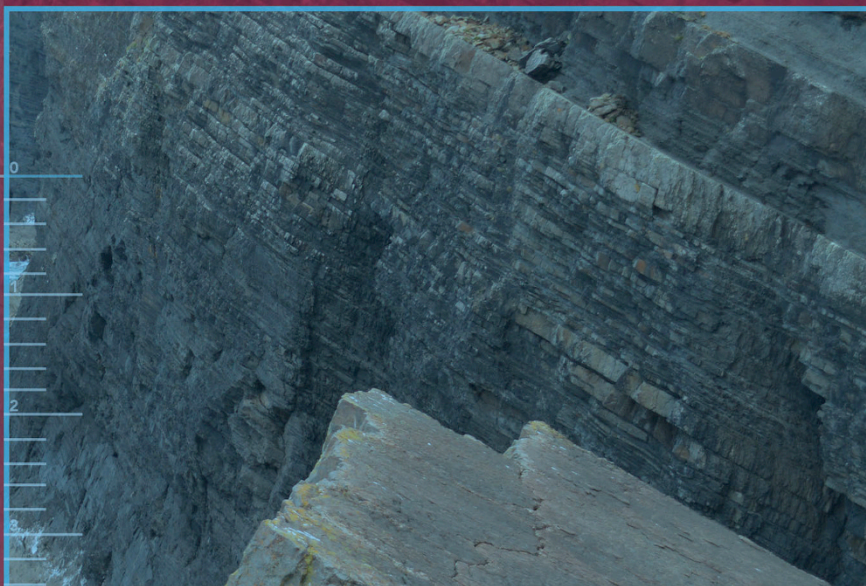




A **Field Guide**
to the **Carboniferous Sediments**
of the **Shannon Basin, Western Ireland**

International Association of Sedimentologists Field Guide



Edited by

James L. Best

Paul B. Wignall



WILEY Blackwell

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Carboniferous Sediments of the
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Finally, we would like to dedicate this field guide to the memory of Trevor Elliott, who sadly passed away on 28th January 2013. Trevor was an inspirational field geologist who fostered the interest of many geologists, including us, in the Shannon Basin. His seminal work on many parts of the basin fill, his mentoring of colleagues in the region and his leadership of many industrial trips to these rocks have left a permanent imprint on many of us who were lucky enough to know and meet Trevor. We, and his many friends in this area of Western Eire, will sorely miss the sight of Trevor striding across the cliff top paths in his brightly coloured field clothes and discussing the geology with him over a Guinness in the evenings. His kindness and inspiration will remain with us for many years to come.

Jim Best and Paul B. Wignall,
January 2016

About the Companion Website

This book is accompanied by a companion website:

www.wiley.com/go/best/shannonbasin

The website includes:

- All figures from the field guide in PowerPoint format for use in teaching.
- GigaPan Images from various sites that are referred to in the field guide.
- All outcrop locations, as both kmz files and text files (UTM Zone 29U and OSI Grid co-ordinates).
- Web addresses for the Ordnance Survey of Ireland and Geological Survey of Ireland.
- Details of accommodation and travel in the region.

Chapter 1

Introduction to the Field Guide

JIM BEST & PAUL B. WIGNALL

1.1 The Aim of this Field Guide

This field guide provides a detailed account of the Carboniferous geology of the Shannon Basin, principally in County Clare and County Kerry, Western Ireland. This region has become a classic destination for field groups from across the world in the past 25 years due to its stunning exposures of a wide range of Carboniferous depositional environments – from carbonate platform to deep sea turbidites, from black shales to delta slope and from shallow marine environments to fluvial channels – that can be viewed on a wide range of spatial scales up to those of interest within hydrocarbon reservoir modelling. The region has become a testing ground for concepts within basin analysis and sequence stratigraphy and has been used as a source of outcrop analogues for many hydrocarbon reservoir studies across the globe. This guide provides a summary of both past work and ongoing debate on the interpretation of these exceptional outcrops, through description of the principal localities and their major features. We hope the guide will be valuable to both professional and amateur geologists, as well as a broader audience who want to know more about the rocks that form this beautiful landscape. This guide thus provides both an account of the deep-time evolution of this region in the Carboniferous some 320 million years ago, as well as setting the stage for a landscape that has a fascinating history of human settlement over the past 6000 years (Jones, 2004, 2007). The guide assumes a basic knowledge of geology but also includes some terminology associated with specific areas and topics, such as palaeontology and sequence stratigraphy.

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Perhaps what strikes one most when walking over and examining the rocks described in this field guide is the incredible variety and wealth of superbly-preserved geological features present. These outcrops have provided the materials for a range of detailed research papers over a 60-year period and have led to this region being perhaps one of the most visited destinations by geological field parties in a global context; and for specialities that include sedimentology, palaeontology, structural geology, geophysics and reservoir geology. Yet, despite this extensive study, the Shannon Basin continues to reveal new features, to stimulate new interpretations and debate and there are many questions that remain to be answered about these sedimentary sequences. This field guide thus not only aims to provide details about many of the key localities, but also highlights areas of ongoing debate and discussion, in the hope that it will provide a synthesis and starting point for future study and teaching.

1.2 Background to the Area

The Carboniferous-age Shannon Basin encompasses an area within Western Ireland that includes the majority of County Clare and parts of County Kerry and County Limerick. The area lies along the Atlantic coast of Western Ireland (Fig. 1.2.1) and encompasses regions both to the north and south of the Shannon Estuary, a waterway whose trend has considerable geological importance as regards the formation and evolution of the Shannon Basin (Graham, Chapter 2). The topography of the area (Fig. 1.2.2) consists of higher terrain to the north in the limestone hills and karst terrain of the Burren and gently rolling hills of the Loop Head Peninsula that lies to the north of the Shannon Estuary, the mouth of Ireland's largest river. The Atlantic coast often possesses high and dramatic vertical cliffs that afford superb exposures within the Carboniferous sediments, but inland on the Loop Head Peninsula and in Counties Kerry and Limerick the exposures are far more limited. The area contains the world heritage area of the Burren in the north that comprises Lower Carboniferous limestones that also make up the Aran Islands (Fig. 1.2.1), and which exhibits superb geomorphology (Simms, 2006), natural history (D'Arcy & Hayward, 1991; Nelson, 2008) and archaeology (Jones, 2004, 2007). The region also contains the world famous Cliffs of Moher that display a section through part of the Carboniferous clastic basin fill, and the striking coastal scenery of the Loop Head Peninsula. The geology of the area allows access to a wide range of sediments that document the formation, fill and later deformation of the Carboniferous Shannon Basin, with many exposures being located along the western Irish Atlantic coast.



Fig. 1.2.1. Map of the region detailed in this field guide, with principal towns, roads and airports marked.

Tectonic deformation of the area occurred during the Variscan Orogeny, with compression from the south producing broadly west-east oriented fold structures, which decrease in their intensity further north. Thus, the limestones and sandstones of northern County Clare, that gently-dip at a few degrees to the south, are increasingly replaced by more intensely folded and faulted sediments further south on the Loop Head Peninsula and south of the Shannon Estuary, where pervasive pressure solution cleavage is also developed. Indeed, the degree of low-grade metamorphism also increases into the outcrops across the Shannon Estuary to the south.



Fig. 1.2.2. Topographic map of the region, derived from Shuttle Radar Topography Mission (SRTM) data (from <http://photojournal.jpl.nasa.gov/catalog?IDNumber=PIA06672>). Colour coding is directly related to topographic height, with green at the lower elevations, rising through yellow and tan, to white at the highest elevations.

1.3 Climate

The present-day climate in Western Ireland (Fig. 1.3.1) is mild, being dominated by the weather systems that track across the Atlantic and providing conditions that are seldom very cold but are often rainy. Weather conditions can range from large Atlantic storms that strike the coast and bring considerable rain, high seas and gale force winds, through to summer anticyclones that yield warm, dry periods. July is the warmest month (at Kilkee (Fig. 1.3.1), the average is 15.2°C (59.4°F) with January being the coldest (Kilkee average = 5.8°C or 42.4°F)). June and December are the

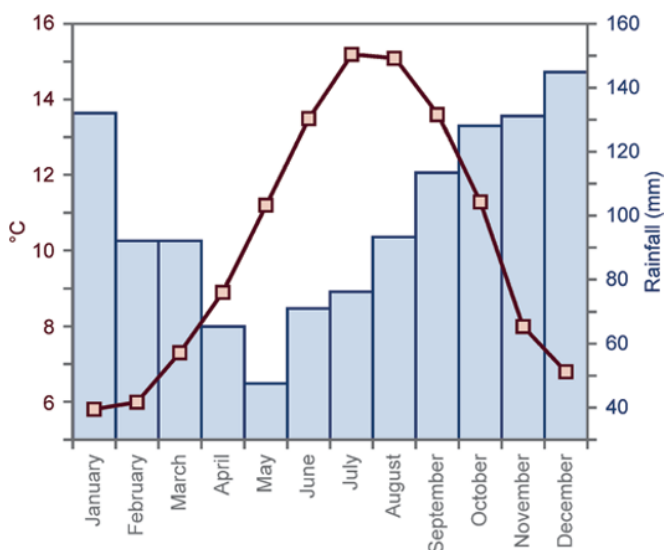


Fig. 1.3.1. Average monthly temperature and rainfall at Kilkee, County Clare (see location on Fig. 1.2.1).

driest and wettest months (at Kilkee, 71 and 154 mm rainfall, respectively). However, rainfall occurs in all months (Fig. 1.3.1) and thus it is always worthwhile packing waterproof clothes for fieldwork in the area, as well as sun-block and sunhats for the summer months. It is also worthy of note that at this latitude the winter days are short (*c.* 7.5 hrs between sunrise and sunset at the winter solstice) but you are rewarded by long days and light evenings in the summer (*c.* 17 hrs between sunrise and sunset at the summer solstice).

1.4 Accommodation, Travel and General Facilities

The field area can be reached easily by car or bus from Dublin (*c.* 4 hours by car) or visitors may also fly direct to either Shannon Airport, which is *c.* 1.5 hrs away from the town of Kilkee (Fig. 1.2.1), or Galway Airport that is *c.* 1.5 hrs away from Lahinch (Fig. 1.2.1). In-field transport along often small roads is easier by car or minibus. Larger coaches can negotiate the small roads that lead to the vast majority of the outcrops detailed herein, but it is essential to discuss the localities to be visited with the local coach operators. Most of the sites can be accessed easily and the local landowners are very gracious and obliging in allowing geologists to visit

these localities. However, it is recommended that visitors ask permission for access to any areas where it is obvious that you are walking across private land and fields.

Tourism is important to the local economy in most of the coastal areas to be visited and consequently accommodation in the area is easily available through a host of options. A range of hotels is available in the larger towns, with excellent bed-and-breakfast guest houses also to be found in towns, villages and in the countryside. In addition, several hostels are present in the area (such as in Kilfenora, Doolin and Lahinch in northern County Clare) and these can cater for student groups. Besides these options, houses, cottages and caravans can be rented at many localities within the field guide area and the local tourist offices of Counties Clare, Kerry and Limerick provide a ready source of excellent information. Some useful sources of contact are given in the linked online website.

1.5 Safety

The field area is generally safe and many of the localities can be visited by large groups, with the extensive exposures providing easy access. However, a series of hazards, some potentially fatal, are present and should be borne in mind when planning visits to these localities. Some of the localities detailed herein are also weather dependent (slippery rocks, high winds, tides) and thus the visitor should always, at each outcrop, conduct a careful safety assessment of local conditions and hazards before proceeding to access the localities described in this field guide. A list of the principal hazards is given below but additional factors and hazards may be present at individual sites.

High cliffs: Some of the coastal outcrops are adjacent to high cliffs that call for great care, especially if the rocks are slippery when wet, as they often are, and when there are high winds, which may be stronger near the cliff edges. All such localities must be approached with extreme care and cliff edges should not be approached due to potential undercutting and instability of any overhanging ledges.

Slippery rocks: One of the most frequent hazards in this region is slippery rocks, caused by either rain or sea-water. Slippery surfaces are often worse in intertidal areas where seaweed and water can make the outcrops truly treacherous. Extreme care should be taken in this regard, with the limestones also providing sharp surfaces on which cuts can be sustained easily during any falls.

Loose rocks: Some localities possess high outcrops and cliffs that have loose rocks overhead and thus, as always, the wearing of hardhats is essential at these localities.

Tides: The western coast of Ireland has large tides (at Kilkee, the tidal range is between c. 2 and 5 m), with the Shannon Estuary being macrotidal and having the largest tidal range on the western Irish coast. Care is thus required at some localities to avoid being cut-off by the tide, with some intertidal localities also being tidally-restricted and covered at high tides. Visitors to the area should thus consult the appropriate tide timetables. Outcrops that are tidally-restricted are highlighted in the text.

Small roads: Access to many of these localities is along small country roads that are frequently narrow, with room only for one-way traffic with occasional passing places. Visitors should be aware of the care needed in driving along such roads, the fact that the soft, grassy edges of the tracks may often be unstable or adjacent to ditches and that cars drive on the left in Ireland. Driving in this region, with the geology and geomorphology making for superb viewing, is enjoyable, but caution is required in negotiating some of these roads. Additionally, at some localities vehicle parking is very restricted and visitors should ensure that they do not block any access points or passing places.

Large waves: The Atlantic Ocean produces some enormous waves that bombard the Irish coast during storms. However, even on calm days between storms, large waves can and do impact the coast and thus great care should also be taken not to access exposures near the water's edge on days when rough seas may produce large waves. Again, care is called for in assessing the sea conditions on arrival at the outcrop and how these may change during the duration of the field visit.

Farm animals and electric fences: Visitors should be wary of farm animals when walking across any fields, taking care to close gates that have been opened and to not disturb these animals. Electric fences are in use in some cattle fields and visitors should be aware of these wires. As always, please leave the countryside untouched and do not leave any litter behind.

1.6 Map Coverage

The Ordnance Survey of Ireland (OSI) has produced a range of topographic maps that cover this region and the link to the OSI website is given in the online website supporting this field guide. The Discovery series of maps are at a 1:50 000 scale and provide an excellent resource for use in the field identifying site access and roads. A series of sheets must be used to encompass the region detailed in this field guide (Fig. 1.6.1), with sheets 51, 52, 57, 58, 63, 64 and 65 covering the main regions of coastal exposure. The OSI also sell an electronic version of this map series that can be downloaded and used on a variety of handheld GPS devices. Additionally, the OSI sell a range of other maps, including historic 25 inch to the mile

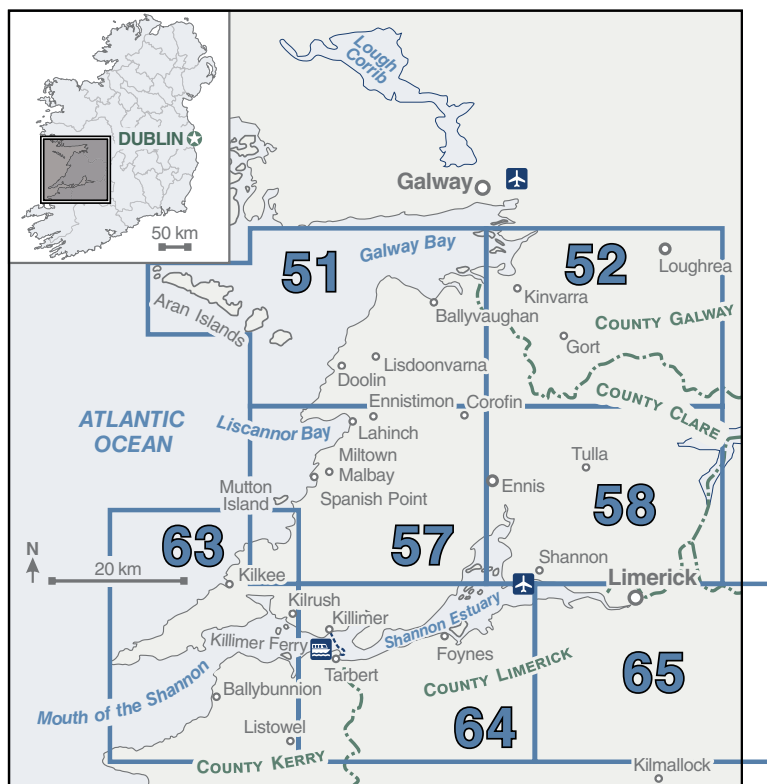


Fig. 1.6.1. Ordnance Survey of Ireland (OSI) 1:50000 map coverage of the area (maps 51, 52, 57, 58, 63, 64, 65).

(1:2534) maps that were produced between 1897 and 1913. Although old, the detail of these maps along the coast is superb and they are a very useful resource for mapping in the region. Google Earth images are also generally excellent for the region and can be well used for locating outcrops. A kmz file for all of the principal localities and stops referred to in this guide is available from the linked online website.

In this field guide, eastings and northings are given for all sites as UTM (Universal Transverse Mercator; Zone 29U) co-ordinates, with six-digit eastings and seven-digit northings. Additionally, in the text all locations are given in Irish Grid co-ordinates that will enable use of the 1:50000 maps; these grid references are given as map number and then a six figure easting and northing. The second and third numbers in these Irish Grid co-ordinates are those given as larger numbers on the 1:50 000 maps: thus a grid reference of Map 63, 087516m E, 160225m N should be read as

087516m E, 160225m N on the maps. For instance, the hostel at Kilfenora is at UTM 29U 485278m E, 5871180m N and its 1:50 000 map reference is Map 51 118167m E, 193910 m N. On the printed 1:50 000 map, readers may wish to simplify this to a six figure grid reference (i.e. for the above location Map 51 181 m E, 939 m N), but the full six figure eastings and northings are given for those using these Irish grid references with a GPS. Conversions to latitude/longitude, the Irish Grid (IG) and ITM Irish Transverse Mercator (ITM) are available using a free application on the OSI website (see resources link in the online website for this guide book; IG and ITM are used on OSI maps).

Geological maps of the region are published by the Geological Survey of Ireland (GSI) and an excellent source of information on their publications is given on the GSI website (see links in Resources in the online website for this guide book). Of most relevance to this field guide, a series of 1:100 000 bedrock geology maps with accompanying booklets have been produced by the OSI that discuss the geology of the Shannon Estuary region (Sleeman & Pracht, 1999), Galway Bay (Pracht *et al.*, 2004) and Dingle Bay (Pracht, 1996). In addition, several very useful books have been written that present broad treatments of the geology of Ireland and some of the localities in this region, including the general textbook by Woodcock & Strachan (2012), the general guide to the geology of the Burren by McNamara & Hennessy (2010), a geomorphological guide to the Burren (Simms, 2006) and recent books specifically concerning the geology of Ireland by Holland & Sanders (2009) and Meere *et al.* (2013).

1.7 Geological Map of the Region and Stratigraphy

The geology of the Shannon region broadly consists of nearly 3km of Carboniferous strata that has been folded into a broad syncline that plunges to the west. The youngest strata are found around Spanish Point in the centre of the County Clare coastline (Fig. 1.7.1). Progressively older strata surround this area with the result that Lower Carboniferous limestones are seen both in the northern-most County Clare outcrops of the Burren region, to the east around Ennis, the county town, and to the south on the County Kerry coast at Ballybunnion. However, as noted above, there is progressively more intense Variscan deformation in the southern area; and the southern limb of the synclinal structure consists of secondary folds with wavelengths of hundreds of metres to a few kilometres, whereas the northern limb simply shows a dip of a few degrees to the south. For the most part, these secondary folds are symmetrical.

The oldest rocks in the region belong to the Tournaisian Series of the Early Carboniferous (Mississippian) and consist of fossiliferous, shallow-water

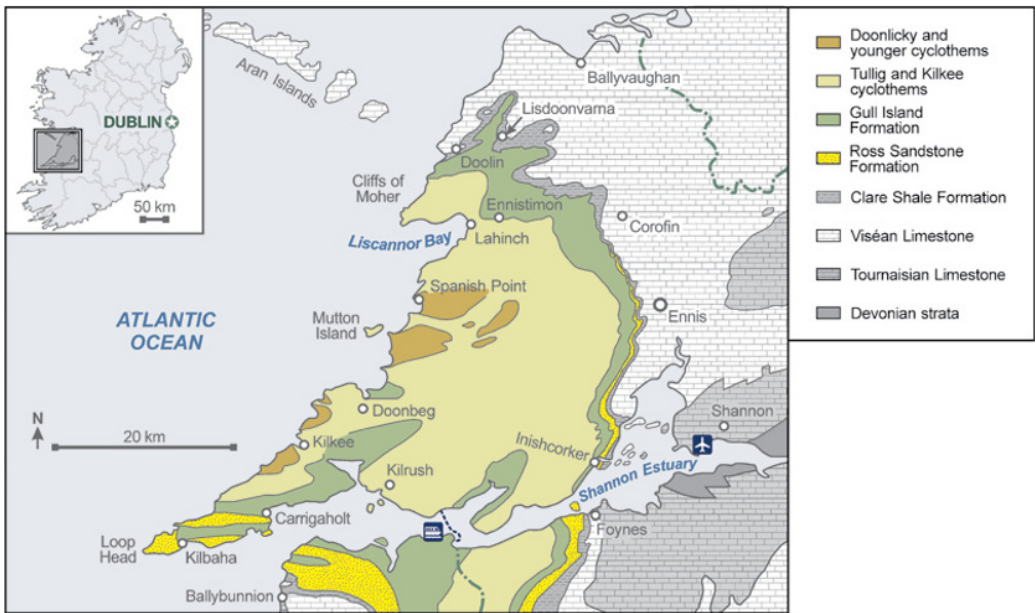


Fig. 1.7.1. Simplified summary geological map of the Shannon Estuary region of western Ireland, based on Sleeman & Pracht (1999), Pracht *et al.* (2004), Gill (1979) and the authors' own data.

limestones and minor shales (Fig. 1.7.2). Outcrops are limited to the banks of the inner Shannon Estuary and are described in Chapter 4. These are succeeded by the Waulsortian Limestones that comprise massive, coalesced mounds of micrite with a large cement component. This enigmatic facies, which was widespread during the middle Dinantian interval, is especially well developed in the Shannon Estuary region from where the thickest developments (~1 km) anywhere in the world are known. The overlying limestones show significant regional variation. In northern County Clare, the thick-bedded limestones contain abundant brachiopods, crinoids and corals, whereas the more southerly correlatives in the Shannon Estuary region are dominated by less fossiliferous, thinner-bedded, more shaly and cherty limestones. Regional thickness trends in these Viséan limestones show the northern County Clare limestones to be slightly thicker than those in the southern area (Fig. 1.7.3) – a thickness trend that is dramatically reversed in the overlying Carboniferous strata.

The transition from the Viséan to Namurian Series (alternatively called the Dinantian-Serpukhovian transition) saw the shutdown of limestone deposition in the Shannon region (and elsewhere, the loss of limestones was a widespread and near-contemporaneous event over a broad area of north-west Europe). This was followed by the deposition of the black shales of the Clare Shale Formation in the Shannon area followed by turbiditic sandstones of the Ross Sandstone Formation and then siltstones of the Gull Island Formation (Fig. 1.7.2). These strata belong to the nearly 1 km thick Shannon Group. Further north in County Clare, the Shannon Group is much thinner (<150 m) and only began to accumulate after a prolonged hiatus of nearly 10 Myr that spanned the entire Serpukhovian Stage. The overlying Central Clare Group consists of thick coarsening-upward packages, known as cyclothems. The lowest two examples, the Tullig and Kilkee cyclothems, outcrop over much of the length of the County Clare coastline and exhibit much less lateral thickness variation, although the major sandbodies that developed within the upper parts of the cyclothems (e.g. the Tullig Sandstone) do show major lateral changes (Fig. 1.7.3). The youngest cyclothems, numbered IV and V, are only seen around Spanish Point in the centre of the regional syncline and so their lateral variation is unknown.

1.8 Organisation of this Field Guide, Areas Covered and Suggested Itineraries

This field guide is broadly arranged in stratigraphic order. The guide commences with a broad analysis of the structural setting and evolution of the Shannon Basin (Chapter 2) and then a chapter summarizing the various

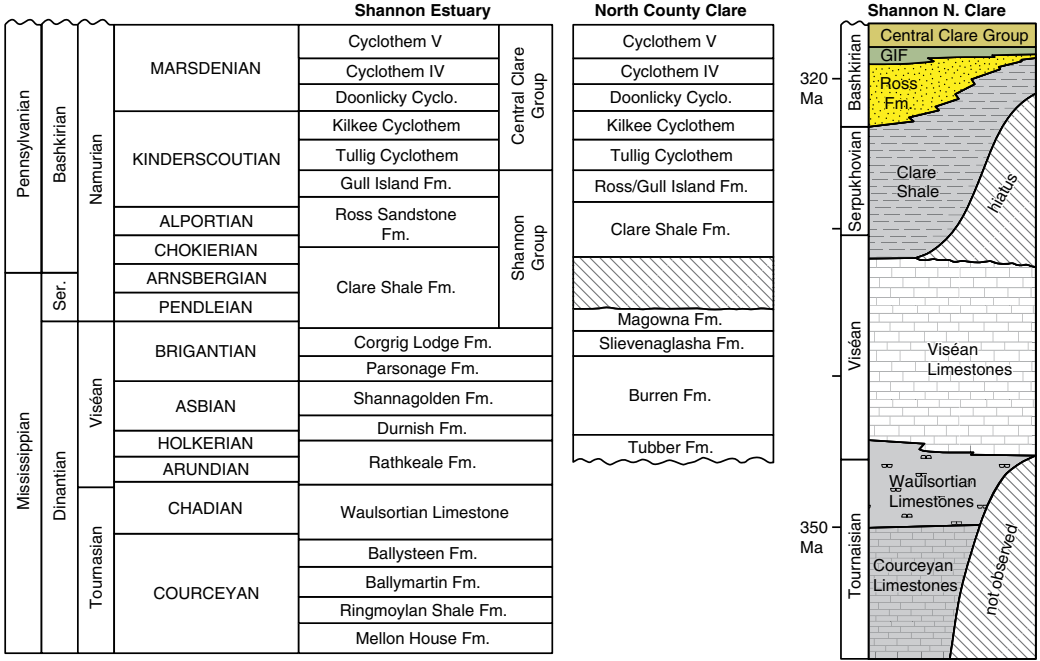


Fig. 1.7.2. Summary of the Carboniferous lithostratigraphy in the Shannon Estuary and northern County Clare regions. The right-hand column shows a chronostratigraphic correlation between the southern Shannon sections and those in northern County Clare, showing the substantial hiatus developed between the Viséan limestones and Clare Shale. Ser. is Serpukhovian.

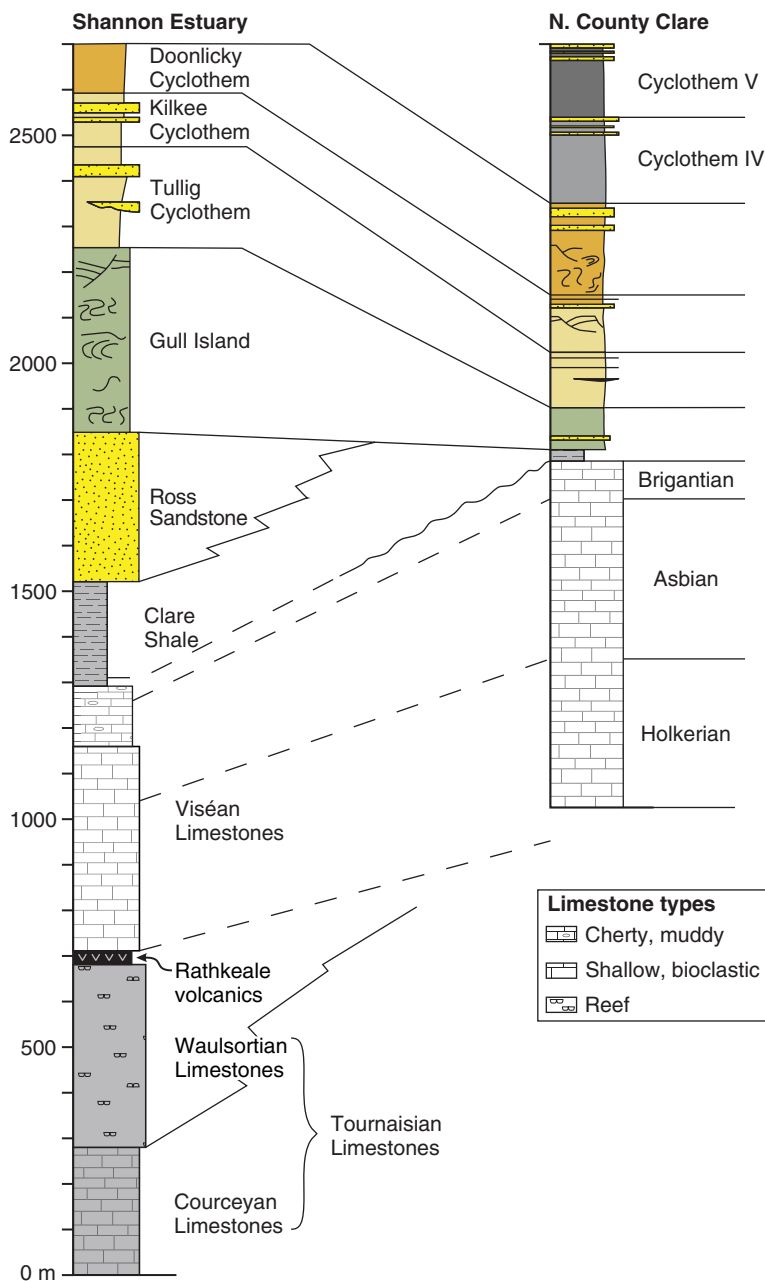


Fig. 1.7.3. Correlation of summary lithostratigraphic columns from the Shannon Estuary region and northern County Clare sections ~50 km to the north. This diagram shows the substantial lateral thickness variations at the level of the Clare Shale, Ross Sandstone and Gull Island formations and much less lateral variation at other levels.

models of sedimentary fill that have been proposed for the Shannon Basin (Chapter 3). The intention of these two chapters is to set the scene for readers, as they use the field guide to examine the stratigraphy and sedimentology described in the following chapters. After these two review chapters, the sediments are subsequently detailed in eight chapters that progressively work up-stratigraphy. Each chapter presents details on a range of localities, with a summary of these locations being shown in Fig. 1.8.1. It is worthwhile to examine this map when planning an itinerary to the region, as some parts of the stratigraphy detailed in separate chapters may lie close to each other geographically in the field. Fig. 1.8.1 shows the

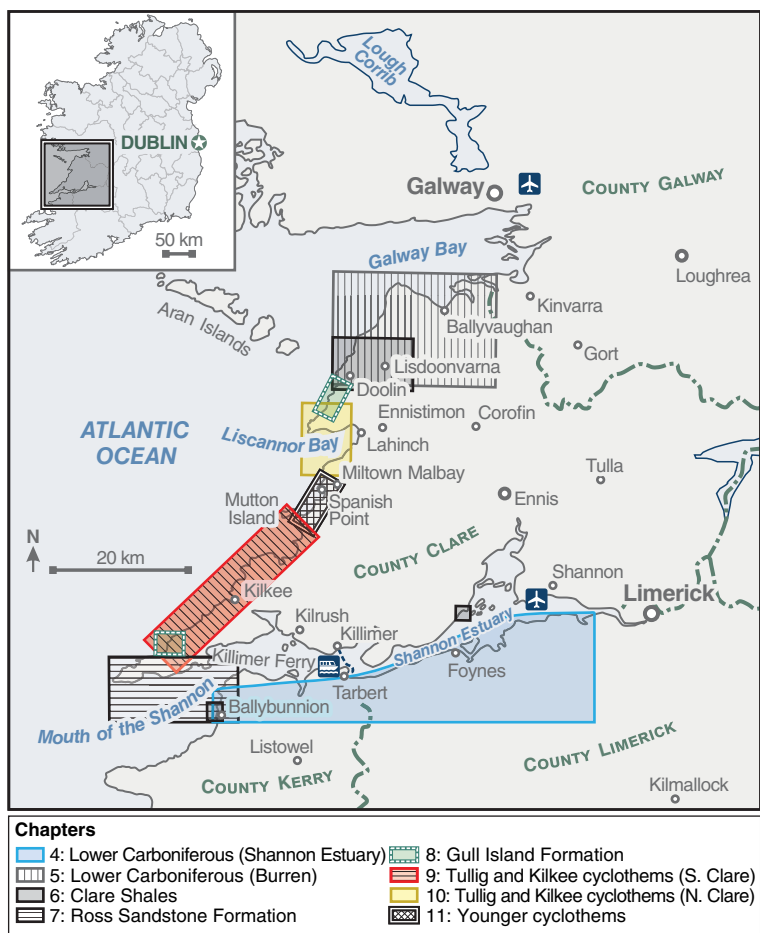


Fig. 1.8.1. Overview map of the field localities detailed in this field guide.

regions of occurrence of the localities detailed in each chapter and allows easy visual recognition of the overlap of the differing localities detailed herein.

In addition to the figures printed in the hard copy of the field guide, there are a range of online resources available on the linked field guide website (www.wiley.com/go/best/shannonbasin). These include:

- 1** Google Earth kmz, Excel and text files of all outcrop locations (in UTM and Irish Grid co-ordinates), subdivided according to Chapter. These allow easy location of all the field stops detailed herein, as well as some key access points to certain localities.
- 2** High-resolution copies of all figures in the guidebook as PowerPoint slides. These will allow users to utilise these diagrams in their own work in the field, in teaching applications and also allow closer inspection of detail.
- 3** High-resolution jpeg GigaPan photo-montages for several key localities that can be viewed to better examine the detail within these outcrops. A listing of these GigaPan images, with cross-referencing to the appropriate chapters, is also given in Appendix 1.
- 4** A list of addresses for useful websites, including the Ordnance Survey of Ireland, Geological Survey of Ireland and various useful field contacts.

Chapter 2

The Shannon Basin: Structural Setting and Evolution

JOHN GRAHAM

2.1 Introduction

During the mid-Carboniferous, around 330 million years ago, the area around the modern Shannon Estuary of western Ireland provided significant accommodation for sediments that are now visible in spectacular coastal exposures. This depositional basin has been referred to as the Shannon Trough, the Shannon Basin, the Clare Basin and the Western Irish Namurian Basin. Despite the considerable interest in, and study of, the coastal exposures, the geographical limits of this basin are very poorly constrained. To the west, the margins are under the Atlantic and geophysical data on their location is equivocal. To the south and the south-east, information is present but it has not been interrogated in detail, partly due to limited exposure of the basin fill. Whilst this does not affect many of the detailed studies that have occurred, it does severely limit those that attempt to make larger scale reconstructions.

In gross terms, the succession represents progressive deepening through a lower carbonate portion, a middle part dominated by deep water muds and then progressive shallowing through turbiditic sands and muddy slope sediments to deltas that have been proposed to bear close comparison to the modern Mississippi system. The history contained in these rocks is, of course, more complex and more informative than this as the subsequent chapters will demonstrate. Since the pioneering work of Dan Gill in the 1950s and 1960s, these rocks have provided useful analogues for petroleum geologists and, as such, that they have become some of the most visited sections in the world. The succeeding chapters discuss many aspects of this succession as well as guiding the reader to where the evidence can be seen.

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