

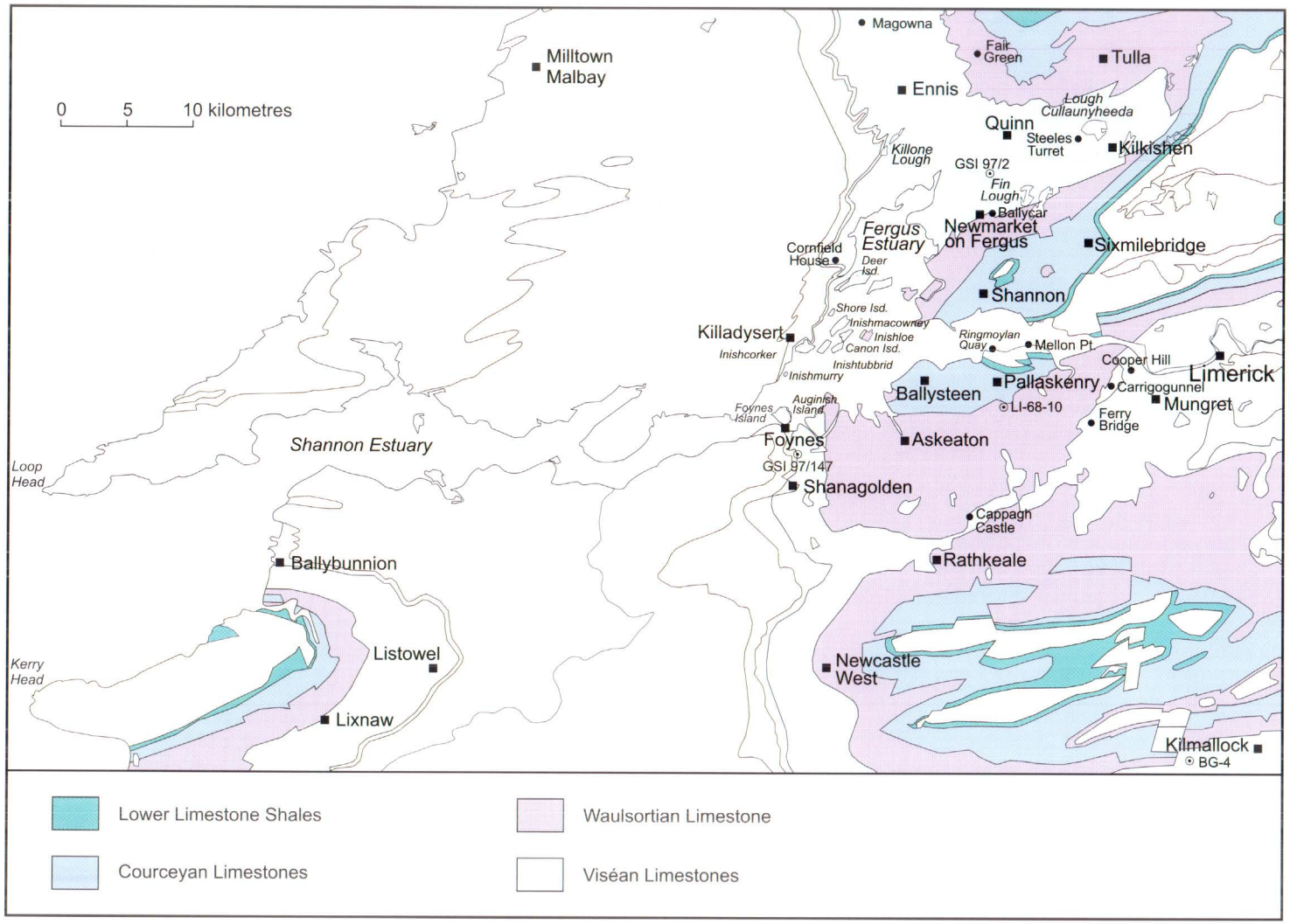


Figure 9. The outcrop of Dinantian rocks.

(M.E. Philcox *pers. comm.* 1998), then thins northeastwards with only 22.8m recorded in the Carahan Borehole (J. Colthurst *pers. comm.* 1998) and 23.47m in the Ballyvergin borehole. It also thins southeastwards on to the adjacent Sheet 18 (e.g. 14.6m Kilteely Borehole OL-81-3; 23.9m Cappamore Borehole 76-TU-4 - Somerville *et al.* 1992). Sporadic exposures are found in East Clare above the Mellon House Formation as at Ballyroe Bridge, estimated as 58m thick (Lewis 1986). The best section recorded is at Firgrove (Lewis 1986; GR 14235 16355) where 27m of the upper part of the formation are exposed in a drain. Non-calcareous, fissile mudrocks, pass upwards into calcareous dark-grey/black, thinly bedded shales and mudrocks. Brachiopod rich black shales occur. These lithologies pass up into crinoidal, argillaceous calcilutites interbedded with crinoid and brachiopod rich wackestones. *Michelinia* sp. and *Syringopora* sp. are found. The conodont *Polygnathus inornatus* is recorded from the base of the Ringmoylan Formation in Borehole LI-68-10 and is also found in the lowest limestone of the Ringmoylan Quay section together with *Patrognathus variabilis* and *Pseudopolygnathus dentilineatus*, which characterise the base of the P. Inornatus Zone in this region (Somerville and Jones 1985).

The Ballyvergin Formation consists of a 5.4m thick greenish-grey non-calcareous mudstone with siltstone laminae in borehole LI-68-10. The unit forms a prominent marker horizon in many boreholes in the Limerick Province, but rarely crops out. It contains a distinctive assemblage of reworked palynomorphs (Clayton *et al.* 1980) and is interpreted as a synchronous depositional event unrelated to volcanism (Sevastopulo 1981; Philcox 1984). At Pallaskenry the formation marks the transition from a mainly argillaceous sequence below to a predominantly limestone sequence above. North of the type borehole (BV-14) at Ballyvergin, however, argillaceous rocks still predominate some way above the Ballyvergin Formation. The formation is not exposed in the Pallaskenry area but crops out at Kilmeady Quarry 25km to the south (J. Colthurst in Somerville and Jones 1985). The formation thickens to 9.75m in borehole Riofinex borehole S-2 near Shannon Town and is 5.62m thick in the Ballyvergin Borehole (Hudson and Sevastopulo 1966; Clayton *et al.* 1980).

At Kerry Head Diemer *et al.* (1987) give a detailed description of the Lower Limestone Shales (their Clashmelcon Formation). The succession consists mainly of dusky-yellow to light olive-grey to dark-grey, very fine to fine-grained bedded sandstones (cm - dm bedded) and dark-grey laminated mudstones (mm - cm bedded). Thin limestones (wackestones and packstones) composed mainly of brachiopod, bryozoan and crinoid debris, are found locally as are intraformational breccias above erosion surfaces. Current and wave-formed sedimentary structures are common and current-formed structures include small and large-scale trough cross-bedding and heterolithic bedding. Cryptalgal laminites containing desiccation features also occur. Examples of wave-formed structures are hummocky cross-stratification, wave-ripple lamination and heterolithic bedding. Trace fossils belonging to the *Skolithos* and *Cruziana* ichnofacies are found particularly in beds of heterolithic facies. Clayton (in Diemer *et al.* 1987, p127) has recorded miospores of the PC Biozone. Diemer and Bridge (1987) interpreted the Lower Limestone Shales here as being deposited in an estuarine environment. Changes in the lithofacies and biofacies record the change from an estuarine setting close to a river mouth to a distal one with normal marine salinity.

Ballymartin Formation (BT)

The Ballymartin Formation, which was included within the Ringmoylan Shales as originally defined by Shephard-Thorn (1963), is described here separately as the lowest formation of the limestone succession following Somerville and Jones (1985).

The formation comprises an alternating sequence of thin pale-grey bedded muddy limestones and dark-grey calcareous shales in about equal proportions. The limestones are bioclastic, the fauna dominated by tabulate corals and brachiopods. The formation can be recognised in boreholes but rarely crops out inland, although it can be seen in outcrop at Ballymartin Point (GR 13910 15690). Consequently over most of the mapsheet it has not been depicted as a separate formation but has been grouped with the overlying Ballysteen Formation. The thickness of the formation where known is quite variable. It is 45.6m thick in the type LI-68-10 borehole and 11.45m thick in the Carahan Borehole (J. Colthurst *pers. comm.* 1998), but 34m thick in the Ballyvergin Borehole further north (Clayton *et al.* 1980). It is again only 25.1m and 35.3m thick in the Kilteely and Cappamore Boreholes respectively (Somerville *et al.* 1992). It is 63.7m thick in Dresser borehole TK-2 at Ballyheigue, Co. Kerry (M.E. Philcox *pers. comm.* 1998). It equates with the

Lower Pale Limestone of Gortdrum and Aherlow (Steed and Tyler 1979) and the "Lower Ballysteen Limestone" of Silvermines (Brück 1982). The formation occurs within the interval of no diagnostic conodonts (Johnston and Higgins 1981; Somerville and Jones 1985).

Ballysteen Limestone Formation (BA)

The base of the Ballysteen Limestone Formation is marked by the incoming of thick-bedded bioclastic limestones with occasional mud wisps. It is distinguished from the underlying Ballymartin Formation by the loss of interbedded calcareous shales in the sequence. In the type section borehole LI-68-10 at Pallaskenry, the formation is 190.5m thick and is divided into two informal units.

The lower unit is well exposed on the coast at Beagh Castle (GR 13580 15700) where Shephard-Thorn noted the presence of dark well-bedded bioclastic limestones. The limestones are mainly argillaceous wackestones with a rich invertebrate fauna of crinoids, brachiopods, bryozoa, calcareous algae and conodonts (Somerville and Jones 1985). The fauna is usually partly silicified and chert nodules are present occasionally. The carbonate/shale ratio is very high (90%) at the base of the formation where a distinctive marker horizon in borehole cores (the calcarenite marker band of Philcox 1984; the Pallaskenry Member of Somerville and Jones 1985) has been recognised. Above this horizon the carbonate/shale ratio is usually about 60 - 70% (Somerville and Jones 1985). The lower unit, including the Pallaskenry Member, is 140m thick and is equivalent to the Middle Pale Limestone of Steed and Tyler 1979 at Gortdrum and the "Middle Ballysteen Limestone" of Brück (1982) at Silvermines.

The upper unit of the formation, about 50m thick, is more argillaceous and has a typical carbonate/shale ratio of 30 - 40% (Somerville and Jones 1985). Black calcareous mudstones alternate with subordinate thinner pale-grey biomicrite limestones.

The uppermost 9.4m in the type Pallaskenry borehole, the Ballynash Member (Somerville and Jones 1985; "Wavy Nodular Member" of Brück 1985), is noticeably more nodular and cherty. Pale-grey micrite nodules are enclosed in dark-grey shale and chert nodules are conspicuous. Large crinoid ossicles are found in some places. This member can be seen at Ballynash Castle (GR 13300 15320) but is too thin to show separately on the map. The Ballynash Member is overlain sharply by massive pale-grey Waulsortian micrites at 67.3m in the Pallaskenry borehole (Somerville and Jones 1985). The Ballynash Member is thicker at the northern and southeastern boundaries of the map and is accordingly shown separately (BAbn). It is 24.35m thick in the Carahan borehole (J. Colthurst *pers. comm.* 1998) and 31.1m thick in the Kilteely borehole (Somerville *et al.* 1992). Lewis (1986) records the member on the southern limb of the east Clare Syncline, but it is not shown separately here. The upper unit of the Ballysteen Formation including the Ballynash Member is equivalent to the Upper Pale Limestone of Steed and Tyler (1979) and the Upper Ballysteen Limestone of Brück (1982).

The entire Ballysteen Formation thins northwards from 190.5m at Pallaskenry to 99.1m at Carahan (J. Colthurst *pers. comm.* 1998) and 116.5m in the Gort G1 borehole on Sheet 14 (Lewis 1986). In contrast it thickens eastwards onto Sheet 18 to 272.9m in the Cappamore borehole (Somerville *et al.* 1992). At Ballyheigue, Co. Kerry, Dresser borehole TK-2 encountered 103m of the formation (M.E. Philcox *pers. comm.* 1998).

Shephard-Thorn (1963) lists the macrofauna of the Ballysteen Formation, and Somerville and Jones (1985) have detailed the macro and micro fauna contained in the Pallaskenry borehole. The formation is of late Courceyan age (*Pseudopolygnathus multistriatus* Local Range Biozone). *Polygnathus communis carina* first appears at 148m in the borehole and continues to the top of the formation. In the Carahan borehole the top of the *P. multistriatus* Local Range Biozone is some 47m below the top of the formation. In the Pallaskenry borehole the base of the *Polygnathus mehli* Local Range Biozone coincides with the base of the Waulsortian Limestone (Somerville and Jones 1985).

The Ballymartin and Ballysteen Formations were deposited on a deep shelf or ramp (Somerville and Strogen 1992).

Waulsortian Limestones (WA)

The Waulsortian Limestones, named after rocks of similar facies from Waulsort, in Belgium, are found in three areas on the mapsheet (Fig. 9). Firstly in West Co. Limerick where the unit may be up to 1000m thick. This is the thickest known Waulsortian succession anywhere in the world (Lees and Miller 1995). The facies is also widespread in East Clare

and North Kerry. Originally the facies was laterally continuous covering most of central Ireland (over 30000km sq). This is also unique, being the greatest extent known anywhere in the world (Lees and Miller 1995).

In the Limerick area the Waulsortian "complex" can be divided into three units: basal and top units with isolated or clustered banks set in offbank bedded limestones, and a main unit of massive coalesced bank limestone (Strogen 1988).

The dominant lithology in the Waulsortian "complex" is commonly a very fine pale-grey massive, unbedded, biomicrite wackestone, with crinoid fragments and fenestrate bryozoa, frequently with large sparry cavities (Stromatactis) floored by multi-layered carbonate muds. These limestones formed banks or mounds, which are in some places separated from each other by more dark-grey argillaceous, sometimes cherty, shelf ("off-bank") limestones, as in the type area in Belgium. Over much of the area the Waulsortian Limestones form a continuous sheet.

At Aughinish Island, however, Lees (1964) has identified the top part of the mudbank complex where an exhumed topography enables individual banks, some of them of knollform, to be recognised, with bedded cherty limestones draped over the top of banks and also interdigitating with them. The steep dips on the flanks of the mudbanks thus represent original depositional dips (regional tectonic dip is only 10°).

The Waulsortian Limestones are thought to represent accumulations below storm wave base in aphotic conditions, more than 200m deep (Lees and Miller 1995). Before lithification the unconsolidated carbonate banks were probably held together by microbial mats or mucus; framework building organisms are absent. Bryozoan fronds may have helped to reinforce and stabilise the muds during burial and diagenesis but played little or no part in trapping or binding the sediment (Lees and Miller 1995). Towards the top of the Waulsortian the banks grew upwards into shallower water, probably within the photic zone, as evidenced by the presence of phase C components (Lees and Miller 1995).

Rich faunas, particularly of brachiopods and cephalopods, have been collected, commonly from pockets, in the bank limestones in the Askeaton and Rathkeale areas (Kinahan and Foot 1860; Foord 1897 - 1903; Shephard-Thorn 1963). These localities have produced good specimens, many of which are in the collections of the Geological Survey (Parkes and Sleeman 1997) and National Museum of Ireland (Monaghan 1983, 1992).

The Waulsortian Limestones of Co. Limerick ranges from late Courceyan (*Polygnathus bischoffi* subzone of the *Polygnathus mehli* Local Range Biozone, Somerville and Jones 1985) to probably Lower Visean (late Chadian of authors), at least in some areas (G.D. Sevastopulo *pers. comm.* 1998). Hill (1971) recorded *Scaliognathus anchoralis*, the eponymous species of the *Sc. anchoralis* Biozone in Belgium which range up to the base of the Visean, from a quarry close to the base of the Waulsortian near Askeaton. The development of the Waulsortian facies started earlier here (and in much of Munster) than in the Midlands of Ireland with the exception of South Cork (Sleeman *et al.* 1986) where it started near the base of the *Polygnathus communis carina* Zone. It spread northwards up the regional palaeoslope (Sevastopulo 1982).

A borehole drilled at Ballygowan, near Newcastle West has penetrated over 500m of Waulsortian limestones bottoming in the Ballysteen Formation (M.E. Philcox *pers. comm.* 1998). The upper part of the Waulsortian limestones in this borehole contained thinly banded dolomitic limestones. Similar thicknesses of Waulsortian limestones are known further east.

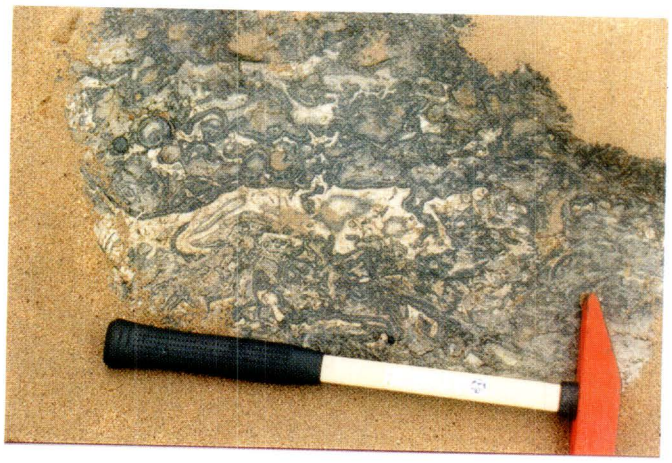


Plate 2. Spar-filled cavities in Waulsortian Limestone at Ballybunnion, Co. Kerry (photo by M. Pracht).

Little is known about the Waulsortian Limestones of North Kerry. The Waulsortian crops out below high water mark at Ballybunnion where typical spar filled cavity structures are beautifully displayed on wave washed surfaces (Plate 2). Dresser Minerals (report in GSI Mineral Exploration Records Databank) estimated that it was about 1000m thick here. The upper part of the Waulsortian on the coastal section is of Lower Visean (late Chadian of authors) age (G.D. Sevastopulo *pers. comm.* 1998) A number of boreholes drilled by Dresser Minerals in the Ballybunnion area encountered "reef". It is not clear from existing documentation, but probable that these limestones are Asbian "reef" limestones. The area in which the boreholes were drilled is designated as "Visean undifferentiated".

Lewis (1986) estimated the thickness of the Waulsortian to vary from about 1000m on the south limb of the East Clare Syncline to between 500 - 800m on the north limb. The Waulsortian Limestone here comprises massive, or at best crudely bedded, pale to dark-grey calcilutites and wackestones with variably shaped spar filled cavities which may or may not be associated with bryozoan fronds. This facies is well seen at Enagh Castle (GR 14970 17070) and Urlanmore Castle (GR 13808 16627) (Lewis 1986). Crinoidal packstone/biomicrite facies is widespread but less common.

VISEAN LIMESTONES - EAST CLARE SYNCLINE

While details of the stratigraphy remain to be worked out, in broad terms, the post Waulsortian stratigraphy of the East Clare Syncline follows that established by MacDermot (see Gallagher 1994) for the Burren. The stratigraphy proposed by Lewis (1986) for the East Clare Syncline is here largely subsumed within the Burren terminology.

Ballycar Formation (BC) - new name

The Ballycar Formation (modified after Lewis 1986) occurs above the Waulsortian Limestones and fills hollows in the local relief. The type section is located at Ballycar (GR 14075 16788) near Newmarket-on-Fergus. Here the formation is 38m thick, much thicker than its equivalent at Gort, Co. Galway (Cregmahon Member of the Tubber Formation - TUcm, C. MacDermot unpublished). It comprises dark-grey, highly silicified calcilutites interbedded with nodular, black chert bands (0.1 - 0.25m thick). The basal 9.1m are medium-grey, tabular, crinoidal packstones and calcisiltites with small chert nodules (less than 5mm). The formation becomes increasingly cherty upwards and the bedding becomes more nodular. The formation is of Chadian age and is equivalent to the Lough Gur, Crosspatrick and Knockordan Formations of Sheet 18 (Archer *et al.* 1996). It is not very well exposed.

Finlough Formation (FL) - new name

The Ballycar Formation is followed by the "Calp like" Finlough Formation (modified after Lewis 1986) on the southern limb of the East Clare Syncline. The formation is best seen on the east and west shores of Finlough, Co. Clare. Lewis (1986) estimates the formation to be about 75m thick. The top of the formation is not seen but is probably in faulted contact with the Tubber and Burren Formations.

The formation comprises dark-grey to black, flat-bedded, earthy, fetid, calcisiltite and fine calcarenite which contain chert nodules and shale partings (packstone and wackestone). Fasciculate corals are common as seen in the lakeside exposures on the west bank of Finlough. A short borehole drilled at Teereen Lough (GSI 97/3; GR 14627 17166) encountered very dark-grey wackestone calcisiltite assigned here to the Finlough Formation. There is very little fossil debris present but fasciculate corals were found. At Ballycar level crossing (GR 14184 16878) coarse pyritous crinoidal packstone and wackestone debris beds with pale limestone lithoclasts are interbedded with very dark-grey argillaceous limestone.

It is not clear how the formation relates to the Tubber Formation. On the map it is shown both in faulted contact and passing laterally eastwards into the Tubber Formation. The formation may be compared to the Rathkeale Formation of West Limerick (Shephard-Thorn 1963), which is interpreted as a distal ramp sequence (Somerville and Strogen 1992). The Finlough Formation may be in an intermediate position nearer the basin margin.

Tubber Formation (TU) - new name

The Tubber Formation (C. MacDermot unpublished; Gallagher 1996) comprises the stratigraphical interval above the Waulsortian Limestones and up to the base of the Burren Formation in the Burren region of Counties Clare and Galway. It is best seen at Tubber, Co. Galway (Sheet 14). It is not as well exposed in East Clare as in the Burren. Lithologically the formation is very similar to the overlying Burren Formation, so it can be difficult to distinguish them. The formation is characterised

by crinoidal medium-grey packstone and wackestone and sometimes has fine-grained limestone with shaly partings.

The basal part of the formation is the Cregmahon Member (TUcm), the "Waulsortian reef cover cherts". It consists of thick-bedded silicified and dolomitised highly cherty packstones and wackestones, with some shale partings. Variations in thickness are attributable to drape over the irregular top of the underlying Waulsortian limestones. The member grades up into cleaner, less cherty limestones and thence into undifferentiated chert-free Tubber Formation. On Sheet 17 it is mapped on the northern limb of the East Clare Syncline from north of Fair Green to the vicinity of O'Callaghansmills. It is laterally equivalent to the Ballycar Formation on the southern limb of the East Clare Syncline, and to the Lough Gur Formation of the Limerick Syncline and adjacent areas.

The upper part of the formation commonly has a significant proportion of dolomites and occasional horizons with black chert nodules. Massive or thick-bedded grainstones, peloidal or oolitic, occur as they do to the north on Sheet 14, but their lateral continuity and correlation with those of sheet 14 are not yet established. The presence of dolomite usually distinguishes the formation from the Burren Formation. Similarly cerioid Lithostrotionids (*Lithostrotion* spp.), which appear at the base of the Holkerian in the succeeding Burren Formation, are absent. Fasciculate Lithostrotionids (*Siphonodendron* spp.) conversely, are abundant in the upper part of the Tubber Formation. The presence of *Lithostrotion martini* at Granahanmore (GR 14170 16999; Lewis 1986) indicates an Arundian age.

The formation is well exposed at Finanagh, immediately north of the cross-roads with the L31 road (GR 13945 17708). Here it is similar to the Ballyaneen Member of the Gort district (C. MacDermot unpublished). 30 - 50cm bedded clean grey uniform bioclastic limestones are interbedded with dolomites. The limestones are medium-grey coarse packstones and grainstones. The dolomites are thin bedded and replacive, destroying the original textures. Some of the limestones are partly dolomitised.

The formation is quite well exposed at Granahan where thick to massive-bedded dark-grey peloidal grainstones and packstone/wackestones are seen in a roadside quarry (GR 14185 16928). The formation is exposed about half a mile further north in Granahanmore in a partially quarried area where the earthy dark-grey wackestones are rich in fasciculate corals and strophomenid brachiopods, bryozoa and crinoid ossicles. The formation is again quite well exposed in small quarries near Kilkeshin where some of the grainstones are partly oolitic and also contain algal material. Nodosarchaediscid foraminifera, which indicate a late Arundian age, were recovered here (Lewis 1986; GR 14862 17200) in well-sorted crinoidal grainstones. Further northeast at Mountallon, Lewis (1986, p. 266; GR 15347 17449) found primitive Archaediscid foraminifera indicating an Arundian age.

The formation is anomalously thin north of Lough Cullaunyheeda, compared to further west in the Burren. It is probable that this is due to strike parallel faulting, as interpreted on the map, associated with the Quinn Shear Zone.

Burren Formation (BU) - new name

The Burren Formation (C. MacDermot unpublished and in Gallagher 1996) passes up conformably from the Tubber Formation without any significant lithological change. The formation is typified by pale-grey packstones and wackestones, but also contains intervals of dark cherty limestones often associated with oolitic grainstones.

North of Ennis the basal unit is the Ballard Member (BUbd), whose type section is to the north on Sheet 14. It consists of dark-grey medium-bedded cherty wackestones/packstones with thin shaly partings, and is taken to be the local base of the Burren Formation, in the absence of cerioid Lithostrotionids whose incoming conveniently marks the base of the Burren Formation on Sheet 14 to the north. Cerioids appear to decrease in abundance towards the southern border of Sheet 14, their value as a stratigraphic marker being nil on Sheet 17. Similar dark cherty limestones occur on the north limb of the East Clare Syncline, especially near Coolshamrock Farm (GR 13955 17325) and can be mapped locally.

The topmost mapped unit, depicted as BUam on the map, consists of the Maumcaha and Aillwee Members (C. MacDermot unpublished, Gallagher 1996) which have been combined on the map as lack of exposure makes their separation difficult on this map sheet. The Maumcaha Member consists of massive medium to pale-grey packstones, whereas the overlying Aillwee Member comprises cyclical "terraced" units with thickly-bedded to massive steely-blue limestones. The brachiopod *Davidsonina*

septosa, diagnostic of the upper Asbian, is found in the Aillwee Member in the upper part of Whelan's Quarry, and also in Lisheen Townland (GR 12980 16730). The Maumcaha and Aillwee members are equivalent to Tattersall's (1963) Ballybeg Limestone.

The Aillwee member can be seen in the woods on the flanks of Steeles Turret Hill (GR 14700 17397), and is especially well demonstrated at Whelan's Quarry (GR 13040 17950), northwest of Ennis. Crinoidal packstones or grainstones are found towards the centre of some cycles. The top of individual cycles are palaeokarstic surfaces overlain by clay wayboards. Clay wayboards can be seen in Whelan's Quarry, including one wayboard 0.5m thick (Plate 3), below which is a micritic crust and rhizoliths. The limestones above and below this wayboard contain abundant productid brachiopods.



Plate 3. Clay way-board resting on a palaeokarstic surface, Burren Formation, at Whelan's Quarry, Co. Clare (photo by A.G. Sleeman).

The remainder of the Burren Formation, especially where it outcrops on the north limb of the east Clare Syncline, contains significant proportions of oolitic and peloidal limestones (oo) which are absent in the type area of the Burren Formation. Oolitic grainstones form a distinct unit which can be traced from Derrybeg westwards to Ballyhannon House, south of Quinn, and on towards Ennis. The stratigraphically oldest records by Schultz and Sevastopulo (1965, loc. 3) of *Lithostrotion sp.* were recorded from this unit suggesting that it occupies a position near the base of the Burren Formation. It is not clear at present how extensive oolitic grainstones are within the Burren Formation. Recent drilling at Lough Ataska (GSI 97/2; GR 14112 17102) suggests that these grainstones, while common, are interbedded with wackestones and much muddier limestones. Oolitic and peloidal grainstones may occur sporadically throughout the Burren Formation from rocks of Holkerian to late Asbian age.

Large *Siphonophyllia* corals are found a little to the south of the peloidal unit near the doline at Dangan cross-roads (GR 14647 17574), and also at a similar stratigraphical position at Poulnagordon (GR 14220 17393) southeast of Quinnn. A cherty unit (ch), found at the doline, can be mapped westwards towards Quinnn.

Slievenaglasha Formation (SL) - new name

The type area for this formation is in the Burren (C. MacDermot in Gallagher 1996). The formation is Brigantian in age. The alga *Girvanella* appears just above the base of the formation and is followed by a marker-bed containing *Saccaminopsis*. On Sheet 14 the formation is characterised by the development of cyclical crinoidal packstones and grainstones interbedded with darker fine grained nodular wackestones, occurring in the lower and upper parts of the Formation, while the middle part is dominated by dark cherty nodular-bedded wackestones and packstones. On Sheet 17 the latter facies predominates.

In East Clare, the base of the Slievenaglasha Formation (Aylecotty Member SLay; modified after Lewis 1986) is seen in a quarry 150m east of Mooghaun Castle (GR 14040 17072). Here thickly-bedded grainstones of the Burren Formation are overlain by thinner-bedded, dark-grey limestones containing the coral *Diphyphyllum sp.* (Lewis 1986). In borehole GSI 97/2 at Lough Ataska (GR 14112 17102) which is close by, cherty calcarenites containing *Saccaminopsis* were encountered. *Saccaminopsis* has also been found in similar rocks to the north near Ardsollus Bridge (near Quinn, GR 14043 17148).

Cherty limestones assigned to the Slievenaglasha Formation are common south of Ennis towards Killadysert (the Inch Bridge Limestones of Tattersall 1963) where Austin *et al.* (1970) record the foraminifera *Neoarchaeadiscus* and *Howchinia*, and Tattersall (1963) records *Lonsdaleia duplicata*. A good section may be seen in Lisheen Townland (GR

12980 16730) south of the main road where the upper part of the Formation consists of medium to dark-grey calcisiltite wackestones with small black chert nodules, occurring in sometimes wavy beds 0.3m - 1m thick, below which the succession is chert-free but of a similar bedding style. The contrast between this and the underlying massive Burren Formation is well displayed.

Elongate cherty lenses on wavy bedding planes are seen in laterally extensive outcrops at Newhall (GR 13250 12790), on the north slope of Killone Lough. Tattersall (1963) mapped the base of the cherts as the base of the Inch Bridge Limestones, but this is some way above the base of the Slievenaglasha Formation. A series of small mudmounds (mk) occur at Cragbrien, Newhall and Bushypark, where they appear to be associated with micritic bedded limestones near the very top of the Formation.

Cherty limestones of the upper part of the Slievenaglasha Formation (Aylecotty Member) also crop out in the woods at Cullaun, on the southwestern slopes of Steeles Turret Hill in East Clare. Here the Aylecotty Member is juxtaposed against the underlying Burren Formation along the northeast - southwest trending Turret Fault. Lewis (1986, p. 274, loc. E) has recorded Brigantian conodonts from the north side of Turret Hill. These conodonts, which include *Gnathodus homopunctatus*, *Gnathodus bilineatus*, *Lochriea mononodosus* and *Lochriea nodosus*, are assigned to Zone 10 of Varker and Sevastopulo (1985) (upper P_1 or lower P_2 Zone).

Turret Volcanic Member (SLtu) - new name

The cherty limestones of the Aylecotty Member are overlain by the Turret Volcanic Member which crops out on Steeles Turret Hill, about 6.5km south of Tulla (GR 14715 17380; Schultz and Sevastopulo, 1965; Lewis 1986). This consists of some 85m of altered bedded basaltic tuffs and lavas of late Brigantian age. Fresh exposure shows blue-green basaltic spheroids which have undergone a Tertiary spalling effect.

Cullaun Member (SLcu) - new name

The Cullaun Member (Killane Limestone of Schultz and Sevastopulo 1965) is restricted to the southwestern slope of Steeles Turret Hill (GR 14702 17390), and overlies the Turret Volcanic Member. It is overlain by black shales assigned to the Namurian Clare Shale Formation. The member is estimated to be 30m thick. The lowest 4m comprise steeply dipping conglomeratic beds (0.25 - 0.45m thick), in which intraformational packstones and silicic wackestone clasts up to 0.5m thick and chert clasts (up to 0.1m) are embedded in a siliceous matrix. The clasts are probably of local derivation, suggested by their size and sub-angularity. Lewis (1986) suggests that the cobbles and boulders were eroded from a scarp formed by movement on the Turret Fault during the late Brigantian, shedding limestones containing conodonts of Asbian age. Volcanic clasts are absent. Thinner, flaggy crinoidal grainstones and packstones are interbedded with the conglomerates and at one level there is a laminated, peloidal, fine-grained wackestone with fenestral fabrics and abundant bryozoa and ostracods. The Cullaun Member contains a late Brigantian fauna similar to locality E (Lewis 1986) but lacking *Gnathodus homopunctatus*.

Magowna Formation (MG) - new name

The youngest beds of the Carboniferous Limestone, of late Brigantian age, are only seen in one area at Magowna, north of Ennis. The formation is only 3m thick at the type section in the top half of a waterfall in the townland of Magowna (GR: 12890 18220) and so is shown as a diagrammatic line on the map. It is sporadically exposed between Magowna and Kilfenora on Sheet 14 (C. MacDermot unpublished). The base of the formation is a 0.1m thick, black, shale overlying a coarse calcarenitic limestone assigned to the Slievenaglasha Formation. The basal shale is overlain by a 0.3m thick, black, fine-grained limestone. The topmost limestone of the Magowna Formation, half way up the waterfall, has yielded the Namurian goniatite *Cravenoceras leion* (E_{1a}). The formation has also yielded archaediscid foraminifera and conodonts of late Brigantian and early Namurian age (G.D. Sevastopulo *pers. comm.* 1998). The formation is overlain by the Clare Shale Formation of Namurian (E_1) age.

It is assumed here that the Magowna Formation, or its equivalents, extends southwards to the Shannon Estuary. It is shown on the map as far south as the area near Cornfield House. South of there its equivalent is assumed to be found the upper part of the Corgrig Lodge Formation as demonstrated in borehole GSI 97/148 drilled near Foynes.

VISEAN LIMESTONES - NORTHWEST LIMERICK

Rathkeale Formation

The Rathkeale Formation is generally poorly exposed. It is named after synclinal sections in the Deel River, near Rathkeale. Shephard-Thorn (1963) estimated a maximum thickness of 1500 feet (460m). It comprises dark argillaceous limestones and shaly mudstones. The formation is unfossiliferous apart from trace fossils. The limestones are well-bedded and brittle and have a fracture cleavage. The lower part of the formation is dominantly shaly. The contact of the Rathkeale Formation with the overlying Durnish Formation was encountered in a borehole drilled near Ardaneer Cottage (GR 12640 15005). About 24m of fine-grained argillaceous burrowed calcarenites assigned to the Rathkeale Formation were intersected in the borehole (M.E. Philcox *pers. comm.* 1998).

East of the type area Shephard-Thorn (1963) recorded the formation in a few small outliers as at Cappagh Castle. Here the beds are more carbonate rich comprising laminated calcisiltites and locally sharp based graded bioclastic beds (Somerville and Strogen 1992). The graded beds are packstones and grainstones ranging from a few centimetres thick to 0.2 to 0.3m thick often with concentrations of crinoid and brachiopod debris and foraminifera.

Austin *et al.* (1970) recorded *Polygnathus bischoffi, Gnathodus symmutatus, Gnathodus texanus, Gnathodus semiglaber* and *Gnathodus girtyi simplex* from the Rathkeale Formation suggesting a latest Chadian to Arundian age. The formation has been interpreted by Somerville and Strogen (1992) as ranging from distal ramp (calciturbidites at Cappagh Castle) to basinal facies.

Boulders of agglomerate are found subcropping within the upper part of the formation southeast of Shanagolden. These are planar bedded moderately well-sorted vitric lapilli tuffs and probably lie within 2 - 3km of a vent and represent explosive ash fall deposits of Strombolian type (E. Sweeney *pers. comm.* 1998).

The Visean outcrop northeast of Adare, towards Limerick City, cannot be divided with our present knowledge. Accordingly it is shown on the map as Visean undivided. Limestones recorded on the western edge of Sheet 18, south of Limerick City as Rathkeale Formation by Smith and Sleeman (1996) should also probably be recorded as undifferentiated Visean. The whole status of the Rathkeale Formation needs further mapping and drilling to determine whether the black shales and shaly limestones in the type area are typical or just a local phenomenon.

Durnish Formation (DU)

Shephard-Thorn (1963) described the formation as made up of some 1000 feet (307m) of uniform, blue-black, bioclastic limestones which commonly contain bands of chert nodules parallel to bedding. These well-bedded cherty packstones and wackestones contain abundant in situ coral beds and brachiopod bands, the corals being chiefly large solitary Caniniid - Clisiophyllid types (Shephard-Thorn 1963). These include the fasciculate coral *Solenodendron furcatum*, which first occurs in the Asbian. At Durnish Point (GR 12590 15205) some 120m of the upper part of the formation are exposed. The lower levels are exposed in a number of quarries locally. GSI Borehole 97/147 (GR 12579 14977) penetrated some 184.4m (apparent thickness) of the formation without reaching the Rathkeale Formation. The upper part of the Durnish Formation, as recognised in borehole GSI 97/147, consists of dark-grey calcilutite with occasional black shale bands and wisps.

The Durnish Formation may extend as far east as the BG-4 (Ballynagoul Borehole), 4 miles west-southwest of Kilmallock. According to I.D. Somerville (*pers. comm.* 1998) at least the upper 151m of the borehole may be attributable to the Durnish Formation, although mapping continuity has not yet been established with the type area (on the map this area is shown as Visean undifferentiated). In the borehole dark-grey argillaceous limestones with chert containing the coral *Siphonophyllia benburbensis* are seen. Below 172.7m in the borehole there is a gradation to chert-free cleaner limestones which may correlate with the Herbertstown Formation (I.D. Somerville *pers. comm.* 1998).

The Durnish Formation facies represents deposition below fairweather wave-base on the mid-part of the Limerick Ramp (Somerville and Strogen 1992).

Shanagolden Formation (SG)

Shephard-Thorn (1963) describes the Shanagolden Formation as 250 feet (77m) of black, well-bedded limestones in which chert is uncommon. As seen in GSI Borehole 97/147 the formation is approximately 48.5m thick (true thickness). The formation is similar

to the underlying Durnish Formation except for the general rarity of chert. In GSI 97/147 the base of the Shanagolden Formation is taken at the base of the conglomeratic calcilutite unit at 86.6m depth and the top at the top of the 1.6m thick packstone/ grainstone at 37m depth. Between 55.4m and 38.6m depth in the borehole lies a 18.4m thick shale unit which has not been seen in outcrop and is therefore not described by Shephard-Thorn (1963). This unit consists of black to very dark-grey calcareous mudstones alternating with thin laminated packstone and grainstone limestones. About 70% of the sequence is mudstone.

The Shanagolden and Durnish Formations were distinguished by Shephard-Thorn on the basis of a distinctive coral fauna. The large caniniids and clisiophyllid corals of the Durnish Formation are replaced by an assemblage of small cyathaxoniids. *Beyrichoceras obtusum* (Phillips) and the clisiophyllids, which are found in the upper 60m of the Shanagolden Formation support a B_2/D_1 subzone age (late Asbian). A few large caniniid corals are found in the basal 15m. A late Asbian age has also been determined from foraminifera contained in a thick grainstone bed (at 37.6m depth) near the top of the formation in borehole GSI 97/147 (H.E.A. and I.D. Somerville, unpublished report to GSI, 1998). This includes many of the diagnostic Cf6g Foraminiferal Biozone taxa such as *Bradyina rotula, Cribrospira pansa, Koskinotextularia cribriformis, Archaediscus* at angulatus stage, with bilaminar palaeotextulariids, *Eostaffella* sp. and *Globoendothyra globulus*. Asbian conodont assemblages, contained throughout the formation in borehole GSI 97/147, include *Gnathodus homopunctatus, Gnathodus symmutatus, Lochriea commutata* and *Vogelgnathus campbelli*. The first appearance of *Gnathodus bilineatus*, which defines the base of the eponymous conodont zone, appears at 57.48m depth (H.E.A. and I.D. Somerville *ibid.*). Previous records (Austin *et al.* 1970; Austin and Husri 1974) indicated that the *Gn. bilineatus* Zone was restricted to the younger Parsonage and Corgrig Lodge Formations.

The Shanagolden Formation represents carbonate deposition on the mid - outer part of the Limerick Ramp in gradually deepening water. Sevastopulo (1981) suggests that the Shanagolden Formation is the bedded equivalent of the bank limestones of the Fergus Estuary (e.g. Inishmurray and Cornfield), since they are overlain by the striped limestones of the Parsonage Formation.

Parsonage Formation (PA) - redefined

The formation, as originally described, comprises pale to dark-grey calcite mudstones (Shephard-Thorn 1963). The base of the formation overlies a thin bed of crinoidal limestone at the top of the Shanagolden Formation. Macrofossils are uncommon. Shephard-Thorn also recorded abundant "algal" structures (the "striped limestones" of Hodson and Lewarne 1961). We concur with Sevastopulo (1981), however, who interprets these laminated structures as pseudomorphs after deep water evaporite beds.

In GSI Borehole 97/147, the base of the Parsonage Formation, corresponding to the base of the "Striped Limestones" of Hodson and Lewarne (1961), lies at a depth of 37.0m and overlies a prominent series of packstones and grainstones some 1.6m thick. The formation is about 23.3m true thickness, the top of the highest striped limestone bed (and top of the formation) being at 13.3m depth. It is suggested here that this interval should be regarded as the type section for the formation. The lowest 7.8m consists mainly of disrupted laminated limestones with conglomeratic horizons overlying a thin basal grainstone. These beds have been described as "striped limestones", that is pale-grey or white, laminated, very fine-grained limestone with bedding often sharply folded and brecciated, with lamination often partly obscured by recrystallisation. There is also some black mudstone interbedded. Massive limestones form a middle unit 5.4m thick. They contain spar filled cavities and concentrically-zoned chalcedonic replacement fabrics and occasional peloidal packstones. These massive limestones are interpreted as mudmound facies to be compared with the mudmounds of similar age at Cornfield and Inishmurray on the northern side of the Shannon Estuary. The top part of the formation (10.5m) comprises calcilutite wackestones with occasional chert blebs, some "striped limestones", thin grainstones and thin interbedded mudstones.

Faunal assemblages are more restricted in the Parsonage Formation, being absent from the evaporitic striped limestones and the mudmound facies. *Gnathodus bilineatus* is present throughout the Parsonage Formation. *Gnathodus homopunctatus* reaches its local acme at 22.5m depth in GSI 97/147. The Asbian - Brigantian boundary is placed at 37m depth in GSI 97/147 above the last sample with a rich and diverse late Asbian foraminiferal/algal assemblage (Cf6g) and at the base of the succeeding sample which contains

a Brigantian (Cf6d) foraminiferal/algal assemblage depth (H.E.A. and I.D. Somerville *ibid.*). This coincides with the boundary between the Shanagolden and Parsonage Formations.

Corgrig Lodge Formation (PA) - redefined

The Corgrig Lodge Formation is combined with the underlying Parsonage Formation on the accompanying map (PA code). Shephard-Thorn (1963) described these, the highest beds of the Carboniferous Limestone succession, as being largely unfossiliferous dark argillaceous limestones and interbedded black shales. He estimated a total thickness of 20 feet (6m), although neither the base or the top of the formation was seen. Only about 2m of thin-bedded black argillaceous calcarenite and shale are to be seen near Corgrig Lodge (GR 12540 15110). GSI Borehole 97/148 located adjacent to the stream section described by Shephard-Thorn half a mile south southwest of Ardaneer Cottage and drilled 60m from GSI 97/147, demonstrates a thicker sequence (24.65m, approximately 24m true thickness).

The borehole shows a sequence of calcilutites, sometimes cherty, interbedded with thin black mudstones and thin limestone conglomerates. The thickness and frequency of mudstones increases up through the formation and in the middle are separated by thin graded, fining-upwards crinoidal packstones and grainstones. These graded limestones have sharp often scouring bases. Towards the top of the formation mottled and burrowed calcilutites predominate again. The calcilutites are more spiculitic, argillaceous and pyritic towards the top of the formation. There is a 1.7m thick mudstone overlain by striped limestones at the top of the formation.

In the stream section a few goniatites were found in shales up to 1 foot thick interbedded with nodular-bedded dark-grey calcilutites with chert. *Goniatites hudsoni* Bisat and *Nomismoceras* sp., recorded by Hudson and Lewarne (1961), suggest a B_2 goniatite zone age for the formation. A fauna rich in foraminifera was also found in a coarse dark calcarenite (Shephard-Thorn 1963) and a limestone breccia was noted.

According to Austin *et al.* (1970) the *Lochriea nodosa* Conodont Zone in the upper Brigantian is missing in the west Limerick area around Foynes (Corgrig Lodge and Parsonage Beds) but is present in Clare, in the equivalent Inishtubbrid Beds (Tattersall 1963) on the islands on the Shannon. However, recent results from Borehole GSI 97/148 indicate that the *L. nodosa* Zone is present in the upper part of the Corgrig Lodge Formation first appearing at 19.75m depth, some 15.65m above the base (H.E.A. and I.D. Somerville *ibid.*). This demonstrates that the highest beds of the Carboniferous Limestone here are mid - late Brigantian in age. There is no noticeable break at the base of the overlying Namurian Clare Shales suggesting that there is no succession missing. The range of *Vogelgnathus postcampbelli* is now shown to be restricted locally to the Corgrig Lodge Formation within the *Gnathodus bilineatus* and *Lochriea nodosa* Zones (H.E.A. and I.D. Somerville *ibid.*). Austin and Husri (1974) previously indicated that this species was restricted to the *Gn. bilineatus* Zone in the Parsonage Formation. This new data now agrees with the range of the species known from Co. Clare, where it is restricted to the equivalent "Inishtubbrid Beds" (Corgrig Lodge Formation here).

The Corgrig Lodge Formation represents deposition in a deep-water basinal setting with turbiditic incursions.

VISEAN LIMESTONES - FERGUS ESTUARY

The limestones of the Fergus Estuary and its islands have not been examined in the field during this compilation. The descriptions below are partly culled from Tattersall (1963) who mapped the area and erected a local informal stratigraphy. The limestones above the Waulsortian and below the Parsonage Formation are shown as Visean (undivided) on the map. Tattersall's stratigraphy is tentatively correlated here with the stratigraphy of Northwest Limerick (Shephard-Thorn 1963).

The lowest rocks, found on Inishloe Island, belong to the Waulsortian Limestones. These are overlain by some 50 - 60 feet (15 - 18m) of cherty limestones (Tattersall's Inishloe Chert Series) which are equivalent to the Ballycar Formation of East Clare and Lough Gur Formation of the Limerick Syncline.

Overlying the nodular cherty limestones are the Mermaid Beds described as consisting of 100 feet (30m) of limestone and brown shaly limestone. The lowest 40 feet (12m) are massive-bedded light grey crinoidal calcilutitic limestone, of similar appearance to the "reef" limestones. Some 60 feet (18m) of thin bluish or brownish limestone, shaly limestone and beds of soft brown shale follow. Sponge spicules are a common feature. Austin *et al.*

(1970) recorded *Gnathodus homopunctatus, Gnathodus symmutatus, Gnathodus texanus, Gnathodus semiglaber, Gnathodus typicus* and *Polygnathus bischoffi* from the Mermaid Beds (*Gn. homopunctatus* Zone).

There follows a gap in exposure between the western shore of Inishloe and the Abbey Limestone on the eastern shore of Canon Island. It is possible that the gap conceals limestones and shales of similar character to the Rathkeale Formation of West Limerick. Such limestones are nowhere exposed in the Fergus Estuary but Austin *et al.* (1970) suggest, from the conodont faunas, that the base of the Mermaid Beds is equivalent to a level low in the Rathkeale Formation, which is of Chadian to Arundian age.

The Abbey limestone is a shaly, brownish weathered, crumbly, shelly, micritic limestone with bed thickness of about 0.3m. Some beds, however, consist of a coarse bioclastic dark-blue sparry limestone rich in brachiopods and foraminifera, interbedded with thin brown shales. Austin *et al.* (1970) recorded *Spathognathodus cristulus* and *Spathognathodus scitulus* from the Abbey Limestone.

The Abbey Limestone passes up into bedded, coarse-grained bioclastic, cherty, blue-black sulphurous limestones and shales of the Canon Island Limestone. The limestone beds are typically two to three feet thick and separated by thinner beds of dark brown to grey shaly limestone or black shale. The sequence is rich in bryozoa, brachiopods, crinoid debris and corals. Shale beds are less common than in the Abbey Limestone and blue black limestones more common, otherwise the units are similar. Solitary corals, particularly *Siphonophyllia cylindrica* and *S.* cf. *cylindrica,* are abundant especially in the lowest 100 feet (30m). Lithostrotionids, including *L. martini* first appear in these lower beds suggesting an Arundian age.

The succeeding Lord's Rock Limestone is 270 - 450 feet thick (83 - 138m) and is a more thickly bedded limestone than the underlying Canon Island Limestone and without the intervening shale beds. Chert is sporadically abundant as enormous blue-black nodules or in thick beds. The limestones are very hard and blue-black biomicrites. In contrast to the Canon Island Limestones fossils are not common, but in thin-section ostracods, calcispheres, foraminifera and a few crinoid ossicles are found. *Lithostrotion pauciradiale* is found as one representative of a restricted coral fauna. Austin *et al.* (1970) suggest that the upper part of the Lord's Rock Limestone is equivalent to the upper part of the Durnish Formation.

Near the top of the Lord's Rock Limestone on Canon Island is a 21 foot thick (7m) unit, the Carraig Limestone. It is a light-grey, yellow mottled, dolomitic pseudo-breccia, fairly dark-grey where unweathered. There is a complete absence of chert. Small corals, crinoid heads and stalks, orthocones and nautiloids are found. The matrix consists of dolomite rhombs, the fossils being undolomitised, giving it the brecciated appearance. The rock was quarried to build the sea-walls at Islandavanna during the famine and also used for the quay at Killadysert.

The succession through the Lord's Rock Limestone is thicker on Inishmacowney (138m) than on Canon Island (83m) or Deer Island to the north. There is another 180 feet (55m) of limestone overlying the Carraig Limestone on Inishmacowney. These limestones are thickly-bedded hard dark-grey to blue-black limestones with varying amounts of chert. The sequence becomes more shaly upwards and the chert nodules become smaller. The highest beds underlying the Slumped Series are a few feet of shale, the lowest bed of which is crammed with *Diphyphyllum smithi.* Some 30 feet of thick-bedded cherty limestone follow before the base of the Slumped Series is reached.

The overlying Slumped Series comprises about 220 feet (67m) of thick limestone beds, dark shaly limestone beds, thin limestones, and brown or black shales. At three levels intraformational slumps are developed involving 20 - 30 feet (6 - 9m) of strata, each separated by unslumped beds. The limestones are very variable. The thinner beds are mostly fine grained, dark blue-grey, calcisphere, sponge spicule, and ostracod rich biomicrites. The thicker beds can be coarsely crystalline and some are conglomeratic (cf. base of Shanagolden Formation). The conglomerates contain shell fragments and intraclasts which have frayed edges set in a micrite matrix. The shales contain a small Zaphrentid - Clysiophyllid coral fauna together with brachiopods and bryozoa. Some of the largest and most spectacular slumps are exposed on the east shore of Inishtubbrid. The slumping fades out northwards on Deer Island where the succession is mostly shaly limestone. All the slumping is directed towards the west. *Dibunophyllum bourtonense* is found at many localities especially near the top of the formation.

Parsonage Formation (PA)

The Parsonage Formation (the Striped Limestones of Hodson and Lewarne 1961 and Tattersall 1963) is found on Inishtubbrid, Inishmacowney, Shore Island, Deer Island and at Crinish. The base of the formation is marked by thin dark coloured flaggy limestones, sometimes containing chert, which may be followed by 1m of thinly laminated limestone. Striping appears as dark-grey and white laminae. The rock is often highly stylolitised. More thickly laminated limestone (3 - 4mm wide rather that 1 - 2mm) may follow (the upper striped limestone). Above the upper striped limestone are some thick beds of smooth grey limestones and the top is marked by "wavy limestone". The wavy limestone is laminated but there is not much variation in colour and the laminae are crinkled, the crinkles being of a similar order of size to corrugated iron. The only fossils present are ostracods and a few calcispheres.

On Inishtubbrid the thinly laminated lower striped limestone is absent (Tattersall 1963). Limestones of the upper striped limestone rest directly on bedded limestone with chert. The striped limestone is thicker on Inishtubbrid than anywhere else. On the east side of the hill that forms the high point of the island the striped limestones crop out in a 10m high vertical cliff. The limestone at the base of the cliff, especially at the northern end is fairly regularly striped, but southwards and upwards it becomes mottled and very stylolitic and ends up as a smooth light grey calcite mudstone almost indistinguishable from mudmound limestones. This is seen in exposures south and west of the hill. There is therefore a transition upwards but more especially northwards from striped limestones through mottled limestones to mud-mound limestones.

The striped limestones form prominent features along the western shore of Inishmacowney. The basal beds are of thickly-bedded dark limestone containing large chert nodules. This is followed by a metre of lower striped limestone. There follows the "Inishmacowney Breccia" which is 10 feet (3m) thick. The clasts are of striped limestones and some are very large. The upper striped limestone, which follows, is also slumped.

At the southern end of Crinish (GR 12946 16354) is a prominent bed of striped limestone about a metre thick which can be traced for about 100m beside the farm track at the base of the knoll. At the southern end of the outcrop it passes up into limestone breccia. Over most of the outcrop it passes up to massive medium-grey calcilutite reef limestone. Here the striped limestones are typically flat laminated, black and white striped limestones passing up to slightly wavy laminated limestones which again pass up to flat laminated limestone.

Corgrig Lodge Formation (PA)

The Corgrig Lodge Formation (Inishtubbrid Beds of Lewarne (1959) and Lewarne and Hodson (1961); Inishtubbrid Shale of Tattersall 1963) form a 100 feet (30m) thick sequence of limestones and shales beneath the Clare Shales on the island of Inishtubbrid. The limestones and shales are mainly pale in colour and the limestones are often shaly. Indeterminate Goniatites, and *Beyrichoceratoides* sp. were recorded (Lewarne 1959). At Rosscliff (GR 12901 16340), Tattersall (1963) records *Caninia lanceolata* and Zaphrentids. Austin *et al.* (1970) record *Gnathodus symmutatus, Gnathodus commutatus commutatus, Lochriea nodosa, Gnathodus bilineatus, Gnathodus girtyi girtyi and Gnathodus girtyi simplex*, indicating a position in the *L. nodosa* Zone. Both the Corgrig Lodge and Parsonage Formations pass laterally northwards into the Cornfield "reef" limestones (Tattersall 1963). Limestone conglomerate and dark-grey micrite containing crinoidal hash can also be seen at Rosscliff and Tattersall (1963) records "reef" limestones separating the Corgrig Lodge from the striped Limestones of the Parsonage Formation here. The conglomerate has probably been derived from the nearby "reef" as a talus deposit.

" Mudbank Limestones" (mk)

The island of Inishmurray, which lies close to the mainland south of Killadysert, consists of Carboniferous Limestone. Lewarne (1959, p 68) records that the uppermost beds on the western shore dip northwesterly and are "massive grey shelly limestone and do not include either striped limestones or limestones and shales". Tattersall (1963, Fig. 20 p 146, p 256) records a diverse brachiopod fauna from "D_1 or D_2 reef limestone" on Inishmurray and equates this to the slumped limestones, Striped Limestones and Inishtubbrid Shale. It seems likely that the Inishmurray limestones are similar to the "reef" limestones further north at Cornfield (GR 12790 16475), Newhall (GR 13393 17228) and Bushy Park (GR 13354 17459) and are equivalent in age to some or all of the Shanagolden, Parsonage and Corgrig Lodge Formations as described here from Foynes.

A fault is inferred between the island and the quay on the mainland which cuts out the highest beds of the Carboniferous Limestone and the Clare Shale Formation.

VISEAN LIMESTONES - NORTH KERRY

The geology of the Visean rocks of North Kerry is not well known and consequently it was thought inadvisable to divide the succession without field revision. The limestones are therefore shown as Visean undifferentiated on the map (VIS). There are, however, certain comments and comparisons with other areas which may be made.

At Ballybunnion the top of the Waulsortian Limestones pass up gradationally to about 3m of cherty bioclastic limestones in outcrop at low water mark described as "calcite mudstone" by Kelk (1960). These limestones contain abundant sponge spicules and some calcispheres. They may be compared to the "reef cover cherts" in Counties Limerick and Clare (Lough Gur and Ballycar Formations).

More or less on strike with the top of the post-Waulsortian cherty limestones described above and to the east of the north - south fault interpreted at Ballybunnion, is a sporadically exposed sequence of bedded, black, bioclastic limestones with finer-grained laminated silicified partings containing reworked and weathered calcite mudstones, with or without bioclastic material (the Breccia Series of Kelk 1960). Lenses of coarser breccia up to 2m long are present in some beds. Within this sequence, some 10m above the base are some 7m of striped limestones (Plate 4) similar to those seen near Foynes and on the islands of the Fergus Estuary. It should be noted that limestone conglomerates or breccias have been seen in both these locations. Further breccia beds appear above the striped limestones and extend to the base of the cliff at the foot of the steps leading from the road to the beach. Some of the beds contain lenses of coarser breccia composed of oolitic limestone (Kelk 1960). A slumped bed is found at the top of the unit. It is likely that lower beds are slumped but the nature of the outcrop prevents their recognition. The Breccia Series is here assigned to the Parsonage Formation and is estimated to be about 70m thick (Dolan 1984).

The breccias at the base of the cliff below the castle pass up to a thick sequence of dark-grey argillaceous limestones and interbedded shales (Plate 5) assigned here to the Corgrig Lodge Formation (Ballybunnion Castle Beds of Kelk 1960). The limestones are well-bedded (0.2 - 0.5m thick), cherty, and commonly graded, fining upwards. Shaly partings increase towards the top of the sequence and the limestone beds contain silt-grade quartz and feldspar. Silicification is common and accompanied by small rhombs of dolomite (Kelk 1960). This sequence is about 80m thick (Dolan 1984) and basinal in character (Sevastopulo 1981). The presence of graded beds (Plate 6) and obviously shelf-derived material such as oolitic clasts suggests that the sequence represents calciturbidites deposited at the deepest end of the Limerick Ramp. The



Plate 4. Striped limestones from the Parsonage Formation at Ballybunnion, Co. Kerry (photo by A.G. Sleeman).

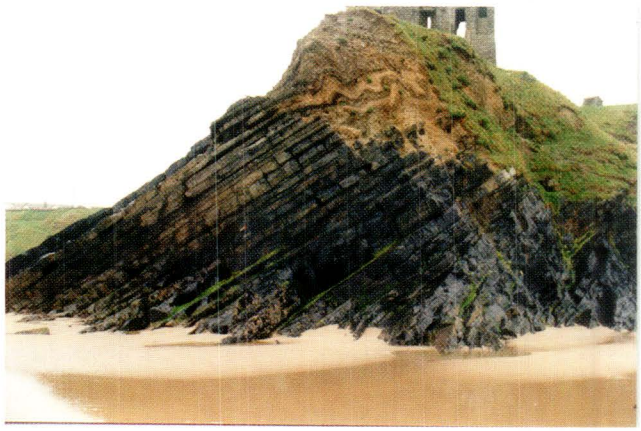


Plate 5. Interbedded basinal limestones and shales of the Corgrig Lodge Formation at Ballybunnion, Co. Kerry (photo by A.G. Sleeman).

calciturbidite sequence at Ballybunnion towards its top contains *Hibernicoceras* sp. indicating a P_1d age (G.D. Sevastopulo *pers. comm.* 1998)

Further south a large quarry at Lixnaw shows interbedded fine-grained dark-grey micritic limestones and black pyritic shales located not far south from outcrop of Waulsortian mudmound limestones. Coarser-grained dark-grey crinoidal limestones make up a minor part of the sequence. It is not known what the nature of the contact is with the Waulsortian Limestones here. The top of the Waulsortian Limestones nearby, however, are overlain by cherty limestones as at Ballybunnion. The dark limestones in Lixnaw Quarry pass up into about 30m of striped limestones similar to those at Ballybunnion. They are strongly banded especially near the top and bottom.

Elsewhere there are mudmound limestones of presumed Asbian age, similar to the Cracoean Limestones of Sheet 20 (Hudson *et al.* 1996; Pracht 1996). This facies is exposed at Ballinaclogher Cross-roads (GR 08536 12765; Dresser Minerals, report in Mineral Exploration Records Databank). It is less fossiliferous than the Waulsortian Limestones and generally coarser-grained. Similar rocks outcrop at Ballyhorgan (GR 09534 13106; Dresser Minerals, report in Mineral Exploration Records Databank). It is not known whether these rocks form a continuous sheet or are isolated mounds. Stratigraphically they appear to occupy a position close to the striped limestones, either above or below.

Well-bedded blackish cherty limestones outcropping in Gortadrishig Townland (GR 08675 12730) are thought to overlie the Visean mudmounds and massive dark-grey limestones in Killfeighny Townland (GR 09170 12600) outcrop close to the boundary with the Namurian (Dresser Minerals, report in GSI Mineral Exploration Records Databank).

Kelk (1960) reported that in the Galley River Section and in the Listowel River the lithology at the top of the limestone succession has changed from limestones with shales to grey nodular cherty bioclastic limestones. *Lithostrotion junceum* was found in the Galley River.

VISEAN LIMESTONES - SOUTH OF LIMERICK CITY (VIS)

An extensive area of limestones south of Limerick City are shown as undifferentiated Visean (VIS), on the map. The Lough Gur, Knockroe Volcanic, and the Herbertstown Limestone Formations clip the edge of the map, where they are found in the western culmination of the Limerick Syncline, and probably in the Ballynagoul (BG-4) Borehole. The top part of the Ballynagoul Borehole may also correlate with the Durnish Formation (see p. 28). The Rathkeale Formation is not present in the Ballynagoul Borehole (I. D. Somerville *pers. comm.* 1998) and probably does not extend east of Adare (see p. 28).

Visean (undifferentiated) (VIS)

The area around and south of Limerick City is not well exposed but exhibits a variety of rock types. Volcanics, both intrusive and extrusive basalts and volcaniclastic rocks are found intercalated with a varied selection of limestones of Chadian to Arundian, or possibly Holkerian age. Somerville and Strogen (1992) have outlined the sequences present in relation to the Limerick Ramp, initiated in late Courceyan times, describing the succession in Mungret Quarry, Limerick, and in the Carrigogunnel - Cooperhill areas in some detail.

Late Chadian oolitic grainstones are interbedded with volcanics at Carrigogunnel, which Somerville and Strogen (1992) have interpreted as deposited in turbulent shallow water as aprons on the flanks of volcanic cones. Similar rocks occur at Roche Castle (GR 15490 15250). Small mudmounds are locally associated with these oolitic limestones as at Vermont (GR 14990 15420). These mounds are low domes, a few metres high and only about 10m across. They are composed of mudstone, or wackestone, locally packstone, with irregular geopetal structures filled by peloidal micrite (Somerville and Strogen 1992).

Away from the volcanic centres the Chadian and Arundian rocks are dark-grey to black thinly-bedded cherty argillaceous wackestones and packstones, locally rich in foraminifera and crinoids. These can be seen at Cooperhill House and at Ballybrown (GR 15050 15430). The limestones are bioturbated, and skeletal remains show less evidence of abrasion than the grainstones interbedded with the volcanics. A similar facies, with entire *Michelinia* sp., solitary corals and *Delepinea* sp. is found to the southwest at Cragbeg, northeast of Glascurram (Somerville and Strogen 1992). Graded packstones and grainstones interbedded with carbonaceous shales of Arundian age are found 1 km southwest of Cragbeg. Herringbone cross-stratification can be seen in grainstones at Kiltemplan (GR 14810 15090) and Glascurrum (GR 14860 15180). The bioturbated

packstones, containing a stenohaline fauna, are the product of quiet sedimentation on a deeper part of the ramp below fairweather wave base. The graded limestones represent periodic storms transporting shallow water fauna and terrigenous mud from higher up the ramp into deeper water (Somerville and Strogen 1992).



Plate 6. Pale weathering, large scale cross- bedded oolitic/skeletal grainstones overlying dark, thin-bedded grainstones,packstones and interbedded shales at Mungret Quarry, Co. Limerick (photo by A.G. Sleeman).

In the late Arundian the dark-grey argillaceous wackestones and packstones pass up to fairly well-sorted fine-medium grained dark peloidal-skeletal grainstones. These in turn pass up to oolitic and crinoidal grainstones similar to the lower part of the Herbertstown Formation in East Limerick. This change is best seen in Mungret Quarry.

Lough Gur Formation (LR)

In west Co. Limerick the Waulsortian Limestones are everywhere overlain by dark-grey to black cherty argillaceous wackestones of Chadian age which have been described by Somerville *et al.* (1992) as the Lough Gur Formation in the Limerick Syncline (Sheet 18). The formation is about 100m thick in the east of the Limerick Syncline and appears to thin westwards to about 50m on Sheet 17. It buries relic topography at the top of the Waulsortian Limestones. Few continuous exposures exist away from exposures adjacent to the volcanic rocks near Lough Gur (GR 16460 14170). The formation is well exposed at Kildimo (GR 14733 15232; Somerville and Strogen 1992), Callow House near Cappagh (Shephard-Thorn 1963), and at Corcamore (Strogen 1973). The formation has also been recognised in the BG-4 (Ballynagoul Borehole) near Kilmallock (I.D. Somerville *pers. comm.* 1998) between 375.5m and 480m depth. The formation is quite varied in the type area. The facies is widespread and marks the return of uniform conditions across the Shannon Trough after the marked differential subsidence during deposition of the Waulsortian Limestones. Similar, but less varied, cherty wackestones are found above the Waulsortian Limestones across East Clare and have been described as the Ballycar Formation.

Knockroe Volcanic Formation (KR)

This formation is the lower of two volcanic formations exposed in the Limerick Syncline (Strogen 1983, 1988) mostly on the adjacent Sheet 18. The earliest volcanic centres on both limbs of the syncline lie on or within the Lough Gur Formation. Early eruptions were highly explosive, reflecting seawater incursion into open vents, and gave rise to accumulations of various types of tuffs (KRl: lithic) and tuff-breccias (KRv: vitric-lithic). These formed small cones which gradually consolidated to allow basaltic lavas (KRb) to emerge and flow down their slopes and across the limestone sea-floor without large explosions. Some lavas cooled slowly and developed columnar jointing. The later, trachytic (KRt), magmas formed shorter flows, commonly filling craters, or intruding as dykes and sills. Subsequent eruptions from the same vent were even more explosive and destroyed the upper parts of the cones, scattering them as pyroclastics rich in older volcanic debris, especially of trachytes. Each vent had its own distinct order of introduction of basic and intermediate magmas, and arrangements of intrusive and extrusive units.

Volcanic lapilli tuffs, tuff breccias, and fine ash, interbedded with limestones, found in the BG-4 (Ballynagoul Borehole) between 273 - 303.5m, are correlated with the Knockroe Formation (E. Sweeney *pers. comm.* 1998).

Subaerial and submarine erosion of the freshly formed volcanic layers within the Knockroe Formation occurred during deposition of the partly pene-contemporaneous Herbertstown Limestone Formation.

Herbertstown Limestone Formation (HE)

The formation crops out in one small area on Sheet 17. Deposition of the Herbertstown Limestone Formation was partly contemporaneous with the earlier Knockroe Volcanic Formation. The Herbertstown Formation (Strogen 1988) consists primarily of coarse grainstone which ranges between oolitic and a more comminuted, coral-bearing limestone facies. Clean chert free limestones between 172.7 - 272.7m depth and oolitic limestones between 303.5 - 373.8m depth in borehole BG-4 (Ballynagoul) may correlate with the Herbertstown Formation (I.D. Somerville *pers. comm.* 1998).

The formation represents deposition of a nearshore (inner ramp) carbonate sand belt lying above fairweather wave base (Somerville *et al.* 1992).

Most of the Chadian Stage in the vicinity was dominated by the Knockroe Formation volcanics, which waned through the Arundian Stage until the Herbertstown Formation limestone alone was deposited during the Holkerian and early Asbian Stages (Somerville *et al.* 1992). A thickness of 500m may have been reached.

Athassel Formation (AT)

The Athassel Formation is shown on the extreme southeastern edge of the map. This unit is mostly exposed on the adjacent Sheet 18 (Smith and Sleeman 1996) where it succeeds rocks of Courceyan age. It is described as "basinal" dark, fine, very cherty wackestones abruptly interbedded with volcanic ashes or lavas, and with masses of coarser oolitic limestones which lack cross-bedding (Carruthers 1985; Archer *et al.* 1996).

Namurian Rocks - Upper Carboniferous

Due to its spectacular outcrop along the western coastline, the Namurian of West Co. Clare (Fig. 10) has attracted the attention of numerous geologists over the past years. However, the inland region received much less attention. The lack of information is reflected on the face of Sheet 17. However, no attempt has been made to hide or adapt inconsistencies based on the lack of information, for example the discrepancy between the succession to the north and south of the mouth of the Shannon west of Glin.

Initial studies focused on stratigraphy, and based on the numerous goniatite bearing marine bands in the succession, a detailed biostratigraphy was erected (Hind 1905, Hodson 1954a, 1954b, Hodson and Lewarne 1961). Later the focus shifted towards a more sedimentological approach (Rider 1969, 1974, Gill 1979, Pulham 1989) and more recently, a sequence stratigraphical angle was taken (Davies and Elliott 1996, Hampson *et al.* 1997). Collinson (1991) has reviewed the geology of the Namurian rocks of Co. Clare.

During the compilation of Sheet 17 a discrepancy between mappable units, i.e. stratigraphical units which can be mapped inland as well as along coastal sections, and stratigraphical units which are based on sedimentological and/or palaeontological data seen in coastal exposures only, became immediately apparent. Thin marine bands containing goniatite faunas (e.g. *Reticuloceras stubblefieldi* - Gill 1979) have been extrapolated far inland, but the more prominent sandstone units (e.g. Tullig Sandstone of the Tullig Cyclothem and Kilkee Sandstone of the Kilkee Cyclothem) which form clear topographical expressions (C. MacDermot *pers. comm.* 1998) have not been mapped inland. The absence of a mappable horizon (i.e. a goniatite bearing marine bed) at the base of the Tullig Cyclothem adds to the stratigraphical nomenclature problem. However, it was considered useful to show the extrapolated marine bands (Gill 1979) and the approximate location of the base of the Tullig Sandstone of the Tullig Cyclothem.

An arbitrary assignment of the d^3 and d^4 units of the one inch to one mile 19th century Geological Survey maps to the Shannon Group, and the coal bearing d^5 unit to the Central Clare Group is made here. The coal seams shown on the map are those from the one inch maps (Sheets 142, 152).

SHANNON GROUP

Clare Shale Formation (CS)

The Clare Shale Formation crops out from northwest Clare southwards along the western margin of the Carboniferous Limestone to the Shannon and thence southwards into northwest Limerick. It also outcrops near Ballybunnion in North Kerry. The formation consists predominantly of dark-grey shales, with bands of siliceous mudstone common in the lower parts. The fauna is dominated by goniatites and bivalves, which are generally restricted to discrete bands, each with its characteristic goniatite assemblage, separated by barren shales.

The formation was first described in northwest Clare by Hodson (1954a), and a regional description is given in Hodson and Lewarne (1961). In its type

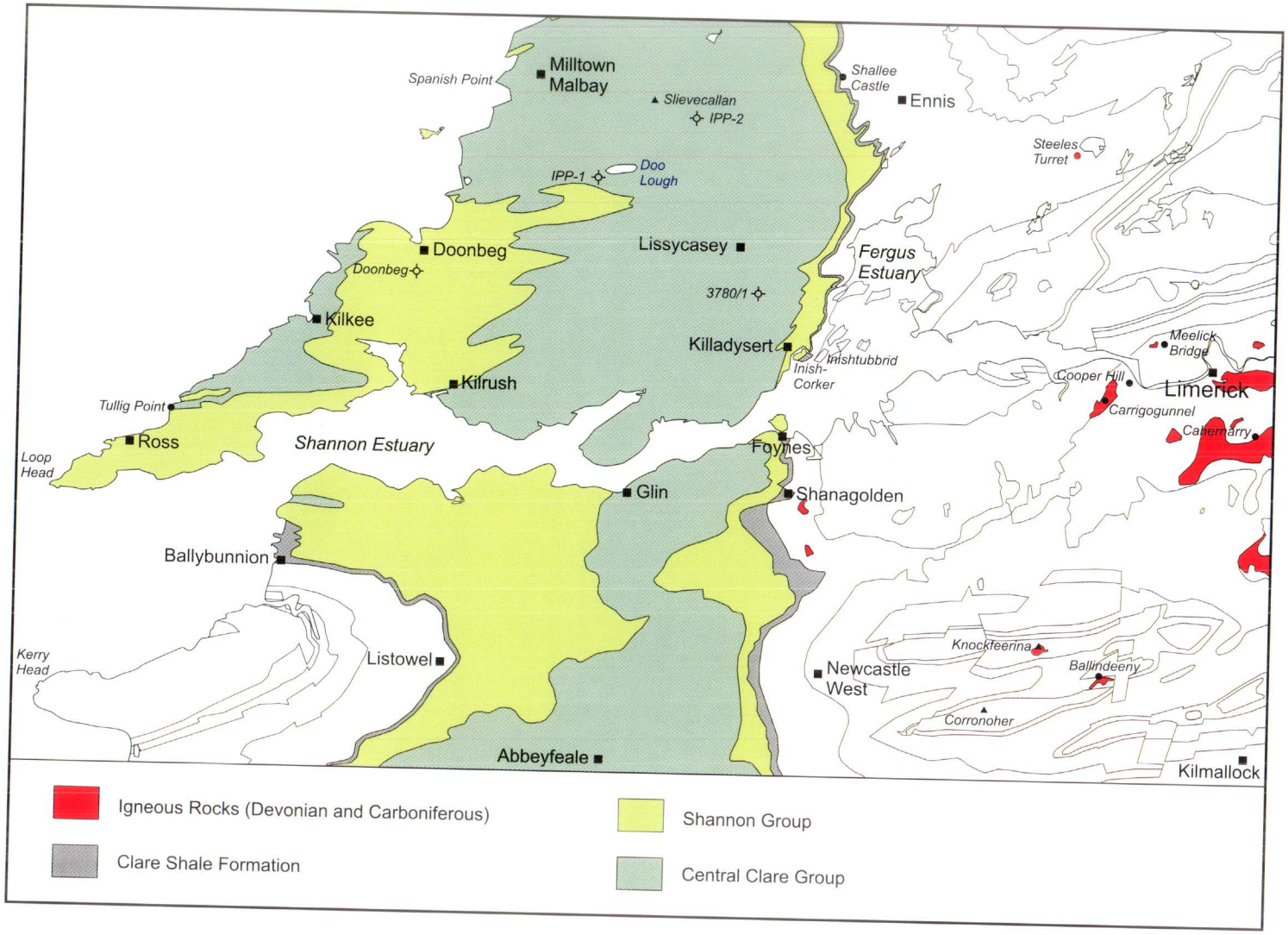


Figure 10. The outcrop of Namurian and igneous rocks.

area the formation is 12m thick, consisting of a condensed sequence of black shales with closely spaced goniatite bands, underlain by shales with many phosphatic horizons. Nodules and bands of clay ironstone occur near the top of the formation. Southwards a basal unit of shales with siliceous mudstones rests on the limestones with shales of the Magowna Formation.

Phosphatic bands are not found on this map sheet, although phosphatic nodules are seen in the section at Magowna (GR 12890 18220), and a basal conglomeratic phosphate occurs in borehole IPP-2. The basal siliceous facies is well developed in northwest Co. Limerick, where Lewarne (1963) describes a section in a disused quarry (GR 12590 14085) northwest of Ardagh. Here 3m of siliceous mudstone occur, described as spongolites, and containing masses of sponge spicules.

A good section can be seen along the shore on the south side of Inishcorker (Hodson and Lewarne 1961). The base of the visible section contains E_1 goniatites and consists of dark-grey platy shales and nodular thinly bedded shales with clay ironstone bands 0.05 - 0.1m thick. This passes up through cherty siliceous shales and platy shales with bullions and goniatite bands of E_2 - H_2 age (Hodson and Lewarne 1961). Many horizons show evidence of synsedimentary deformation. The lowest beds are hidden under the water separating Inishcorker from Inishtubbrid.

At Ballybunnion Kelk (1960) records a nearly continuous section, 150m of shales ranging from P_1B (Goniatites granosus) to E_2 in age, of which the lower 50m contains siliceous mudstones, overlain by 42m of shale containing horizons of calcareous bullions, of H_1 age.

The formation reaches its maximum thickness at surface at Inishcorker (232m), while further west near Doonbeg (GR 09637 16382) some 280m were intersected in a borehole. There is a northward thinning to 32m near Slievecallan in the IPP-2 borehole (GR 11768 17602; Goodhue 1996), and to 2m in northwest Clare (Hodson and Lewarne 1961). 192m are present at Ballybunnion (Kelk 1960).

The base of the formation ranges from P_2 age (Brigantian) at Ballybunnion (Kelk 1960), to E_1 age immediately north of the Shannon (e.g. at Inishtubbrid) and west of Ennis. The youngest beds of the formation are of R_{1b} age (*Reticuloceras subreticulatum* marine band), and are seen in northwest Co. Clare (Hodson and Lewarne (1961) (see Table 1).

Ross Sandstone Formation (RS)

The Ross Sandstone Formation, whose type section is between Loop Head and Ross Village, only crops out in southwest Clare. It consists of parallel-bedded sandstone beds, with interbeds of dark shale. Flute, groove, and rill casts are sometimes displayed at the base of the sandstones. Shale-filled scours may be up to 1.5 - 9m wide, while sand-filled channels are up to 10m deep and 100m wide.

Goniatites from three black shales date the formation to between H_2 and R_1 (Rider 1974), thus making it the lateral equivalent of the middle and upper part of the Clare Shale Formation (Rider 1974, Gill 1979).

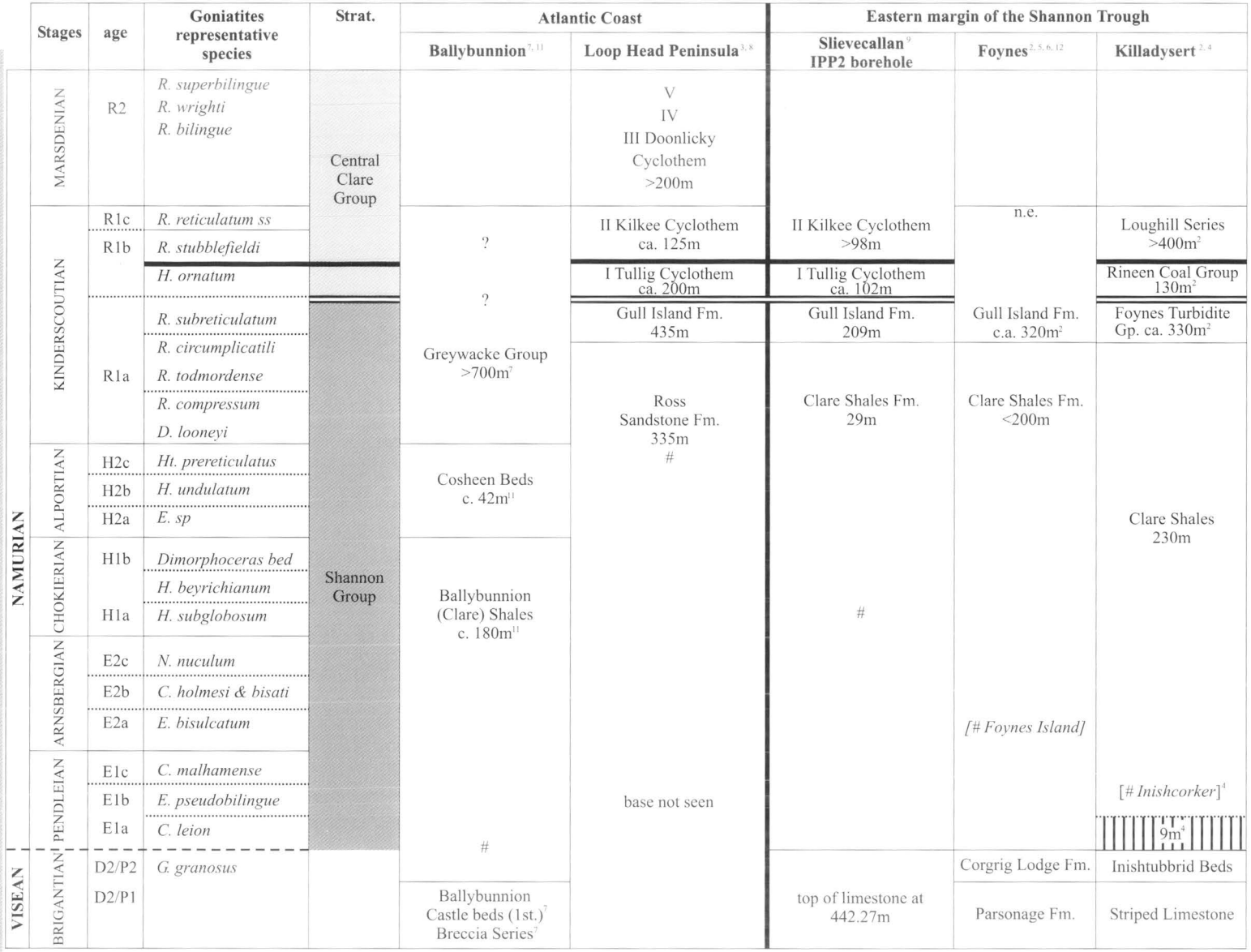
The sediments are thought to have been deposited in a deep marine mud-dominated trough or sub-sea fan with turbidites depositing sands from time to time. Palaeocurrents show a marked southwesterly origin (Gill 1979).

Gull Island Formation (GI)

The type section of the Gull Island Formation is between Ross Village and Tullig Point (Rider 1974). The base of the formation is defined as the bed above the *Reticuloceras paucicrenulatum* marine band at the top of the Ross Sandstone Formation (Gill 1979) while the top of the formation is taken at the base of the overlying Tullig Cyclothem. However, as



Plate 7. Intraformational slumping of interbedded sandstones and mudstones in the Gull Island Formation south of Tullig Point (photo by C. MacDermot).



Comparative and interpretative schematic stratigraphic succession from different parts of the Namurian Shannon Trough. NOT TO SCALE
Sources: [1]Clarke 1966, [2]Hopkins, [3]Rider 1974; [4]Hodson & Lewarne 1961; [5]Somerville and Somerville (unpubl.); [6]Shephard-Thorn 1963; [7]Kelk 1960; [8]Gill 1979; [9]Goodhue 1996, MacDermot (unpubl.); [10]Hodson 1954b; [11]Dolan 1984; [12]GSI this publication.

Table 1. Comparative, interpretative and schematic stratigraphic succession from the Namurian rocks of the Shannon Trough

discussed above, this boundary cannot be shown on the map, simply because it has not been mapped. Instead the *Reticuloceras stubblefieldi* marine band is shown as a marker horizon, which is found at the top of the Tullig Cyclothem as interpolated by Gill (1979). Where possible, instead of redefining genetically related units, we chose to show the locally mappable Tullig Sandstone of the upper part of the Tullig Cyclothem on the map.

The formation is dominated by grey siltstones with up to 20% sandstones at the base of the succession, decreasing towards the top. The sandstones are usually graded and exhibit flute casts at their base and ripple marks at their top. The sandstones are found in groups, with bed thicknesses decreasing upwards within each group. The siltstones are extensively slumped (Plate 7) and little of the original internal structure remains. Syndepositional faults occur (Rider 1974).

The lowest 30m in north West Clare consists of turbidite sandstones and siltstones distorted by a massive slump, the Fisherstreet Slide (Gill and Kuenen 1958, Gill 1979). The remaining 90m are undistorted siltstones and shales, which have, in their lower part, occasional shallow channels filled with turbidite sandstones. The formation thickens southwards and rests on the turbiditic sandstones of the Ross Sandstone.

On Inishcorker ribbed beds of fine sandstone, following a gap in the section at the top of the Clare Shales, are succeeded by medium bedded to thick sandstones with groove casts and tool marks on their base. Slumps occur in the silty mudstones interbedded with sandstones and mud diapirs are seen.

At the type section the formation is 400m thick (Gill 1979). Near Foynes, the formation has a thickness of more than 320m (Hopkins 1964), further west it reaches 430m and in the north of West Clare decreases to approx. 270m - 135m (Rider 1974). In borehole IPP-2 (GR 11768 17602) approximately 200m was encountered.

The sandstone beds are interpreted to be of turbiditic origin, deposited in submarine channels with a high width to depth ratio of greater than 100.

Shannon Group, undifferentiated (SHG)

In North Kerry the Shannon Group is very poorly exposed and little, if any, mapping, except on the coast north of Ballybunnion (Kelk 1960; Dolan 1984) has been accomplished since that of the Geological Survey in the nineteenth century (Sheets 141, 142, 151). The Shannon Group has been distinguished from the Central Clare Group in this area largely on the basis of the old one inch map series which distinguishes d^3 and d^4 from d^5 by the occurrence of coal seams in the latter.

Dolan (1984) describes about 700m of sandstone and shale (Greywacke Series of Kelk 1960) which is equivalent to the Ross Sandstone and Gull Island Formations of West Clare. Kelk's (1960) Lower Greywacke Group is equated with the Ross Sandstone Formation by Dolan (1984) and is about 220m thick. This unit is dominated by turbidite sandstones. Above this unit the succession shows an upward decrease in the dominance and bed thickness of the sandstones. Throughout the succession sole structures and ripples are common in the turbidite sandstone facies. The mud/siltstones are extensively slumped with slump horizons up to 5m thick. There is an upward increase in the dominance of mud siltstone facies and a corresponding decrease in turbidite sandstone facies.

Feale Sandstone Formation (FS)

A tiny finger of the Feale Sandstone Formation appears on the southern edge of the mapsheet abutting on to Sheet 21. This formation is a cyclothemic succession of brown and green sandstones and shales with occasional coal seams (Brennand 1965). The base of the formation coincides with the base of the R_2 biozone (Marsdenian) with the first appearance of *Reticuloceras gracile.*

CENTRAL CLARE GROUP (CCG)

The base of the Central Clare Group is defined at the base of the first cyclothem, the Tullig Cyclothem. The top of the Tullig Cyclothem is taken at the base of the *Reticuloceras stubblefieldi* marine band, which in turn is the base of the Kilkee Cyclothem (Gill 1979). However, since the base of the Tullig Cyclothem cannot be traced inland, where exposure is generally poor, this stratigraphical boundary cannot be shown on the map (see Table 1). The *Reticuloceras reticulatum* marine band marks the top of the Kilkee Cyclothem and the base of the succeeding Doonlicky Cyclothem.

The *Reticuloceras stubblefieldi, Reticuloceras reticulatum, Reticuloceras bilingue* and *Reticuloceras superbilingue* marine bands are shown on the map.

A characteristic cyclothem consists of a laminated shale unit with a thin (7 - 18m) goniatite, bivalve, brachiopod, gastropod, crinoid and occasionally coral bearing marine band at the base, a thick (35 - 80m) laminated to massive grey siltstone unit in the middle and a thick upper unit usually dominated by laminated sandstone and possibly capped by coal and rootlet horizons. Some of the sandstone units are channelled or show minor cycles. The laminated sandstone beds are often graded, show ripples and abundant trace fossils. The channel-sandstones have an erosive base, are fine to medium grained, and fine upwards. The minor cycle sandstones consist of a thin fossiliferous shale at the base, a thicker central siltstone and an upper sandy siltstone or sandstone. At the top of a cyclothemic unit, root horizons, coal horizons, burrows (e.g. *Zoophycos)* and ripple marks are common.

According to Rider (1974) slumping is a common feature of the cyclothemic succession and especially common in the laminated siltstones and sandstones. It is usually associated with synsedimentary normal faulting. Local features include flow-folding, ball and pillow structures and sand volcanoes.

A borehole (3780/1) drilled at Lissycasey (GR 12277 16265) by Eurostone Ltd. encountered 358m of cyclothemic siltstones and sandstones assigned to the Central Clare Group (GSI Mineral Exploration Records Databank report on Prospecting Licence 3780). Poorly preserved goniatites from a horizon one metre above the base of the highest cyclothem (1.5 - 93.9m) suggest an R_1 or R_2 age (N. Reilly in Goodhue 1996).

Kelk (1960) reported a 12 foot thick band of shales with very thin impersistent limestones at the top of his Lower Mudstone Group containing *Reticuloceras* sp. south of Kilconly Point, Co. Kerry. F. Hodson (in Kelk 1960) suggests that these goniatites may be *Reticuloceras stubblefieldi,* for in Co. Clare the only limestones to be found within rocks of *Reticuloceras* age are always associated with *R. stubblefieldi.* If this is correct, then the sandstone and shale succession in the core of the Kilconly Syncline is equivalent to the Central Clare Group, as shown on the map.

ENVIRONMENTAL INTERPRETATION OF THE NAMURIAN

The Clare Shale facies represents basinal mud-dominated sedimentation. The laterally equivalent Ross Sandstone Formation was deposited in the deepening basin and might represent a sub-sea fan (Rider 1974). The sedimentological characteristics of the succeeding Gull Island Formation suggests turbiditic deposition on an unstable shelf margin, slightly shallower than the Ross Sandstone Formation (Rider 1974).

Based on the modern day Mississippi analogue, the cyclothemic Central Clare Group is interpreted by Gill (1979) to be the result of delta progradation (shale, siltstone and laminated sandstone) with main channels and point bar deposits (channel sandstones) and sub-deltaic minor cycle units (but see below for an alternative interpretation). The laminae within the cyclothemic succession are thought to be the product of seasonal variations in the sedimentation pattern. According to Rider (1974) the channel sandstones represent point bar sedimentation in alluvial channels. Palaeocurrent data (Rider 1974) for the lower two cyclothems indicate southwest to northwest provenance of the sediments.

The repeated occurrence of goniatite bearing marine beds with distinct goniatite species, used as marker horizons for basin-wide correlation, are interpreted to be the result of glacio-eustatic transgressions due to relative sea-level fluctuations. The onset of the main glaciation phase was in the early Namurian and reached its peak in the Westphalian and Stephanian. At this time large parts of the Gondwanan supercontinent was covered by ice sheets (Caputo and Crowell 1985; Veevers and Powell 1987; Crowley and Baum 1991).

Recently, sequence stratigraphy has been used to develop an alternative explanation for the cyclothemic succession of the Shannon Trough (Hampson *et al.* 1997). They showed that the marine goniatite bearing bands are not the only key surfaces of time-stratigraphical significance in the Namurian of West Clare. They interpret the deeply eroded surfaces at the base of major fluvial sandstone complexes, the Tullig Sandstone, Kilkee Sandstone and Doonlicky Sandstone, and laterally equivalent palaeosols, developed on interfluves at the margin of the fluvial complexes, as widespread sequence boundaries. The sandstones are interpreted as incised valley fills resulting from a eustatic fall in sea-level arising from the Gondwanan glaciation. The interfluves are a non-depositional emergent surface which should be represented by a palaeosol, but few have been recognised to date. Recognition of interfluves is a critical test of this interpretation (Hampson *et al.* 1997).

Post Carboniferous geology

No known outliers of Mesozoic age and only one deposit of Tertiary clays have been recorded from this map area to date. The youngest rocks exposed are of Marsdenian age (Namurian) and by comparison with successions south of the Shannon, are likely to be about 350m below the base of the Westphalian (Fitzgerald *et al.* 1994). It is possible that up to 2.5km of Westphalian rocks were deposited and later stripped during the Variscan Orogeny (Fitzgerald *et al.* 1994). Little or no Permo-Triassic rocks may have been deposited in this region due partly to the effects of the end Carboniferous/Permian Variscan Orogeny. The region probably remained above sea-level during much of Mesozoic times (Naylor 1992, Fig. 7). Evidence for onshore Jurassic sedimentation is limited to a couple of small localities at Cloyne (Co. Cork) and Piltown (Co. Waterford). Beese and Higgs (1986) describe Lower - Middle Jurassic non-marine lacustrine clays preserved in palaeokarstic hollows within the Carboniferous Limestone near Cloyne. Lagoonal clays found in a borehole drilled by Pasminco at Piltown suggest evidence of late Jurassic partial inundation of the south of Ireland (G. Ll. Jones and K. Higgs *pers. comm.* 1998). Evidence for late Cretaceous (Campanian) inundation of the south of Ireland is provided by the Ballydeenlea Outlier (Walsh 1966; Naylor 1992) near Killarney on Sheet 20. This was a time of global sea-level rise (Vail *et al.* 1977) and thick deposits of chalk were laid down in the Porcupine and Celtic Sea Basins to the west and south of onshore Ireland (Naylor 1992). There is little evidence for significant thicknesses of Tertiary deposits except in Northern Ireland. Tertiary clays, however, have been recorded filling karstic depressions at Aughinish, Co. Limerick (Clarke *et al.* 1981; Mitchell 1985). Preservation of the Ballydeenlea chalk, Cloyne Jurassic clays and non-marine Tertiary clays at low topographic levels suggests that erosion did not reduce the land surface much during Mesozoic and Tertiary times. Mean reflectance data from the Cloyne deposit suggests a maximum of 0 - 1.25km burial post Middle Jurassic (G. Clayton *pers. comm.* in Naylor 1992).

High onshore maturation levels of the Namurian rocks of the Shannon Trough may be partly related to post-Namurian cover which is estimated to amount to about 3km or alternatively it could be related to higher heat flow (Croker 1995; Robeson *et al.* 1988). Fitzgerald *et al.* (1994), however, argue that the observed maturation levels far exceed values for simple burial maturation based on the estimated burial history and "normal" geothermal gradients, and do not increase with depth in the Doonbeg No. 1 exploration well. They suggest that the high temperatures reached (340 - 370°C) reflected in high maturation values (Rmax 6-7.5%) are due to fluid advective heating, that is, hot fluids migrating from dewatering sediments to the south or west prior to and during the Variscan deformation.

Igneous Rocks

On Sheet 17 igneous rocks crop out in several areas (Fig. 10, Table 2). Wherever their stratigraphical position and mode of occurrence is defined, they are discussed in the text according to their occurrence (e.g. Turret Volcanic Member). However, in most areas the stratigraphical position is ill defined (not least due to the stratigraphical uncertainty of the enveloping sedimentary units) and they are therefore described in the following paragraph. The following section is largely based on the Geological Survey memoirs for Limerick by Lamplugh *et al.* (1907) and explanations to accompany Sheet 142 (Kinahan *et al.* 1860) and 153 (Jukes *et al.* 1861) and is intended to summarise the available data.

The volcanic rocks of the Carrigogunnel area (Table 2) have been described in some detail by Strogen (1973). The igneous rocks of the Limerick Syncline, of which a small area overlaps onto Sheet 17, are not described here (see Sheet 18; Archer *et al.* 1996) but a brief summary of the Knockroe Formation is given within the section on the stratigraphy of the Visean limestones south of Limerick City (p. 35).

In general, there are two distinct major igneous lithologies on Sheet 17. One consists of fragmented igneous rocks with various amounts of non-igneous components, referred to as "volcaniclastic rocks", the other of un-fragmented basic rocks usually of basaltic composition. The scale of the map and the small areal extent of some of the occurrences does not allow them to be shown on the map.

	LOCALITY / AREA	GRID REFERENCE	LITHOLOGY TYPE	relative "age"
1.	Limerick City to Annacotty	GR 15770 / 15650 to GR 16420 / 15760	volcaniclastic, basalt	Visean
2.	Ballycummin (Roche) Castle	GR 15530 / 15245	volcaniclastic, basalt	Visean
3.	Ballyseedy East	GR 15835 / 15380	volcaniclastic, basalt	Visean
4.	Donaghmore	GR 16035 / 15380	basalt	Visean
5.	Ballysimon to Donaghmore	GR 16120 / 15490	basalt	Visean
6.	Lemonfield townland (Kilpeacon)	GR 15620 / 14960	volcaniclastic, basalt	Visean
7.	Roxborough	GR 15765 / 15160	basalt	Visean
8.	Drombanny	GR 16100 / 15200	volcaniclastic, basalt	Visean
9.	Cahernarry	GR 16215 / 15240	volcaniclastic, basalt	Visean
10.	Carrigogunnel: (Massey's Bridge to the townland of Newton)	GR 14980 / 15520 GR 14936 / 15320 GR 15000 / 15700	Upper volc. - clas. basaltic lava flows lower volc. - clast.	lower Visean
11.	Meelick House	GR 15320 / 15920	volcaniclastic	lower Visean
12.	Gilloge Bridge	GR 16135 / 15950	volcaniclastic	lower Visean
13.	Ballinroche East: townland of	GR 15345 / 14770	volcaniclastic	Waulsortian
14.	Shanogolden East	GR 12670 / 14650 (approx)	volcaniclastic	Durnish Formation
15.	Carron's House	GR 12705 / 14285	volcaniclastic	Rathkeale Formation
16.	Ballinleeny	GR 14992 / 13350	volcaniclastic and basalt	Upper ORS
17.	Knockfeerina	GR 14535 / 13605	volcaniclastic and basalt	Upper ORS

Table 2. The location of igneous rocks in the Shannon region.

VOLCANICLASTIC LITHOLOGIES

Volcaniclastic rocks 27m thick were reported in a well-boring in Limerick City at a depth of 33m (Lamplugh *et al.* 1907). Recently many site investigation boreholes have been drilled in the Limerick City area. Four of five boreholes drilled by Geotec Services penetrated volcaniclastic rocks (0.2 to 5.3m thick), the fifth encountered a 1.2m thick olivine-basaltic lava. All of these volcanic rocks are situated close to surface (between 2.7m to 11.3m below surface). The rocks consist of various proportions of igneous and non-igneous material.

The volcaniclastic rocks, formerly described as "tuffs" are blue, green, red and purple coloured fine to coarse grained occasionally porphyritic or amygdaloidal, brecciated and/or conglomeratic igneous rocks. The ratio between non-volcanic and volcanic components varies widely ("ashy limestone" to "limestone ash"). This together with alternating volcaniclastic limestone beds and crinoid stems found in the volcanic matrix indicates their syn-sedimentary nature. In the area of Cooper Hill a gradual change from volcaniclastic deposits, dominated by igneous fragments, through limestones containing volcanic components, to limestones without igneous components can be studied.

The non-volcanic fragment assemblage consist of "limestone, grit, slate, and chert " with limestone clasts being most abundant. Volcanic clasts are described as "lapilli and larger fragments of a green epidote, finely vesicular, easily sectile basic pumice".

Near Carrigogunnel the volcanic succession is approximately 120m thick (Strogen 1973). Here a lower and upper volcaniclastic unit are separated by a central sequence of five lava flows. Various lithotypes are recognised, all being vitric or vitric-lithic lapilli tuffs or tuff breccias with less than 20 Vol.% of lithic fragments (Strogen 1973).

In the anticlinal structures of Ballinleeny and Knockfeerina volcaniclastic rocks crop out within the Old Red Sandstone succession. They range from tuff size material to conglomerates and/or breccias and are interbedded with the sandstone beds of the Old Red Sandstone. Individual bed thicknesses range from 0.16 to 0.6m. The matrix is green. The clast assemblage consists of "felstone", amygdaloidal basalt and altered "Silurian" shales and grits. From Ballinleeny "well developed crystals of dark green hornblende" are reported (Kinahan and O'Kelly 1861).

MASSIVE IGNEOUS ROCKS

The massive igneous rocks are generally black porphyritic olivine basalts, weathered to various degrees, containing numerous amygdales filled with calcite. "Olivine" is usually represented by calcareous and chloritic pseudomorphs. Magnetite, calcite and "glass" are all listed in the memoir (Jukes *et al.* 1860). Two generations of augite and plagioclase feldspars are common. Locally flow structures (plagioclase alignment) are described (ca. 1 mile southwest of Carrigogunnel, Roxborough area).

A sample from a recent borehole drilled in the Limerick City area, although strongly altered, is fine-grained and shows a strong trachytic texture of sericitised feldspars and pseudomorphosed olivine crystals. Chlorite, calcite and opaque minerals (iron oxides) dominate the sample. Apatite is found as an abundant accessory mineral.

At Donaghmore the basalt contains plagioclase phenocrysts of labradoritic composition and augite. At Roxborough the plagioclase is of andesine composition and shows two generations. The phenocrystic andesine is completely weathered as are the augites and olivines.

At Cahernarry several lava flows crop out in a large disused quarry ranging from highly vesiculated to compact generally extensively chloritised basalt. The vesicles are usually filled with several generations of calcite cement, the vesicle wall lined with chlorite. The K-feldspar phenocrysts are all sericitised to various degrees and chlorite is pseudomorphosed after olivine. The plagioclase feldspar has oligoclase (An_{20-30} composition.

At Knockfeerina a small area of exposed columnar jointed igneous mass appears to be intrusive and might represent the conduit for the igneous rocks found here (Jukes *et al.* 1861).

As mentioned above, at Carrigogunnel five lava flows can be distinguished between the volcaniclastic units; a sixth lava flow occurs but its stratigraphical position is unclear. At the castle all five flows together reach about 40m thickness but decrease towards the south where about 2km to the southwest of the castle the flows are only 13m thick. Eastwards the flows die out rapidly.

At Carrigogunnel, Strogen (1973) suggested a possible sequence of volcanicity. Starting with a Surtseyan phase of hydromagmatic explosive activity and the build up of a subaerial pyroclastic cone ("Tuff-ring") and followed by a Hawaiian phase of alkali basalt extrusion, the activity culminating in an ultravolcanic explosive gas explosion.

Tectonics

CALEDONIAN TECTONICS

The Iapetus Suture

A line extending northwards from the Shannon Estuary, through Silvermines and Navan to Clogher Head marks the position of one of the most important tectonic lines in Ireland, the Iapetus Suture (Phillips *et al.* 1976). The Iapetus Suture is the join between two continents that collided during the Caledonian Orogeny. The pre-Caledonian continents of *Laurentia* and *Gondwana* were separated by the Iapetus Ocean in Cambrian and Ordovician times (Figs 4 and 5). Continental drift led to closure of the ocean by Silurian times through subduction under both continents (Lowe and Jacob 1989; Klemperer 1989; Klemperer *et al.* 1991).

The suture separates Lower Palaeozoic rocks with different stratigraphies, palaeontology, sedimentology and rocks with different tectonic structures. On the northern side, on which Slieve Bernagh and the Arra Mountains fall, there is a relatively complex history of polyphase deformation. Here strike faults segment a succession of cherts, graptolitic shales and terrigenous

greywackes into a large number of blocks (Phillips *et al.* 1979). Deformation intensifies southwards towards the suture. In the northern part of Slieve Bernagh, larger-scale S_1 monoforms produce zones of flat-lying cleavage and recumbent F_1 folds for up to 4km across strike (Sanderson *et al.* 1980). The rocks up to 50km south of the suture (Slieve Phelim, Sheet 18) show a more simple style of deformation, with upright F_1 folds, with little refolding.

The Iapetus Suture zone cannot be examined directly in the west of Ireland as it is covered by the thick Carboniferous sedimentary rocks of the Shannon Trough. A northward dipping reflector on the BIRPS seismic profile due west of the Shannon Estuary (Klemperer 1989), however, has been interpreted as the geophysical trace of the Iapetus Suture. The character of the reflectors here are similar to other seismic reflectors interpreted to represent the Iapetus Suture east of Ireland and east of England (Hall *et al.* 1984; Freeman *et al.* 1988). Onshore gravity data suggests that dense, perhaps obducted ophiolitic material, lies at an unknown depth within the crust in this zone (Ford *et al.* 1991).

VARISCAN TECTONICS

The Shannon area falls into Zone 2 of Gill (1962) and Cooper *et al.* (1984). This is an area of relatively low strain on the Variscan orogenic margin, in which north - south compression and an east - west to east-northeast to west-southwest dextral transcurrent shear couple are resolved as the main deformation components (Coller 1984). The tectonics are characterised by ductile - brittle transcurrent (strike -slip) shear zones, major open folds, and heterogeneous vertical cleavage (Coller 1984). The main deformation probably took place post Westphalian B and pre Upper Permian (Coller 1984). The irregular shapes of the Lower Palaeozoic inliers of Slieve Bernagh, Slieve Aughty, and Cratloe suggest basement control, identified as Caledonian cratonic blocks (Gill 1962).

Shortening

Diemer *et al.* (1987) consider that the folding, cleavage, and thrusting which can be demonstrated at Kerry Head (and throughout the area covered by the mapsheet), can be explained in terms of north - south, or north-northwest to south-southeast shortening. Ford *et al.* (1992) have noted Variscan shortening of 30% north of the Killarney - Mallow Fault. Le Gall (1991) calculated a minimum 7% shortening along a line of section from Dingle to Kerry Head, considering only the large-scale folding of the Devonian/Carboniferous boundary. In contrast the Namurian strata between the Cliffs of Moher and Ballybunnion show a shortening of some 15%, but decreasing northwards. Cooper *et al.* (1986) have suggested that blind thrusts extend some 100km north of Dingle Bay within Caledonian basement. Southward dipping reflectors on the BIRPS wire line 1 could be interpreted as Variscan thrusts (Klemperer 1989). In that case the geometry of the image on Wire 1 represents not the end Caledonian position of the Iapetus Suture, but rather a geometry modified by Variscan northward movement of the reflectors within the upper half of the crust (Klemperer 1989). Diemer *et al.* (1987) reject the idea (Cooper *et al.* 1986), that there are major thrusts within the sequence and that the Clare Shale Formation acts as a major sole thrust, on the basis that there is continuity of structures throughout the sequence. Thrusting, veining and rounded folding characterise the Devonian sandstone sequences. Shale units, such as the Namurian Clare Shale Formation, act as a local detachment horizon, but folds develop both below and above this horizon without any evidence for major displacements within them (Diemer *et al.* 1987). Dolan (1984) describes regional scale box folds in south Co. Clare which accommodate 20% shortening and indicate a detachment at about 2km, while North Co. Clare has not suffered any shortening.

Fold Style

Structural studies within the map area have been limited to date to a number of small areas (e.g. Dolan 1984, Ballybunnion area; Diemer *et al.* 1987, Kerry Head) and a couple of regional studies (Gill 1962, Variscan fold belt; Coller 1984, Fergus and Quinn Shear Zones). Several authors have noted that the nature of folding is markedly determined by lithology. Where the Dinantian Limestone is thick and homogenous, as for example the Waulsortian limestones in West Limerick, the fold style is relatively broad and simple, in contrast to the Namurian (Gill 1962). Lees (1964) comments that at Aughinish the Waulsortian banks acted as resistant bodies responding by rolling rather than folding. Stress was relieved by shearing around and between the mudbanks. Dolan (1984) records that folds are upright, east - west trending, that axial planar cleavage is found and that the fold axes vary from horizontal to a shallow easterly plunge. The folds control the outcrop pattern and coastal topography

and the style, size and tightness of the folds is clearly lithostratigraphically controlled.

The style of folding in any one unit depends on the nature, thickness and homogeneity of the unit relative to the overlying and underlying units. In the case of the post-Waulsortian limestones, it is possible that the Waulsortian Limestones have acted as a decollement in the formation of the overlying box folds (Dolan 1984). Folding in the Clare Shales is largely controlled by that of the underlying limestones but second order monoclinal and conjugate kink folds are developed in the lower part of the Clare Shales adjacent to the steep limbs of box folds developed in the Corgrig Lodge Formation limestones and shales (Dolan 1984). Folds in the sandstone dominant units overlying the Clare Shale Formation have more rounded fold hinges, which become more angular and tighter as the mud - shale ratio increase. Chevron folds are found in the regular interbedded bedded sandstone - shale units while thrusting is found in the less regularly bedded units (Dolan 1984).

A similar relationship of folds to lithology has been noted by Diemer *et al.* (1987) at Kerry Head. The east - west fold and cleavage trend at Ballybunnion and at Kerry Head, contrasts with the regional east-northeast to west-southwest trend. This may be a reflection of basement control (Dolan 1984).

The Kerry Head Anticline forms a major east - west, upright, non-cylindrical fold which plunges 20° at Kerry Head but becomes horizontal and curves to plunge more gently to the northeast when traced eastwards. Thus anticlockwise swing in the trace of the fold axis contrasts with the clockwise swing in the minor structures. Diemer *et al.* (1987) attribute the anticlockwise swing to left lateral and normal offsets on roughly north - south faults. This contrasts with the minor structural evidence for the dominance of dextral movement on the north - south faults. It is possible that the left-lateral displacement either predates or post-dates the right lateral movements. Diemer *et al.* (1987) note that Coller (1984) describes north-northwest sinistral movement, coeval with folding in the Fergus Shear Zone in Co. Clare (see below).

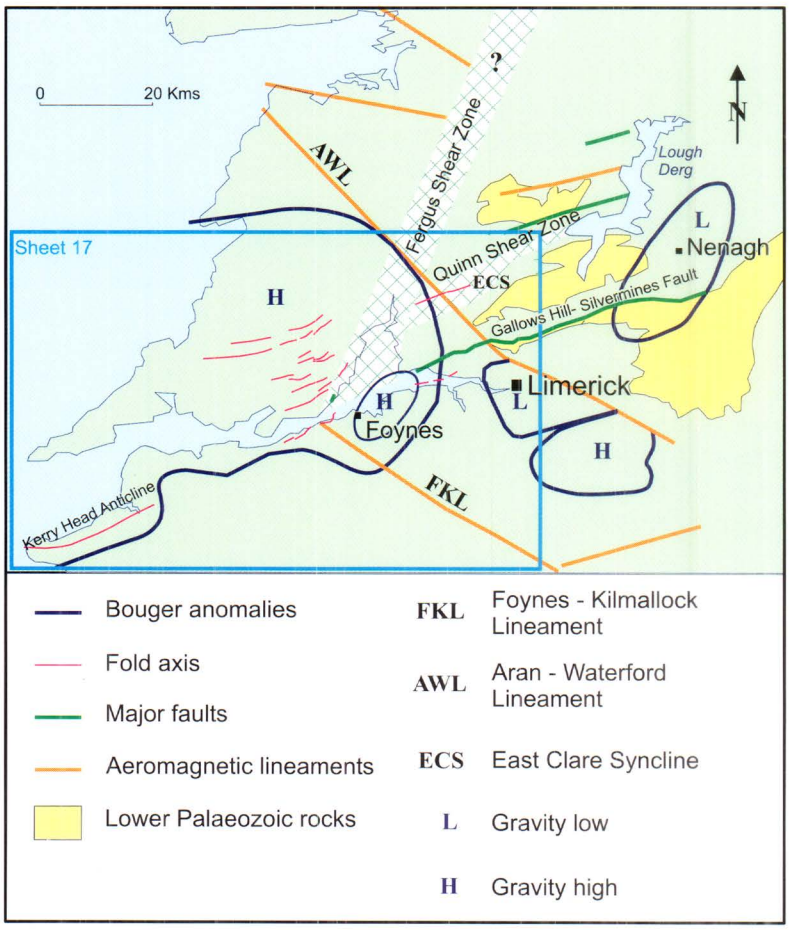


Figure 11. The trend of major structural lineaments and geophysical features.

The trend of major folds in the Namurian of West Clare is between east - west and east-northeast to west-southwest. Second order folds are superimposed on the major fold limbs, probably reflecting a high degree of strain (Gill 1979). Gently plunging minor folds, with a wavelength up to 500m, are found in trains and are predominantly angular (Coller 1984). The box folding south of the Shannon changes northwards to progressively more open folds, commonly widely spaced monoclines (Coller 1984). The intensity of folding decreases northwards.

Fergus Shear Zone

Coller (1984) has identified a major north-northeast trending shear zone, the Fergus Shear Zone (Fig. 11), which marks the western boundary of the central Ireland transpression regime. This shear zone is not easy to identify on the ground in the Visean limestones, which superficially appear to be undisturbed and whose outcrop does not exhibit extensive faulting along the trend of the shear zone.

There are, however, subtle indications within the Dinantian limestones and Namurian rocks to suggest deep seated tectonic control by shearing along the proposed north - south Fergus Shear Zone and the subsidiary east - west Quinn Shear Zone (Coller, 1984; Boland 1984).

Subsidiary folds within the Namurian of West Clare are turned anticlockwise from an east - west orientation to north-northeast to west-southwest (Fig. 11) as the Fergus Shear Zone is approached (approximating to the Namurian/Dinantian boundary between Ennis and Killadysert (Hopkins 1964). This is interpreted to be due to sinistral movement on the shear zone (Coller 1984).

Quinn Shear Zone

The Quinn Shear Zone is recognised on similar criteria to those of the Fergus Shear Zone. It is sub-parallel to the trace of the East Clare Syncline (Fig. 11). According to Coller (1984), on the margins of the shear zone a weakly developed spaced cleavage strikes between north - south and northeast - southwest and is roughly paralleled by the axial trace of minor folds. In contrast, within the shear zone, the cleavage is well developed and strikes sub-parallel to the shear direction (Coller 1984). Lewis (1986) also notes a bimodal distribution of cleavage with a predominantly east-northeast to west-southwest trend and a subsidiary north - south trend (*ibid.* Fig. 6.3).

In the area where the Quinn and Fergus Shear Zones meet, the minor folds are typically basin and dome style, interpreted by Coller (1984) as interference folds due to the superimposed or coeval shear movements on the two zones. The sense of shear movement on extension veins has also been used by Coller (1984) to corroborate the presence of shear zones.

Further evidence for the Quinn Shear Zone is suggested by the need to interpolate a strike parallel fault on the north side of the East Clare Syncline south of Tulla between Wyndam's Bridge (GR 14915 17749) and Lough Cullaunyheeda. Cherty limestones of the Tubber Formation (Cregmahon Member) are in close proximity to Holkerian Burren Formation grainstones containing cerioid Lithostrotionid corals (Schultz and Sevastopulo 1965, Loc. 3). There is insufficient space to accommodate the remainder of the Chadian and Arundian Tubber Formation limestones whose outcrop pattern is anomalously thin here. Similarly, approximately strike parallel faults have been interpolated on the southern flank of the syncline where Waulsortian limestones and even older Ballysteen Formation limestones are in close proximity to Arundian limestones assigned to the Tubber Formation in the Kilkishen area.

Magnetic anomalies

There are two prominent magnetic anomalies crossing the map-sheet (Fig. 11) along a northwest - southeast trend (Max and Inamdar 1983). The first is a lineament from the Aran Islands through Ennis and Shannon and Tipperary to Waterford (the Aran - Waterford Lineament). Most of the Caledonian basement falls on the northeast side of this lineament. Significantly the Limerick Volcanics fall on the line. Le Gall (1991) suggests that normal movement took place along this line at various times, e.g. at the time of emplacement of the volcanics, and perhaps in the early Tertiary causing uplift and differential erosion of the northeast block related to large-scale block tilting in response to the opening of the North Atlantic Ocean. The second lineament, from Foynes to Kilmallock, is possibly a major dyke associated with the Limerick Volcanics (Coller 1984).

Upper Palaeozoic Shelf and Basin development

During the Upper Palaeozoic, southwest and south central Ireland was the site of a number of important basins. To the south of the mapsheet, the Dingle Basin, sited immediately to the north of the Dingle Bay - Galtee Fault Zone, was initiated in late Ludlow times and filled during the Pridoli and Early Devonian. Several authors have speculated that the lower part of the sequence in the Dingle Basin (Dingle Group) was part of a larger basin (the Dingle - Shannon Basin) that covered most of Ireland (Gardiner and MacCarthy 1981; Allen and Crowley 1983). Todd *et al.* (1988), however, have shown

from the facies and syndepositional tectonics of the Dingle Group that the basin was a localised feature within the Iapetus Suture Zone. In Upper Devonian times the northern margin of the Munster Basin to the south was controlled by the Dingle Bay - Galtee Fault Zone (Williams *et al.* 1989; Ford *et al.* 1992) downthrowing to the south. During latest Devonian and Carboniferous times, however, sedimentation was confined to the more restricted South Munster Basin controlled by faulting along the Cork - Kenmare Line (Naylor *et al.* 1981: Williams *et al.* 1989). At this time carbonate ramp sedimentation spread across most of central Ireland and thickened into the Shannon Trough (Hodson and Lewarne 1961; Sevastopulo 1981; Strogen 1988) from late Courceyan times onwards.

SHANNON TROUGH

According to Strogen (1988) the Shannon Trough was initiated in the upper Courceyan (Waulsortian times) by transtensional movement on basement faults at its margin. Thickening of the Mellon House, Ringmoylan, and Ballyvergin Formations from Pallaskenry northwards to Shannon Town, demonstrated in boreholes (p. 19), however, suggests that the basin started to develop earlier in the Courceyan. The basin is essentially a half-graben (as is the partly contemporaneous South Munster Basin). It is bounded by faults on its southern side but presents a gentle ramp up to the north where it comes into contact with the buried extension of the Galway Granite which may be interpreted from the Bouger anomaly maps of Ireland (Murphy 1974; Readman *et al.* 1995, 1997). Le Gall (1991) postulates that the Aran - Waterford Lineament (Fig. 11) is likely to have partially controlled the evolution and extent of the Shannon Trough during the Upper Carboniferous. Based on wells 36/16-1 and 35/15-1 and supported by seismic wire line logs, gravity and magnetic data it can be demonstrated that the Shannon Trough extends offshore to the west of Ireland. Although it is truncated on its western margin by the much younger Porcupine Basin, palaeogeographic reconstructions from wells drilled within the Porcupine Basin suggest that an Upper Carboniferous basin may have existed in this region (Croker 1995 - Clare Basin). That the basin is asymmetrical, broadly elliptical rather than elongate in plan (at its eastern end), and exhibits extensive volcanism on its southern margin is evidenced as support for a transtensional origin (Strogen 1988). Nowhere, however, did the basin bounding faults reach the surface, as happened in the case of the Dublin Basin (Strogen *et al.* 1994). The basin bounding fault(s) lie well to the south of the proposed trace of the Iapetus Suture, the Silvermines Fault (Phillips *et al.* 1976), in contrast to the northern margin of the Dublin Basin.

THE LIMERICK RAMP

Following deposition of the Waulsortian facies in late Courceyan and early Chadian times, an extensive carbonate ramp (Limerick Ramp - Somerville and Strogen 1992) developed over Co. Limerick, dipping northwestwards. Its initiation is related to the sag phase of the Shannon Trough when some 1200m of Waulsortian limestones were deposited in the Shannon area (Lees and Miller 1995). Evidence suggests that everywhere the Waulsortian represents deep water (more than 200m). Following a period during the early Chadian when cherty limestones blanketed the top of the Waulsortian limestones (Lough Gur and Ballycar Formations), the subsidence rate increased again in the Shannon area resulting in the differentiation of facies down the ramp which persisted throughout the Visean. The inception of the ramp was a response to excess carbonate production with the result that the facies belts prograded from late Arundian times onwards by migrating and widening westwards rather than agrading to form a rimmed platform (Somerville and Strogen 1992).

In Chadian to early Arundian times coarse oolitic and skeletal grainstones, characterising the nearshore inner ramp facies, are represented by the Herbertstown Limestone Formation of east Limerick (Somerville and Strogen 1992).

The time equivalent mid-ramp facies is represented by dark-grey to black thinly bedded cherty argillaceous wackestones and packstones as found southwest of Cooperhill House and at Ballybrown (Somerville and Strogen 1992, p. 65). Graded limestones of Arundian age interbedded with thin carbonaceous shales are exposed in the more westerly quarry at Glascurram (Somerville and Strogen 1992). Oolitic grainstones are interbedded with volcanics at Carrigogunnel and probably represent accumulations on the flanks of volcanic cones which formed topographic "highs" some 100m above the sea-bed (Somerville and Strogen 1992).

The outer ramp facies is represented by the Rathkeale Formation of west Limerick suggested by the absence of in-situ benthic faunas, sedimentary

structures and high proportion of terrigenous mud. Near Cappagh Castle, more carbonate rich beds, laminated calcisiltites and locally sharp-based graded bioclastic beds of packstones and grainstones suggest deposition from waning turbidity currents below storm wave base (Somerville and Strogen 1992).

In late Arundian times the facies described above prograded northwestwards so that the sequence at Mungret is represented by large-scale cross-bedded oolitic grainstones succeeded by thick-bedded skeletal grainstones (Somerville and Strogen 1992). Beds similar to the latter limestones are also seen at Kiltemplan Quarry (GR 14810 15090) and at Glascurram Quarry (GR 14860 15180), where cross-bedding is also seen.

It is more difficult to unravel developments between the Holkerian and Brigantian Stages. No rocks later than Holkerian age have been identified in North Limerick (Somerville and Strogen 1992). In West Limerick, the deep water Chadian - Arundian facies, represented by the Rathkeale Formation, is replaced by the Durnish Formation. The Durnish Formation, with a diverse coral and brachiopod fauna and abundant foraminifera (Shephard-Thorn 1963; Austin *et al.* 1970; Conil and Lees 1974; George *et al.* 1976) represents deposition below fair weather wave base on the mid-ramp (Somerville and Strogen 1992). The succeeding Shanagolden, Parsonage and Corgrig Lodge Formations in West Limerick are interpreted as a deepening sequence which by late Asbian and Brigantian times was in an outer ramp position. The contemporaneous calciturbidites recognised at Ballybunnion are likely to be even deeper water facies.

THE NORTHERN MARGIN OF THE SHANNON TROUGH

The nature of the northern side of the Shannon Trough in Co. Clare during the time interval represented by the Limerick Ramp (Chadian to Brigantian Stages) is less certain. Widespread cherty limestones overlying the Waulsortian Limestones, represented by the Cregmahon Member (Tubber Formation) and the Ballycar Formation, indicate the start of widespread regression in Chadian times.

These limestones were followed in East Clare by packstones and grainstones, including oolitic limestones during the late Chadian and Arundian Stages (Tubber Formation). Comparison with the Burren area to the northwest, from the limited data available at present, indicates that grainstones and cross-bedded oolitic limestones are more common in East Clare.

Broadly contemporaneous fine-grained muddy limestones outcropping east of Newmarket-on-Fergus (Finlough Formation), however, are interpreted as occupying a mid - outer ramp position, analogous to the Rathkeale Formation on the Limerick Ramp, suggesting that there was a fairly steep basin margin slope in East Clare probably running in an east-northeast to west-southwest direction.

Later developments, during the Holkerian - early Asbian Stages suggest widespread shallow-water platform conditions covered most of Ireland, including Co. Clare (Sevastopulo 1981; Somerville and Strogen 1992). In East Clare these carbonates include comparatively abundant oolitic grainstones (oo) and cherty limestones (ch). Whether these oolitic grainstones were significant enough to form barrier bars is open to conjecture. Oolitic barriers, however, are typical of regressive sequences on the South Wales Ramp (Wright 1986; Gully Oolite). Somerville and Strogen (1992) suggest that the lack of barrier oolites on the Limerick Ramp may be due to either a greater tidal influence, or that the Limerick Ramp lay on a lee shore whereas the South Wales Ramp was on the windward side (as is the Clare side of the Shannon Trough).

During the late Asbian widespread regression brought periodic emergence everywhere with the development of karstic surfaces and clay wayboards, exemplified by the cyclic terrace limestones of the Burren. The terrace limestones outcrop in the woods close to Steeles Turret and along the eastern margin of the Carboniferous Limestone outcrop north and south of Ennis. One point on the margin of the trough can be identified, near Ballycorick Bridge on the west side of the Fergus Estuary. To the northeast the Slievenaglasha and upper part of the Burren Formation are in platform facies, very similar to that of the Burren. At Cornfield mudmounds of Asbian and Brigantian age mark the margin of the trough, while to the south in the islands of the Fergus Estuary deeper water facies of Asbian and Brigantian age occur. Another constraint on the northern margin of the Trough is given by boreholes drilled just south of Slievecallan. To the north, in IPP-2, typical Burren and Slievenaglasha Formation limestones are well developed, while to the south in IPP-1, drilled near Doo Lough, striped limestones (probable Parsonage

Formation) overlies mudmound facies, a situation similar to that seen on the shores of the Fergus Estuary.

Cyclic platform conditions continued into the Brigantian with deposition of the Slievenaglasha Formation. It is only in the late Brigantian that deep outer ramp conditions can again be identified in the islands of the Fergus Estuary with recognition of the Parsonage and Corgrig Lodge Formations as at Foynes. The late Brigantian Cullaun Member of the Slievenaglasha Formation at Steeles Turret, however, overlies probably sub-aerially erupted volcanics. The volcanic rocks extruded here (Turret Volcanic Member) may have formed cones above sea-level, the pyroclastic material being deposited in the sea overlying shallow water carbonate sediments (Schultz and Sevastopulo 1965). The Cullaun Member contains boulders of Asbian limestone which are probably derived from movement on the Turret Fault contemporaneous with extrusion of the volcanics (Lewis 1986). It can thus be deduced that in late Brigantian times the northeastern boundary of the Shannon Trough lay somewhere near to Steeles Turret.

THE SHANNON TROUGH IN POST DINANTIAN TIMES

The Doonbeg No. 1 borehole (GR 09637 16382) drilled by Ambassador Irish Oil Company in 1962 - 1963 penetrated 783m of Namurian marine shale and turbidite, 276m of Clare Shales, and 2287m of Dinantian limestones and shales (Ambassador Irish Oil Company unpublished report to GSI, 1963). The Dinantian rocks dip to the south, while the Namurian rocks dip to the north. This may indicate that the axis of the basin was different in Namurian times or may indicate the beginning uplift of the southern areas, south of the Namurian depocentre, caused by the approaching Variscan deformation front (Croker 1995). Croker (1995) suggests that the Shannon Trough extended westwards to the Porcupine Basin. Little is known of the sedimentary sequence offshore, but it is likely to contain Dinantian, Namurian and Westphalian strata. Well 36/16-1, on the western margin of the Trough (Clare Basin of Croker 1995) proved 4000 feet of Westphalian (A - D) strata. It is likely that sedimentation continued in the Shannon Trough until inversion took place during the Variscan Orogeny. Croker (1995) suggests that late Cretaceous sedimentation and a thin Tertiary veneer could also have been deposited in the western offshore end of the basin.

HYDROGEOLOGY

Introduction

Groundwater in the region, provides a large proportion of the total water supply by way of public supplies, group water schemes and private wells. Much of the groundwater is abstracted through boreholes although there are also a number of large springs.

Average annual rainfall ranges from approximately 850mm in lowland areas to 1400mm on the mountains. Potential recharge to the main aquifers is of the order of 300 - 850mm per year, although actual recharge depends on the nature of the overlying sediments (Deakin *et al.* 1998).

In the lowland areas the water table is often within 10m of ground surface, but unsaturated zones of up to 30m have been reported (Deakin 1994). The levels are variable depending on the permeability and the elevation of the rocks, and are subject to seasonal fluctuations of, for example, 6m in Aughinish and at least 4m at Fedamore. In the upland areas water levels can be within a few metres of ground level in winter, falling to more than 20m below ground surface in dry summers.

There are a number of large groundwater sources in the area, the two biggest of which are a group of 12 springs located west of Kilmallock called the Knocksouna Group (29,000 m^3/d), and a large spring supplying the town of Ennis (Drumcliff: 12,000 m^3/d) which both discharge from limestones. Most of the other known large sources also discharge from limestones, with the exception of the Rathkeale spring source (1850 m^3/d) which comes from the Old Red Sandstone. Many other medium to large abstractions are used for public supply, creameries, factories, golf courses and hotels, and many individual houses and farms depend on groundwater for their supply.

Regionally Important Bedrock Aquifers

The principal bedrock aquifers are (a) the upper Old Red Sandstones found in the Ballingarry, Corronoher and Rockhill ridges, and (b) the cleaner limestones of the Lower Carboniferous which are present in most of the lowland areas. Groundwater storage and movement is via a secondary permeability created by fractures and fissures which, in the limestones, has been further enhanced by the enlargement of the fractures by chemical solution (karstification).

Several of the cleaner Carboniferous limestones, such as the Waulsortian rocks between Rathkeale and Aughinish, the Tubber and Burren Formations around Ennis, and the Visean limestones in north Kerry, are extensively karstified. The substantial fall in sea-level during the Pleistocene allowed drainage of the limestones, and therefore karstification, to take place considerably below present-day drainage levels. There are caves, springs, swallow holes, and in some cases limestone pavements, and groundwater flow is relatively rapid. Flow velocities traced to Drumcliff spring, for example, are of the order of tens of metres per hour (Coxon 1995).

Exploitation of the limestone aquifers can be difficult because of the unpredictability of the fracturing and because of karst cavities encountered in drilling, which can lead to problems such as loss of drilling fluid and deviation of the hole from the vertical.

Water quality in the regionally important aquifers is generally reasonably good. The limestone waters are always hard usually 250 - 400 mg/l ($CaCO_3$) while the sandstone waters are much softer. The karstic nature of the limestones, however, which ensures rapid travel times through the aquifer, and the frequent absence of an adequate protective subsoil cover, renders these aquifers very vulnerable to contamination.

Locally Important Bedrock Aquifers

Locally Important aquifers in the area include: the remainder of the Devonian Old Red Sandstone in the upland areas, the volcanic rocks, and the more argillaceous limestones such as the Ballysteen Formation, Rathkeale Formation, and more muddy

shelf Visean limestones to the west of Newcastle West and in the Shannon Estuary area. Permeabilities in these rocks are dependent solely on the degree of fracturing created as a result of the Variscan Orogeny, as there has been little additional solution along the fracture planes.

Well yields are typically lower than in the Regionally Important Aquifers although occasional high yields have been encountered in major fracture zones, particularly to the south of the sheet closer to the Variscan orogenic front.

Water quality in these aquifers is variable, being hard in the limestones and softer in the sandstones or other non-carbonate rocks. The argillaceous limestones and Old Red Sandstone can also often produce groundwaters with iron and manganese problems.

Poor Bedrock Aquifers

The slates and mudstones of the Silurian and Devonian rocks, the Lower Limestone Shales, and the Namurian sandstones and shales of west Clare, west Limerick and northeast Kerry, although fractured, generally have a low permeability and are regarded as poor aquifers. Such rocks will often yield enough water for a well to supply a house or small farm, and occasionally in major fracture zones may yield a better supply. However, since the yield often depends on the permeability developed in the uppermost few metres of broken and weathered rock, the quantities of abstractable water will often decrease markedly in dry spells as the water table falls, and the supplies may therefore be unreliable.

Water quality is also often poor as the sources have small catchment areas and are located on private sites which also often have septic tanks or farmyards nearby.

Quaternary Sand and Gravel Aquifers

Although the Quaternary sand and gravel aquifers are limited in extent (generally less than 2 km^2) and therefore are classified as Locally Important Aquifers, they are sometimes capable of supplying high yields to boreholes and have been successfully harnessed for medium-sized supplies in places such as Carrigkerry and Montpelier, Co. Limerick (Deakin *et al.* 1998), and Duagh, Co. Kerry (Conlon and Wright, 1998). Generally, the Quaternary deposits are exploited by many small dug wells and springs, and provide additional storage for the underlying and adjacent limestone aquifers.

Water quality in the Quaternary aquifers is very variable, depending on the nature of the gravel. Where limestone material is dominant, the waters tend to be hard (over 200 mg/l as $CaCO_3$). Travel times through the aquifers are generally slower than in fractured rock and there is a certain degree of filtration of potential contaminants which does not occur in the bedrock aquifers.

Warm Springs

Sheet 17 encompasses a part of the Munster Geothermal Province, in which a number of springs yield slightly warm water, at temperatures of 13° to 22°C, compared with a normal groundwater temperature of 11°C. (The remainder of the province lies within Sheet 21 to the south). The known localities of thermal waters on Sheet 17, all in Co. Limerick, are:

- Newcastle West: St. Bridget's Well, located to the west of the town, which is a small spring yielding water at just over 13°C and Cregan's Well to the south of the town which is larger with rising spring waters of approximately 14°C.
- The Knocksouna Group, near Kilmallock, which has an average temperature of 15.6°C.
- Camas, known locally as Sconse Well, which has a temperature of 12.8–13°C.
- Tobergal, a group of 4 springs (1640 m^3/d) with a temperature of 13.4–14.1°C.

Until recent times, St. Bridget's was one of only two recorded warm springs in Munster, but research in the late 1970s and 1980s uncovered several others in counties Cork, Kerry and Limerick, though none is as warm as that at Mallow (Brück, P.M. *et al.* 1986). Despite the research programme completed in the 1980s, the exact source of the warm waters and the details of their flow regime remain unclear. They must, however, be coming from a considerable depth and are presumed to be associated with major fault zones.

MINERAL RESOURCES

The mineral deposits depicted on the map are summarised in this section. The descriptions of the mineral deposits rely on the published work of the Geological Survey of Ireland, the published work of others (referenced as appropriate) and upon records from the Geological Survey's databanks. No new research or site investigation was carried out in compiling this summary. The deposits described are those which have had past production, which are considered to be major prospects, or have been well documented. The choice of deposits remains the responsibility of the writers. The numbers in brackets after the deposit name are those assigned to that locality in the Geological Survey's Minerals Locality Database (Minlocs). More detailed mineral locality maps and information may be obtained on request from the Minerals Section, GSI. Details of sites described in this section currently operating are to be found in the Directory of active quarries, pits and mines in Ireland (Claringbold *et al.* 1994).

The deposits have been categorised as follows:

- Metallic deposits;
- Coal deposits; and
- Industrial mineral deposits.

A mineralogical note concerning new minerals discovered, of academic interest, is appended.

Metallic deposits

While there are no active metallic mines in the map area today, there are a number of sites where silver, lead, copper, and zinc were mined, primarily, in the 19th century. Over the past 40 years parts of the area have been explored by mineral prospecting companies for both base metals and gold, but to date, no economically viable deposits have been found. The reports of the exploration work carried out by these companies is available from the Geological Survey's Mineral Exploration Records Databank. Stanley (1990) summarised the exploration data available for the Limerick Basin.

During the 19th century the principal metals produced from the deposits within the map area were silver, lead, and copper. The deposits, occurring as veins, consisted for the most part of the sulphides of lead (galena), copper (chalcopyrite), and zinc (sphalerite), occurring together in varying amounts with calcite and dolomite gangue. Pyrite was also a common sulphide mineral found in the veins but had no economic significance. Silver occurred mostly associated with galena (argentiferous galena) at each of the deposits. For convenience the deposits will be described according to the principal metal produced or main metal present in deposits which were not worked.

SILVER AND LEAD

Ballyvergin (1784) lies approximately 6km west-northwest of Tulla in Co. Clare. Lead and silver were produced in 1859 and 1860 from a vein which extended down to 20m. The vein trends north-northeast for approximately 300m. The lode bifurcates with an eastern branch, which is approximately 1m wide, and a western branch which varies from 1 - 3m in thickness. The vein occurs in the lower part of the Ringmoylan Formation.

Carahan (1799) is 7km west of Tulla in Co. Clare. Recorded Pb output is intermittent with production in 1863, 1879 and 1880. Workings at Carahan were at two separate sites. The mine area has been cleaned up somewhat and mineralised material can be found locally in walls. The principal minerals are galena, sphalerite, calcite, and pyrite. Traces of cobalt bloom have also been recorded. The mineralisation is located at the base of Waulsortian Limestones and top of the Ballysteen Formation. More recent exploration in the 1960s failed to discover any further significant mineralisation.

Ballyhickey (1695) is located 3km north of Quinn and was stated by Cole (1922) to be the most important of mines in Co. Clare. The mineralisation, consisting of argentiferous galena, occurs in large calcite veins with pyrite and sphalerite. Assays of up to 77% Pb with 15oz Ag per ton were recorded. The main vein was 5 - 6m wide. Production from the mine was recorded from 1838 to 1846. The pit measured some 60m in length and was 30m deep. It has variously been described as having been found when carrying out exploration for extensions to Kilbreckan in 1834 or when drains were being dug in the area.

Crowhill (1797) is 5km west of Tulla, Co. Clare. Galena and sphalerite mineralisation occur in an east - west striking vein. The workings on the vein extended to some 44m depth; exploitation was finished by 1862. More recent exploration in the 1960s failed to discover any further significant mineralisation.

Kilbreckan (1802) lies some 2.5km northwest of Quinn, Co. Clare. The deposit consists of a main lode up to 1m in width striking north - south. A second lode, also up to 1m thick, strikes northwest. The lodes contain argentiferous galena, pyrites, chalcopyrite, sphalerite, and calamine in a calcite gangue. The mineral Kilbreckanite (described as a sulphide of antimony and lead) is also known from the deposit. The main lode was said to contain 70% Pb and 120oz Ag per ton. The deposit was discovered when cutting a drain through a bog in 1833 and opened in 1834 with intermittent production up to 1853. The known workings extend down to 60m.

Ballysteen (2103) is 5.5km north of Askeaton, Co. Limerick. Argentiferous galena and sphalerite with a calcite gangue are present in an east - west trending vein. The workings on the vein measured some 160m in length and extend down to 34m. The deposit had ceased operation by 1836.

Cloghatrida (1932) occurs approximately 5.5km north of Askeaton, Co. Limerick. Argentiferous galena, sphalerite, chalcopyrite, and pyrite were found in a gangue of calcite and iron bearing dolomite. The mine was abandoned by 1857.

Ballinglanna (3136) occurs some 2km north of Causeway, Co. Kerry. Numerous lumps of galena were found but the site of a disused mine is uncertain.

COPPER

Ballyvergin (2106), as described above, is better known as a silver and lead mine but some copper was produced. More recent exploration has been carried out and resulted in the identification of an extension to the east of the known mine workings (Creighton 1988). The mineralisation occurs as disseminated and fracture filled sulphides (mainly chalcopyrite) in the Ringmoylan Formation. Estimates of the tonnage vary from 150,000 tonnes grading 1.2% Cu and 15g/t Ag, to 230,000 tonnes grading 0.97% Cu and 15g/t Ag. Descriptions of the mineralisation are provided in the exploration reports lodged with the Geological Survey and by Andrew (1986).

Maghera (1843) lies close to Ballyvergin, described above. The deposit is composed of disseminated chalcopyrite and pyrite and is similar to Ballyvergin in stratigraphic setting and structure. More recent exploration in the 1960s failed to discover any further significant mineralisation.

Shannaknock (1495) occurs approximately 4km west of Broadford in Co. Clare. The lode contains copper and iron pyrites in quartz veins in Silurian blue and black shales and greywackes. The lode has an overall width of about 2.5m. Workings on the lode date from about 1750.

Pallaskenry (1905) lies 1.5km north of Pallaskenry, Co. Limerick. The deposit comprises galena and chalcopyrite in a quartz gangue. The vein is hosted by Old Red Sandstone lithologies.

ZINC

Miltown (1709) is 2.5km from Tulla, Co. Clare. This is the first recorded zinc production in Ireland (mid 1850s). The production of zinc was recommended so that exploration costs, for lead and silver, could be raised, (Cowman and Morris 1998). The vein was composed of sphalerite, galena, and pyrites in a calcite gangue. There were earlier workings in the 1820s for lead and possibly even before then. Lead was also produced from the deposit in the period from 1858 to 1860. The deposit is hosted in the Dinantian Limestones at or about the base of the Waulsortian Limestones.

Courtbrown (1750) is situated on the River Shannon Estuary 4km northwest of Askeaton in Co. Limerick. Modern exploration, commencing in 1962, was carried out by a number of companies. This exploration resulted in outlining a deposit with approximately 1 Mt at a grade of 3.5% Zn plus 2.0% Pb with 14 g/t Ag which were classified as being both "possible and inferred". The principal minerals are sphalerite and galena with chalcopyrite, tennantite, and arsenopyrite also found. Pyrite may occur massively (up to 1.5m thick) 1 - 5m above the main sulphide zone. The mineralisation occurs at the base of the Waulsortian Limestones and in the topmost part of the Ballysteen Formation. The mineralised zone is 1 - 8m thick and is found along strike for some 425m and approximately 100m down dip. The deposit was described by Grennan (1986) and the exploration history summarised by Stanley (1987).

Ballycullane (5595) lies some 3km to the northeast of Kilmallock, Co. Limerick. Geochemical exploration in the 1970s led to the discovery of

anomalous values of zinc and lead in a brown mud. Drilling intersected low grade Zn and Pb mineralisation in Waulsortian Limestones and in the nodular cherty limestones of the Ballynash Member of the Ballysteen Formation. Descriptions of the exploration work on this prospect are recorded in the Geological Survey's Mineral Exploration Records Databank.

GOLD

Kilbane (4341) is located approximately 5km northeast of Broadford in Co. Clare. Some small gold colours were found in recent reconnaissance exploration. The area is underlain by the Broadford Formation which is composed of fine to conglomeratic graded greywackes.

Oatfield (4342) lies some 6km to the southwest of Broadford, Co. Clare. Anomalous gold values up to 4297ppb have been recorded from stream sediments in recent exploration. The area is underlain by the Old Red Sandstone.

Coal deposits

The Crataloe Coalfield lies just north of Abbeyfeale in Co. Limerick. The coal seams are located within an area 3.2km long by 1.6km wide. The seams are generally flat lying in the eastern part of the area but in the western part dips are steeper with values of about 20° along the southern margin and 60° - 85° along the northern margin. There was only one seam of economic importance which was 230 - 380mm thick (British Mining Consultants 1982). The seam was worked near Glen Bridge. Exploration was carried out in the 1950s by Cement Limited and in the 1980s by Sea Scoop Limited.

Industrial minerals and rocks

DIMENSION STONE

Dimension stone is produced by cutting stone into regular shaped pieces and it is used for architectural, building, roofing and monumental purposes.

Limestone

The Geological Survey of Ireland carried out a survey of limestone sites to assess their potential for use as dimension stone. This survey covered over 330 sites in eleven counties and sites have been classified into high, medium and low potential. On this map there are two sites which have been classified as having high potential for dimension stone production and these occur in the townlands of Maghera (4735), in the Ballysteen Formation, and at Moyriesk (4719) in the Waulsortian Limestones (Bell, 1992. Limestone dimension stone digital database, Minerals Section, GSI).

South of Limerick City at Rossbrien (2017) there are a series of disused building stone quarries. The rock is described as compact and when polished is included among the black marbles of Ireland, however, occasional fragments of fossils are present which tend to decrease its reputation as a material for ornamental work (Flegg and Sheridan 1981). In Co. Clare in the townland of Rineanna (1814) marble was formerly quarried; the stone is red or sometimes red clouded with grey and it is said that good size blocks can be obtained from this deposit (Bell, 1992. Limestone dimension stone digital database, Minerals Section, GSI).

Slate

In the vicinity of Broadford, Co. Clare, there are a series of disused slate quarries within the Broadford Formation. The Ardskeagh slate quarries (1436) were worked prior to 1860 and at one time there were extensive workings producing good quality slate. This site is unsuitable today due to haphazard workings in the past, dumping of spoil, flooding, as well as, economic problems. The pit at Kilseily (1434) ceased operating as it progressed into slates full of concealed joints and greatly ruptured by faults, ensuring no large working could be carried out (Kinahan 1888).

AGGREGATES, CEMENT AND AGRICULTURAL GROUND LIME

"Aggregate" is the term applied to any rock or mineral used in bulk, in crushed or ground form, for a wide range of construction purposes such as road building and concrete manufacture.

Basalt

Northwest of Kilmallock, basaltic pyroclastics were extracted at Ballineeny Quarry in the townland of Coolrus (1857) from within the Old Red Sandstone. This rock is reported to be purplish in colour and brecciated, with dark basaltic fragments. It is thought likely that the rock was used for road surfacing aggregate as it is reported to have good skid resistance properties.

County	Min. locs number	Townland	Nearest town	Limestone extracted
Clare	1772	Fortrane More	Tulla	Waulsortian limestone
Clare	1839	Ballyneillan	Ennis	Burren Formation
Clare	1767	Bunratty west	Shannon	Ballysteen Formation
Clare	1774	Ballybrody	Ennis	Burren Formation
Limerick	5524	Graggs	Askeaton	Waulsortian limestone
Limerick	1856	Glenbane East	Askeaton	Waulsortian limestone
Limerick	1859	Conigar	Limerick	Visean limestone
Limerick	1860	Kilfinny	Croom	Waulsortian limestone

Table 3. Active quarries extracting limestone for aggregate

Limestone

There are eight quarries extracting limestone for aggregate and these are shown in Table 3. Full details are available from the Directory of active quarries, pits and mines in Ireland (Claringbold *et al.* 1994).

Limestone is being extracted for use in cement manufacture, southwest of Limerick City at Castlemungret Quarry in the townland of Conigar (1859). At this site cement is manufactured using the energy efficient dry process of production. Limestone and shales, which provide the calcium carbonate, silica, alumina and iron, are ground into a powder and then fused in a kiln to produce a clinker. The clinker is then ground and gypsum is added to produce cement. Currently there are two cement plants in Ireland the Castlemungret plant and the Platin works in Co. Meath, between them they have a total capacity of 2.1 Mt of cement production per year.

In Kerry, south of Listowel, Monument Quarry (3315) has been worked as an aggregate source in the past by the County Council. The quarry has been assessed as being of interest as a source of walling stone (Bell, 1992. Limestone dimension stone digital database, Minerals Section, GSI).

Sandstone

Namurian sandstone is currently extracted southwest of Ennis, at Lismulbreeda (1771). It is reported that this stone has a good Polished Stone Value and is therefore suitable for road surfacing material. At Guhard South (3316) about 10km northwest of Listowel a grit from the Shannon Group has been worked in the past and is reported as being good quality stone (Minlocs).

Sand and gravel

BallyQuinn Pit in BallyQuinn More (3034) is extracting sand and gravel which have quartz greywackes as the predominant lithology. The material is used as concrete aggregate and for road building due to the skid resistance properties of the greywackes.

Shale

Northwest of Limerick in the townland of Ballycar North (1775) there is an active shale quarry in the Cratloes Formation.

OTHER INDUSTRIAL MINERALS

Calcite

There is a history of calcite mining in Co. Clare and the calcite veins are found in the north and east of the county. There are 24 calcite localities recorded in the Minlocs database for this area, the most significant of which are described below. Calcite is commonly ground and used as an inert pigment or filler in numerous manufactured products, such as paper, paints, plastics and rubber. Its function may be to add colour, stiffness or opacity or increase electrical conductivity or resistance to heat.

The Kilbreckan calcite deposit (Plate 8) is situated in the townland of Monanoe (4344) near Quinn within the Burren Formation. Diamond drilling has established a measured resource of 425,500 tonnes



Plate 8. The old mine chimney at Kilbreckan Mine, Co. Clare (photo by C. MacDermot).

with a further 267,000 tonnes in the indicated resource category. The deposit which is open at depth, is a steeply dipping body elliptical in shape. Tests have indicted that the calcite is of a very high purity (greater than 99.1% $CaCO_3$) and is suitable in the manufacture of glass, rubber, plastic, paper and paint (Flegg 1994).

East of Ennis, the Spancil Hill deposit occurs in Tullyvoghan (1703) within the Tubber Formation and is situated in a relatively large body of coarse calcite which measured 46 x 27m. This quarry which is now disused and flooded was operated by Irish Whiting Manufacturers Ltd. Nearby at Ballycrighan (1694), within the Waulsortian Limestones, there is a disused calcite pit approximately 10 metres wide which narrows with depth. The calcite is white, clear, and in the past was also worked by the Irish Whiting Company.

Recent drilling within the Burren Formation carried out by the Geological Survey in the townland of Dangan (5594), intersected calcite from a depth of approximately 12m below ground in a single borehole to the end of the borehole at 20m (Minlocs).

Clays

At the turn of the century red coloured bricks were made at Rossmanagher (1776) and Ballycorick (2474) in Co. Clare from the clays of the River Fergus valley (Flegg 1980). Local clays have in the past been used all over the county to produce bricks of indifferent quality, however at Ballyhahill (2472), the clays were raised to produce good quality bricks (O'Meara 1974).

Mineralogical note

The copper selenite chalcomenite ($CuSeO_3 \cdot 2H_2O$) has been described by Francis and Ryback (1987) from Ballybunnion, Co. Kerry. The minerals forms bright blue transparent elongated crystals up to 0.4 x 0.15mm in size, scattered singly or in radiating clusters on joint surfaces of black shale in the Clare Shale Formation.

More recently four sulphate minerals have been described for the first time in Ireland from Ballybunnion by Moreton *et al.* (1995). The minerals are basaluminite [$Al_4SO_4(OH)_{10} \cdot 5H_2O$], hydronium jarosite [$(H_3O)Fe^{3+}_3(SO_4)_2(OH)_6$], meta-sideronatrite and sideronatrite [$Na_2Fe^{3+}(SO_4)_2(OH) \cdot 3H_2O$].

REFERENCES AND ADDITIONAL READING LIST

Most of the references below are available for reading in the Geological Survey Library, where the Geological Museum (H.M.S.O.) publications are also available for sale.

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APPENDIX 1

Brief lithological descriptions of all units appearing on the accompanying geological map.

Ailwee Member BUam
Thick-bedded to massive pale limestones with well-marked discontinuous clay wayboards.

Athassel Limestone Formation AT
Dark-grey shale-parted fine-grained wackestone limestones with frequent chert bands and nodules, regular parallel beds.

Aylecotty Member SLay
Thin-bedded, dark-grey cherty limestones.

Basalt B
Generally massive black olivine basalts, weathered to various degrees.

Ballard Member BUbd
Dark-grey medium-bedded cherty wackestones/packstones with thin shaly partings

Ballycar Formation BC
Dark-grey, highly silicified calcilutites interbedded with nodular, black chert bands (0.1 - 0.25m thick).

Ballycar South Member CRbs
Fossiliferous conglomeratic sandstone.

Ballymalone Formation BO
Black, pyritous, graptolitic shales and dark-coloured cherts.

Ballymartin Formation BT.
Dark-grey muddy bioclastic limestones and interbedded dark-grey calcareous shales.

Ballynash Member BAbn
Grey, orange-weathering shaly, cherty and wavy-nodular often micritic wackestones, variably fossiliferous.

Ballysteen Formation BA
Dark-grey bioclastic, wackestone, packstone and grainstone, shale-parted limestones becoming increasingly muddy upwards.

Ballyvergin Shale Formation BV.
Greeny-grey non-calcareous mudstone with thin interlaminated siltstone bands.

Broadford Formation BF
Graded and plain greywackes, graptolitic siltstones and conglomerates.

Burren Formation BU
Skeletal pale-grey packstones and wackestones with cyclical units shallowing up to karstic surfaces and clay wayboards towards the top of the formation.

Central Clare Group CCG
Cyclothemic units typically with a fossiliferous marine band followed by laminated shales, laminated to massive siltstones, and laminated sandstone possibly capped by coal and rootlets.

Chert ch
Cherty limestones within the Burren Formation.

Clare Shale Formation CS
Dark-grey shales, siliceous mudstones towards the base.

Conglomerate and Coarse Greywacke cg
Conglomerates and coarse greywacke horizons within the Slieve Bernagh Formation.

Corgrig Lodge Formation PA
Calcilutites, sometimes cherty, interbedded with thin black mudstones and thin limestone conglomerates and graded crinoidal packstones and grainstones.

Cornagnoe Formation CE
Green silt and mudstones with dark mottled or graptolitic shales.

Cratloes Formation CR
Thin to medium bedded, laminated, grey to green siltstones which are occasionally calcareous and grade up to fine-sand size.

Cregmahon Member TUcm
Thick-bedded silicified and dolomitised highly cherty packstones and wackestones, with some shale partings.

Cullaun Member SLcu
Thin, flaggy crinoidal grainstones and packstones interbedded with intraformational conglomeratic limestones.

Durnish Formation DU
Well-bedded, blue-black, brachiopod and coral rich, cherty packstones and wackestones.

Feale Sandstone Formation FS
Cyclic brown to green flaggy or cross-bedded sandstone and shale with occasional coal seams.

Finlough Formation FL
Dark-grey to black, flat-bedded, earthy, fetid, cherty calcisiltites and fine calcarenites (packstones and wackestones) which contain chert nodules and shale partings.

Glandahalin Formation GH
Olive, olive-grey, brown and red trough cross-stratified and planar-stratified, medium to fine-grained sandstones and red and yellow cross-laminated bioturbated siltstones.

Glennagross Member CRgc
Unfossiliferous conglomeratic sandstone.

Greywacke sandstone gw
Greywacke sandstone horizons within the Broadford Formation.

Gull Island Formation GI
Grey slumped siltstones with up to 20% usually graded sandstones at the base of the succession, decreasing towards the top.

Inshaboy Formation IY
Predominantly yellow trough cross-stratified and planar-stratified fine - medium grained sandstones and red, green, and yellow cross-laminated siltstones.

Herbertstown Limestone Formation HE
Blue-grey grainstones, oolitic, peloidal and crinoidal.

Kilmore Formation KM
Yellow, olive, and brown fine-grained sandstones and yellow and green siltstones.

Knockroe Basalt Lava Flow Member KRb
Basaltic lava flows.

Knockroe Vitric-Lithic Tuff Member KRv
Vitric-lithic tuffs and agglomerates, basaltic and mixed volcanics, locally trachyte-predominant.

Lough Gur Formation LR
Pale crinoidal grainstone to micritic wackestone limestones with much chert and some grey shale.

Lower Limestone Shale LLS
Thin-bedded heterolithic mudstones sandstones and thin limestones.

Magowna Formation MG
Black thin bedded limestones and shale.

Maumcaha Member BUam
Massive pale to medium-grey packstone/wackestone limestone.

Mellon House Formation MH
Dark-grey, laminated siltstones and fine-grained sandstones, alternating with bioturbated calcareous shales and occasional thin skeletal limestones.

Mudbank limestone mk
Massive mudbank facies limestones of Visean age.

Old Red Sandstone (undifferentiated) ORS
Red conglomerate, sandstone and mudstone.

Oolitic limestone oo
Oolitic limestone horizons within the Burren Formation.

Parsonage Formation PA
Disrupted laminated limestones with conglomeratic horizons ("striped limestones"), massive "mudbank" limestones, and cherty calcilutite wackestones.

Purple grit pg
Purple grits within the Cornagnoe Formation.

Rathkeale Formation RK
Dark-grey argillaceous limestones and shaly mudstones.

Ringmoylan Formation RM
Massive unbedded pale-grey clean crinoidal wackestone limestones and micritic limestones with thin bedded cherts.

Ross Sandstone Formation RS
Parallel-bedded sandstone beds often with flute and groove casts at the base of beds.

Shanagolden Formation SG
Black, well-bedded, generally chert free and poorly fossiliferous packstone and wackestone limestones.

Shannon Group SHG
Mudstones, siltstones and rippled sandstones commonly with sole structures.

Slieve Bernagh Formation SB
Slaty banded siltstones and fine to conglomeratic greywackes.

Slievenaglasha Formation SL
Thin cyclic crinoidal limestones (packstones to grainstones) and non-cyclic cherty, well-bedded, dark-grey to black bioturbated packstones and wackestones.

Tubber Formation TU
Crinoidal medium-grey packstones and wackestones, sometimes with shaly partings, cherts and dolomite.

Tullig Sandstone TS
Thick-bedded pale sandstone.

Turret Volcanic member SLtu
Altered bedded basaltic tuffs and lavas.

Visean Limestones (undifferentiated) VIS
Undifferentiated limestones.

Volcaniclastic Rocks V
Volcaniclastic rocks within the Dinantian limestones.

Waulsortian Limestones WA
Pale-grey, sparry, fossiliferous (bryozoan) poly-mud micritic limestones, often massive knoll forms, with crinoidal or pale cherty shaly interbeds, frequently dolomitised.

APPENDIX 2

Glossary

ALLUVIAL; ~ FAN: pertaining to deposition by a stream; fan-shaped mass of loose rock material where a stream issues from a mountain valley to a plain.

ALLUVIUM: sediments deposited by fluvial processes.

ANTICLINE: convex upwards fold (like a ridge), where older rocks are bordered on two sides by younger rocks.

BED (-ding): (a) single unit of sedimentary rock, distinct from those on either side and usually more than one centimetre thick. A stack of beds (or layers); (b) smallest formal lithostratigraphical unit.

BOREHOLE: an artificial hole cut or drilled into the Earth to explore for valuable minerals or to secure scientific data.

BRYOZOA: aquatic colonial invertebrates belonging to the phylum Bryozoa, ranging from Ordovician to present, often found as frond-like fossils.

CALCAREOUS: containing calcium carbonate.

CARBONATE: a sediment formed by the organic or inorganic deposition from an aqueous solution of carbonates of calcium, magnesium or iron, e.g. limestone or dolomite.

CHERT: hard material composed of microcrystalline quartz or opaline silica, occurs as nodules or beds in limestone.

CLAY: particles of sediment derived from the breakdown of mineral and rock fragments whose size is less than 0.005mm.

CLAY WAYBOARD: thin bed of clay (mudstone), representing a fossil weathered soil.

CLEAVAGE: finely spaced planar parting caused by compressive deformation of rocks (commonly forms oblique to bedding).

CONGLOMERATE: coarse-grained rock consisting of over 50% of rounded clasts over 2mm in diameter.

CRINOID, ~AL: n., adj. any pelmatozoan echinoderm belonging to the class Crinoidea, characterised by a fivefold symmetry, with a disk shaped or globular body enclosed by calcareous plates from which appendages extend radially; commonly anchored to the sea-floor by a stem. Commonly known as sea lillies.

DELTA: fan-shaped plain of alluvial sediments at river mouth crossed by many distributaries, often extending beyond the general trend of the coastline.

DRUMLIN: low, smooth, rounded elongate hill of glacial till.

DYKE: a sheet-like igneous intrusion that cuts across older rocks.

ERRATIC: rock moved by glacial or floating ice from its original outcrop.

ESKER: long narrow sinuous ridge of sand and gravel deposited by a sub-glacial stream and left behind after the ice melted.

EXTRUSION, ~IVE,: n., adj. volcanic igneous rock emplaced at the earth's surface and therefore part of the sedimentary succession.

FAULT (-ing): planar fracture in rocks across which there has been some displacement; commonly inclined but may be vertical; **normal fault** - in which the hanging wall has moved downward relative to the footwall; **reverse fault** - in which the hanging wall has moved upward relative to the footwall; **wrench fault** - in which the rocks on either side have moved laterally relative to each other, *see also* footwall and hangingwall.

FOOTWALL: the rocks underlying an inclined fault.

GRAPTOLITE: extinct organism of the phylum Hemichordata with colonies consisting of one or more fine branches with tiny cups (thecae). Range - Middle Cambrian to Carboniferous.

GREYWACKE: dark-grey, impure, poorly sorted sandstone, composed of quartz, feldspar grains and rock fragments in a clayey matrix, *see also* matrix.

HANGING WALL: the rocks overlying an inclined fault.

IGNEOUS: those rocks or minerals formed from magma, either volcanic or intrusive.

INTRUS(ION), ~IVE: n., adj. igneous rock emplaced within the Earth's crust.

JASPER: a variety of chert commonly associated with iron ores and containing iron-oxide impurities that give it various colours, though characteristically red.

JOINTS: fractures in a rock with no observable relative movement between the sides.

KAME: mound, knob or ridge of stratified sand and gravel deposited by a sub-glacial stream, cf. esker.

KARST: features produced by dissolution of rock, usually limestone.

LAVA: general term for molten extrusive, or the rock solidified from it.

LIMESTONE: sedimentary rock composed of calcium carbonate, commonly formed from the fragmented remains of calcareous organisms.

LITHOSPHERE: the Earth's crust and uppermost part of the upper mantle that together make up the plates of the outer Earth.

LITHOSTRATIGRAPHY: the organisation of strata into units based on lithological character.

LOW GRADE (RANK): metamorphism that is accomplished under conditions of low to moderate temperature and pressure, *see also* metamorphism.

MACROFAUNA: living or fossil animals large enough to be seen with the naked eye.

MATRIX: fine-grained material filling the spaces between the larger grains in a sedimentary rock, or between larger crystals in an igneous rock.

METAMORPH(ISM), ~IC: n., adj. alteration of rocks by heat and/or pressure often accompanied by deformation; metamorphic grade - the intensity or rank of ~ism, "high", "medium" and "low" grade are used in a relative sense. *see also* low grade.

MORAINE: Landform of unconsolidated glacial deposits.

MUDSTONE(S): very fine-grained rock with a particle size less than 0.002mm.

NORMAL FAULT: *see* fault.

OBLIQUE FAULT: a fault with both strike-slip and dip-slip movement. *see also* fault and strike-slip.

OOLIT(H)IC: said of limestone containing spherical sand-sized grains with a concentric structure (ooids); oolith - a limestone made up of ooids.

OROGEN(Y), ~IC, ~ESIS: n., adj., n: the process by which structures within fold-belt mountainous areas (**orogenic belt**) were formed, including thrusting, folding, and faulting in the outer and higher layers and plastic folding, metamorphism and plutonism in the inner and deeper layers. Commonly a result of interactions involving convergence of lithospheric plates.

OROGENIC BELT: *see* orogen.

OXIDATION: the process whereby a substance combines with oxygen to form an oxide or other oxygen compound, e.g. the process of rust formation by a combination of oxygen and iron.

PELAGIC: fully oceanic environment.

PLATE, ~ TECTONICS: a part of the rigid outer layer of Earth; global theory of the movements and interactions of plates.

PYRIT(E), ~IC, ~OUS: n., adj. iron sulphide: pale yellow-gold coloured mineral which commonly occurs as cubes ("Fool's Gold").

REDBEDS: sandstones, siltstones and shales, predominantly red, due to haematite (Fe_2O_3); associated with arid/semi-arid environments.

REVERSE FAULT: *see* fault.

RIPPLE MARKS: an undulatory surface consisting of alternations of parallel ridges and hollows formed at the interface between a fluid and incoherent sediment.

SANDSTONE: sedimentary rock characterised by sand-sized grains.

SAND VOLCANO: an accumulation of sand resembling a miniature volcano or low volcanic mound, produced by expulsion of liquefied sand to the sediment surface.

SEDIMENTARY: formed by the deposition of sediment, i.e. rock particles or chemical precipitate, or pertaining to the process of sedimentation.

SHALE: fine-grained sedimentary rock, like mudstone but with an irregular parting.

SILICEOUS: containing silica minerals.

SILL: igneous body with sheet-like form intruded parallel to bedding, *see also* intrusive and igneous.

SILT: particles of sediment derived from the breakdown of mineral and rock fragments whose size ranges between 0.062mm and 0.005mm.

SILTSTONE: sedimentary rock composed of silt-sized particles.

SLATE: metamorphosed mudstone with a near perfect closely-spaced, planar cleavage, hence can be split into slabs and thin plates.

STRATIGRAPHY (-ic): the study of the original succession and age relations of rock strata.

STRATIGRAPH(Y), ~ICAL: n., adj. (study of) all aspects of the science of rock strata; the sequence of rock strata.

STRIAE: ice-scratches on rock surfaces caused by debris carried by moving ice.

STRIKE-SLIP: in a fault, the component of movement that is parallel to the strike of the fault; a fault with displacement predominantly parallel to strike.

SUCCESSION: stratigraphical sequence of rocks.

SYNCLINE: fold which has the youngest rocks at its core, commonly basin-shaped (concave-up).

TERRANE: (syn. exotic ~) far travelled fragment of oceanic/continental material accreted to an active continental margin, lacking stratigraphical relationships with its continental hinterland; **suspect ~** - structurally isolated rock unit of any size suspected of being a terrane.

THRUST: shallowly inclined fault in which one unit has overridden another unit, *see also* fault.
TILL: Unsorted and unstratified glacial deposits.

TURBID(ITE), ~ITY CURRENT: n., adj. sediment or rock deposited from turbidity current; density current in water (*inter alia*) with gravity causing suspended matter to move down subaqueous (e.g. continental) slope.

UNCONFORM(ITY), ~ABLE: n. adj. an erosional break in the geological record at which strata truncate the structure of older strata.

VEIN QUARTZ: a tabular or sheet-like body of the silicate mineral quartz which has been intruded into a joint/s and/or fissure/s in rock.

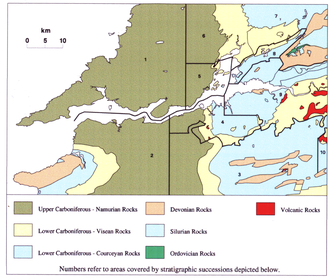
WRENCH FAULT: fault in which the rocks on either side of the fault-plane have moved horizontally, *also see* fault.

BEDROCK GEOLOGY 1:100,000 MAP SERIES

Geological Survey of Ireland

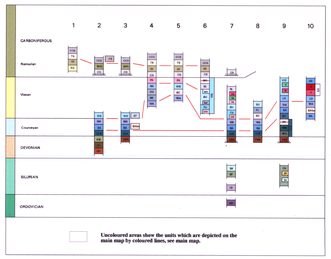
SHANNON ESTUARY - SHEET 17

SUMMARY GEOLOGY



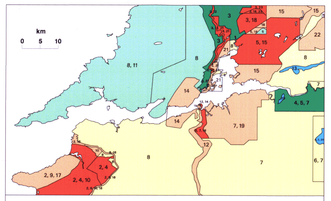
Numbers refer to areas covered by stratigraphic successions depicted below.

STRATIGRAPHIC SUCCESSIONS



Uncoloured areas show the units which are depicted on the main map by coloured lines, see main map.

DATA SOURCES



MAIN DATA SOURCES

Geological Survey Mapping
1. A.M. Flagg (1968-1972)
2. R.R. Horne (1974 unpubl.)
3. C.V. MacDermot (1998 unpubl.)
4. M. Pracht (1998 unpubl.)
5. A.G. Sleeman (1997-1998)
6. D.C. Smith (1984-1995)
7. G.Stanley (1988)
8. GSI Data (19th Century)

Other Sources
9. J.A. Diemar, J.S. Bridge and D.J. Sanderson (1987)
10. Dresser Minerals International Inc.
11. D. Gill (1979)
12. F. Hodson and G.C.Lewarne (1961) and Lewarne (1959)
13. C.H. Holland, J.Pelton and E.M. Williams (1988)
14. D. Hopkins (1964)
15. D. Lewis (1986)
16. B. Kelk (1960)
17. M.F.H. Khan (1955)
18. D.H. Oswald (1952 unpubl.)
19 E.R. Shephard-Thorn (1958)
20. P. Stevens (1973,1983)
21. J. Tattersall (1963)
22. J. Weir (1962)
23. F. Thomas - Irish Base Metals (1975)

GSI detailed mapping
Other detailed mapping
GSI reconnaissance over earlier detailed mapping
GSI compilation over earlier detailed mapping
GSI reconnaissance mapping
GSI compilation over earlier reconnaissance mapping
GSI desktop compilation

ADDITIONAL DATA :

Ambassador Irish Oil Co. Ltd. (1962-1963)
Anglo United Development Corporation Ltd.
Billiton Exploration Ireland Ltd.
Comtel Mining Finance
Dresser Minerals International Inc.
Groundhills Mining Company
Irish Petroleum Prospecting Ltd.
Irish Base Metals Ltd.
Irish Geotechnical Services
Noranda Exploration Ireland Ltd.
SMM Penarroya
Rio Tinto Finance and Exploration Ltd.
R.E. Somerville
I.D. Somerville
G.D. Sevastopulo

STRATIGRAPHY

CARBONIFEROUS

Tournaisian

Courceyan

Chadian - Arundian

(3)	AT	**Athassel Limestone Formation** Dark shaly cherty limestone
(8)	FL	**Fisheigh Formation** Dark grey shaly & cherty fine limestone
	BC	**Ballycar Formation** Dark grey fine cherty limestone

Chadian - Brigantian?

(2,3,5,6,9)	VIS	**Visean Limestones (undifferentiated)** Undifferentiated limestone
(2-4,5,7-10)	WA	**Waulsortian Limestones** Massive unbedded lime-mudstone
(3,9,10)	BA	**Ballysteen Formation** Fossiliferous dark-grey muddy limestone
(2,3,7-10)	bn	**Ballynash Member** Wavy-bedded cherty limestone, thin shale
	BT	**Ballymartin Formation** Limestone & dark-grey calcareous shale
(9)	~~BV~~	**Ballyvergin Formation** Non-calcareous mudstone & siltstone
	RM	**Ringmoylan Formation** Calcareous shale & crinoidal limestone
	MH	**Mellon House Formation** Siltstone, sandstone & calcareous shale
(2,3,7-10)	LLS	**Lower Limestone Shale** Sandstone, mudstone & thin limestone

Visean

Chadian - Asbian

(6,7)	BU	**Burren Formation** Pale grey clean skeletal limestone
	am	**Allwee & Maumcaha Members** Massive to thick bedded clean limestone
	bd	**Ballard Member** Fine grained dark limestone with cherts
	TU	**Tubber Formation** Crinoidal & cherty limestone & dolomite
	cm	**Cregnashon Member** Crinoidal limestone with cherts
(4)	SG	**Shanagolden Formation** Black well bedded skeletal limestone
	DU	**Dovish Formation** Blue-black cherty bioclastic limestone
	RK	**Rathkeale Formation** Dark muddy limestone & shaly mudstone
(10)	HE	**Herbertstown Limestone Formation** Blue-grey limestone & interbedded ash
	KR	**Knockroe Volcanic Formation** Not depicted undivided on map
	E	**Knockroe Basalt Lava Flow Member** Basaltic lava flows
	v	**Knockroe Vitric-Lithic Tuff Member** Vitric-lithic tuff & agglomerate
	LR	**Lough Gur Formation** Pale cherty crinoidal limestone

Brigantian

(6)	~~MG~~	**Magowna Formation** Dark limestone & shale
(4,5)	PA	**Parsonage & Corgrig Lodge Formations** Fine laminated & muddy limestone & shale
(6,7)	SL	**Slievenaglasha Formation** Cherty limestone, crinoidal intervals
	cu	**Cullaun Member** Crinoidal & conglomeratic limestone
	tu	**Turrett Volcanic Member** Basaltic tuff & lava
	ay	**Aykeerby Member** Thin bedded dark grey cherty limestone

DEVONIAN

Upper Devonian

(2)	KM	**Kilmore Formation** Yellow - olive mudstone to sandstone
	IY	**Inishabroy Formation** Sandstone, siltstone & mudstone
	GH	**Glandahafin Formation** Red cross bedded siltstone & sandstone
(3,7,9)	ORS	**Old Red Sandstone (undifferentiated)** Red conglomerate, sandstone, mudstone

SILURIAN

Wenlock

(9)	CR	**Cratloes Formation** Laminated siltstone & sandstone
	bs	**Ballycar South Member** Fossiliferous conglomeratic sandstone
	gc	**Glennagross Member** Conglomeratic sandstone

Llandovery-Wenlock

(7)	SB	**Slieve Bernagh Formation** Fine & some coarser greywacke
	BF	**Broadford Formation** Fine to conglomeratic graded greywacke

Caradoc-Ashgill

(7)	CE	**Corrungrane Formation** Green, mottled siltstone & mudstone
	BO	**Ballymalone Formation** Black graptolitic shale & chert

ORDOVICIAN

SEDIMENTARY LITHOLOGIES

oo	**Oolitic limestone**
mk	**Mudbank limestone**
ch	**Chert**
cg	**Conglomerate & coarse greywacke**
gw	**Greywacke sandstone**
pg	**Purple grit**

IGNEOUS LITHOLOGIES

V	**Volcaniclastic Rocks**
B	**Basalt**

Strike & dip of bedding, right way up
Strike of vertical bedding
Horizontal bedding
Strike & dip of bedding, way-up unknown
Bedding or foliation, old GSI data

Anticlinal axis
Synclinal axis

Stratigraphical boundary
Lithological boundary
Stratigraphical unit, diagrammatic
Goniatite marine band (R1 - R4)
Coal seam
Unconformity
Fault

R1 : Reticuloceras stubblefieldi
R2 : R. reticulatum s.s.
R3 : R. bilingue
R4 : R. super bilingue

MINERALS INFORMATION

EXPLOITATION STATUS

■ Working quarries, pits & mines non-metallic
□ Disused quarries, pits & mines non-metallic
○ Disused metal mines & pits
▲ Prospects, metallic & non-metallic

MINERAL LOCATION No.

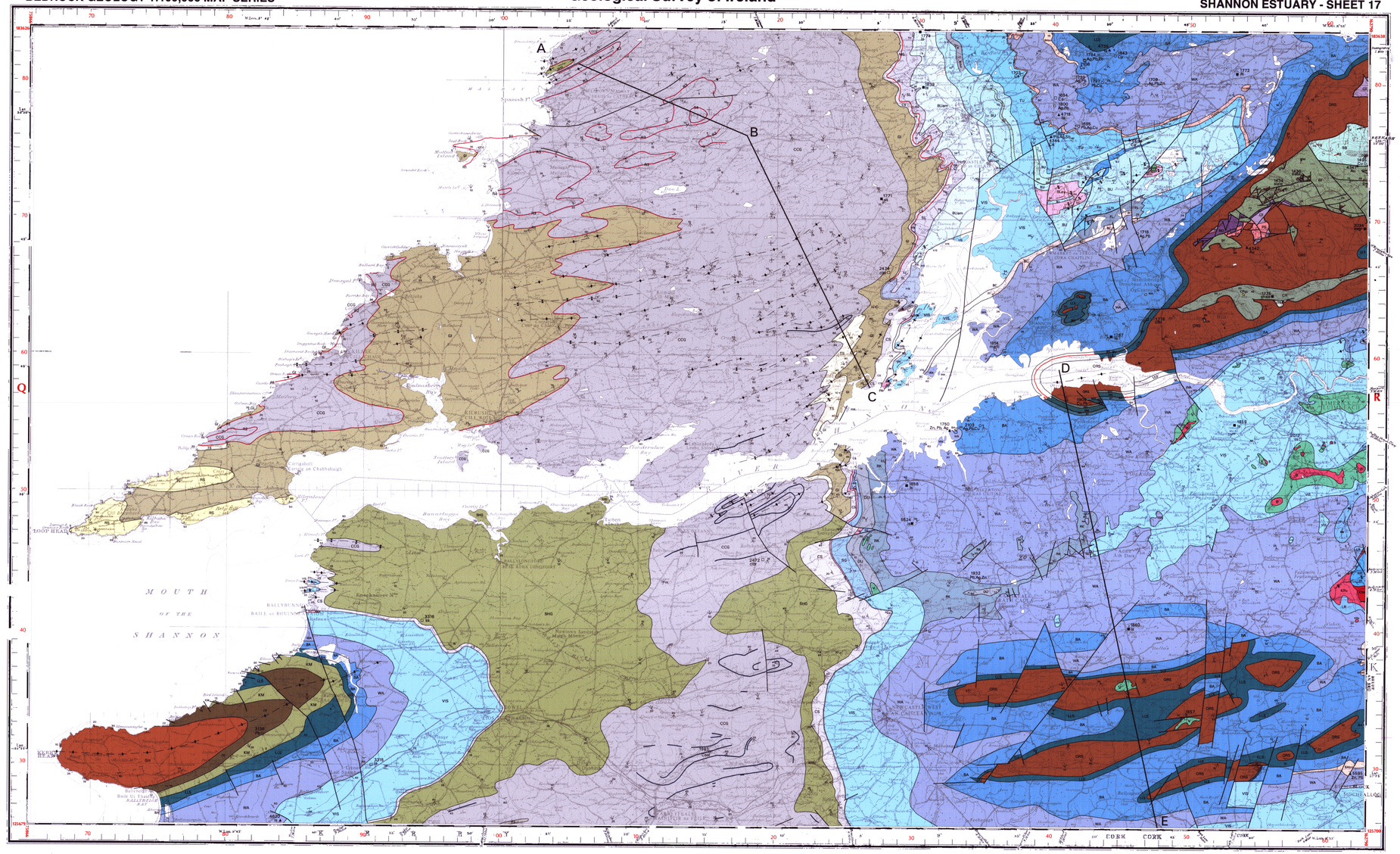
686 G.S.I. Mineral Localities Database number

COMPILED BY:

G. Stanley and K. Claringbold
Minerals Section, GSI

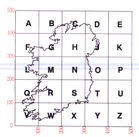
MINERALS

Ag	Silver	Sb	Antimony
Au	Gold	slate	Slate
b	Basalt	ss	Sandstone
Ca	Calcite		
clbr	Brick Clay		
Coal	Coal		
Cu	Copper		
ls	Limestone		
marb	Marble		
Pb	Lead		
sagr	Sand and gravel		



vertical exaggeration (x1)

vertical exaggeration (x1)



The National Grid

The grid is divided into lettered Sub-zones as shown by the diagram.
Emphasised grid lines define the Sub-Zone limit on the map. A grid reference consists of the appropriate Sub-Zone letter, the Easting Co-ordinate and the Northing Co-ordinate of the position, given in the sequence.

At the centre of this map Magnetic North is 8° 56' West of Grid North (1995)
Annual decrease 10.3'

At the mid-point of the Eastern edge of this Sheet True North is 0° 26' E of Grid North

At the mid-point of the Western edge of this Sheet True North is 1.27° E of Grid North

The topographic base used here is derived from the Ordnance Survey of Ireland 1:126,720 scale and is reproduced with their permission.

National Grid Sub-Zone values in kilometres are shown on the perimeter of the map.

The representation on this map of a road or footpath is not evidence of the existence of a right of way.

This map is purely representational and is designed for general information and strategic planning use only. Boundaries are interpolated on the basis of data available to the Survey at the time of publication. Many of these are sources, and local details have been generalised to fit the map scale. The accuracy of the data used, or interpolations made, is neither stated nor implied. Evaluation of specific sites will normally require further and more detailed assessments, and will frequently require site investigations.

Advice of any additional geological information known to the user will be welcomed by:

The Geological Survey of Ireland
Beggars Bush
Haddington Road
Dublin 4

Geology of the Shannon Estuary

Sheet 17

Scale 1:100,000

0 5 10
Kilometres

Geology compiled by A.G. Sleeman, M. Pracht and C.V. MacDermot

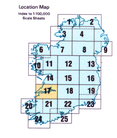
Digital data preparation in AutoCad® with the assistance of Information Technology section.

The map was produced digitally by the Cartography Unit in ARC/INFO® using Cartographics® software from T-Kartor AB.

Software customization by Paradigm Technology Ltd., Paradigm House, Dundrum, Dublin 14.

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Location Map
Index to 1:100,000 Rock Sheets



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