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SEDIMENTOLOGY AND STRATIGRAPHY OF THE CARBONIFEROUS DONEGAL BASIN

A thesis presented for the degree of Doctor of Philosophy in the Department of Geology, University of Dublin, Ireland

By

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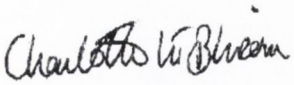

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ABSTRACT

The Dinantian onshore Donegal Basin is situated at the northerly exposed margin of the Northwest Carboniferous Basin of Ireland. Subsidence patterns in the Northwest basin were strongly controlled by an existing template of major NE/SW trending Caledonian faults. The Donegal Basin exposes a sequence of rocks, which were deposited in a range of environments. These comprise fluvial, tidally influenced, marginal marine and shelf to open marine areas. As this area lay close to or on the palaeo-shoreline during Viséan, it is an ideal place to study relative changes in base level.

This study has outlined the Donegal succession which indicates an overall transgressive sequence from Tournaisian to Arundian (and possibly Holkerian) times. During the Arundian, a regional regression affected large areas of northern Ireland, which is also recognised in south Donegal. It has been demonstrated within this work that the events causing these changes can be temporally constrained using information gained from field mapping and foraminiferal biostratigraphy.

Within this general scheme (of a widespread transgression in the Lower Viséan, followed by a regression), shorter-lived relative sea level changes can also be elucidated. These are characterised by calcareous, relatively muddy intercalations with distinctive brackish or open marine fauna which transgress northwards over fluvial dominated clastics. These lateral facies changes are the result of the depositional area's proximity to the shoreline.

The role of tectonism within the Donegal Basin has also been outlined. Two sequences can be recognised as having formed due to syn-sedimentary activity. These units are relatively local and cannot be matched elsewhere within the basin.

The relationships outlined above have been elucidated through detailed mapping, section logging and facies recognition and their inferred depositional environments.

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A special thanks to my parents and my family and Gavin's parents for their continual support during the course of this study. To my friends and colleagues, past and present: Caitlin, Fiona, Sonja, Kay, Mags, Corrado, Jeff, Louise, Niall, Judith, Mark, John, Johan, Malachy, Davida, Michael.

Lastly, the fact that this thesis has finally seen the light of day is due to Gavin ! Thanks for your limitless support and friendship.

EXPLANATION TO TEXT

Member or formational names from previous publications are depicted in smaller font size, to avoid confusion with the terminology used in this study.
e.g. 'Bruckless Grits'

The term Fig. is used in smaller font size where a diagram or plate from a previous publication is referred to, to avoid confusion with the term Figures used in this study.
e.g. (Graham 1996, Fig.8)

A smaller font size is used where a page number or text from another publication is referred to,
e.g. 'a single unit, which was deposited coevally at all three localities'

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CHAPTER 1 INTRODUCTION

1.1 PREFACE

During the Dinantian, the southern part of Donegal lay close to or formed the coastal zone. This area delineates the northern extent of the Viséan marine transgression, which had covered most of central and southern Ireland. The coastal proximity allows for easier detection of changes in base level, depicted as transgressive and regressive events. The shoreline position reflects the balance between influxes of terrigenous material (sediment supply) and accommodation space. Eustatic sea level variation and tectonic activity affect both of these parameters.

The succession in southern Donegal is represented by an initial fluvial-dominated regime, followed by minor marine incursions which are subsequently followed by the more widespread transgressive event within the Lower Viséan, and finally into a regression at the top of the preserved succession. These events are generally recognised over the entire Carboniferous Northwest Basin of Ireland. However, the succession within the Donegal Basin does differ somewhat, due to it proximity to the shoreline. Although there have been previous studies of the Carboniferous Donegal Basin, there has been a lack of uniformity in assessment of lateral facies changes and detailed correlation.

1.2 OBJECTIVES OF THE STUDY

This study has attempted to clarify the basinal evolution of the Carboniferous Donegal Basin by erecting a logical series of events, while incorporating facets from previous stratigraphic work. A more detailed facies analysis has been completed. This clarification of the basin evolution was achieved by detailed field mapping, facies analysis and biostratigraphical work.

1.3 GEOLOGICAL SETTING OF THE DONEGAL BASIN

The general stratigraphy of the Donegal Basin (Figures 1 and 2) is most appropriately discussed by initial reference to the Northwest Carboniferous Basin of Ireland (Millar

1990, Baily 1992). The Northwest Basin comprises a series of sub-basins (Donegal Basin – discussed in this study, Sligo Syncline, Omagh Syncline, Lough Allen Basin, Ballymote Syncline, Carrick-on-Shannon Syncline and Slieve Beagh Syncline), situated at the northwestern extremity of the Irish Carboniferous region (Figure 3). A total Dinantian-Namurian succession in excess of 2.5 km (post-compaction value) has accumulated within the NW Basin. It is delineated to the north by the Moinian and Dalradian metamorphics, and Caledonian granitoid plutons of Donegal and to the south by the Ordovician-Silurian slates, greywackes and volcanic rocks of the Longford-Down Massif (Higgs 1984). The region is structurally compartmentalised by long, anastomosing, northeast-southwest trending faults (Figure 4). Many of these appear to have been generated during Caledonian times or earlier. However, these have also been reactivated in response to the evolving post-Devonian stress fields. The faults manifest in the cover rocks as reactivated strike-slip faults, and control the siting and distribution of the sub-basins (Millar 1990). These sub-basins or "synclines" (with axial trends parallel to the faults), are not just a function of later fragmentation by fault reactivation as each contains its own slightly different stratigraphical succession. This appears to be at least in part, due to syn-sedimentary tectonism rather than just gross lateral facies changes.

As discussed later in Section 4.1, five small outliers of Carboniferous rocks (Shalwy Syncline, Roelough, Muckros Head and two smaller residual patches on Slieve League) are situated to the west of the main Donegal outcrop (Figure 1). The main outcrop will be referred in the text as the 'main Donegal Basin'.

The main Donegal Basin (approximately 200 km^2 in size) comprises an estimated 1400 metres of clastic and carbonate rocks, spanning in age from Tournaisian (Edergole Formation) to Arundian or Holkerian (Mullaghmore Sandstone Formation) times. It extends from Bruckless and McSwyne's Bay in the west to Lough Eske in the east (Figures 1 and 2). Both the western and the eastern margins of the basin display unconformable boundaries with the underlying Dalradian rocks. However, many northeast/southwest faults splice through this boundary, resulting in side-stepping of the margins. The Carboniferous rocks dip from both margins towards the core of the syncline at Mountcharles, on an axis trending from the Edergole and Lough Eske area towards Doorin Point.

The foothills of Binbane Mountain and the Blue Stack Mountains delineate the topographical northern boundary, resulting from the unexposed Northern Boundary Fault. This fault forms a curved configuration around the northern part of the basin. The southeastern boundary of the basin merges with the Sligo Syncline towards the Ballintra area. The southern limit of this study is the NE/SW trending Donegal Fault, which runs parallel with the Eske River from south of Lough Eske towards Donegal Town.

Banagher Hill at 322 m (in the east) and Killin Hill at 244 m (towards the west of the basin), form the topographical highs within the Donegal Basin. The prominence of the northeast/southwest structural grain is inherent in the Quaternary cover. This is especially noted in the northeast/southwest trending ridges along the Doorin Peninsula and inland northwest of Mountcharles village. In general, exposure is generally limited to the coast, with the exception of some good isolated inland quarry, field and river sections.

1.4 PREVIOUS RESEARCH ON THE DONEGAL BASIN

The groundwork for the stratigraphy and the structural geology of the Donegal Basin was initiated by Griffith in the Geological Map of Ireland (1837). He presented the 'subdivisions of the Carboniferous formation of Ireland' in 1855, which included a review of the Donegal area. The fossils of the Donegal area were described by McCoy (1844), Brongniart (1857), Haughton (1860), Scott (1856, 1864) and Harte (1865). The Geological Survey of Ireland pursued a more detailed examination of the area (one-inch to one-mile sheets 22, 23, 24, 30, 31 and 32). This work was conducted by Egan, Kilroe & Mitchell (1888), Symes (1891), Hull, Kilroe & Mitchell (1891) and accompanied by explanatory memoirs.

George (1953) outlined the stratigraphy of the Dinantian succession in northwest Ireland. George and Oswald presented a more extensive study on the Donegal Basin in 1957. With the help of maps and field notes provided by L.B. Smyth, they presented a firm geological overview on which later work was based, including this present study. They subdivided the Donegal Succession into units, which, with some modification, are easily recognisable in the field. However, their nomenclature does not conform to

modern usage (Holland *et al.* 1978, Whittaker *et al.* 1991). George (1958) included his work on the Lower Carboniferous rocks of Donegal in his discussion of the Lower Carboniferous palaeogeography of the British Isles. George *et al.* (1976) discussed a correlation of Dinantian rocks within the British Isles. This included a regional description of the northern region of Ireland, with a brief discussion on the individual stages and biostratigraphical dating of the Donegal 'syncline'. Sevastopulo (1981) and Sevastopulo and Wyse Jackson (in press) reviewed the Dinantian rocks of the Donegal Basin in their stratigraphical framework and regional settings of the Lower Carboniferous of Ireland.

Leedal and Walker (1954) reported on tear faults in the northeastern part of the Donegal Basin. Pitcher *et al.* (1964) in their discussion on the Leannan Fault, proposed that the main movement occurred during the deposition of the Lower Carboniferous rocks in Donegal, although subsequent movements took place after deposition. This conclusion is reached by reference to the structural and sedimentary evidence within the basin.

Hubbard (1966) studied the 'Ballyshannon Limestone' and the basal beds of the Carboniferous of northwest Ireland with reference to depositional conditions. She utilized the stratigraphy outlined by George and Oswald (1957). A population study of the corals (Hubbard 1966) within the Northwest Basin, included work on the 'Rinn Point Beds' within the Shalwy Syncline. Hubbard (1970) published work on the sedimentological factors affecting Viséan caninioid coral distribution and growth. Coastal sections along Donegal Bay (including Muckros Head, Shalwy and Kiln Point) were examined. Hubbard and Pocock (1972) examined sediment rejection by recent scleractinian corals. They applied the model to ancient environments and cited the corals within the 'Rinn Point Beds' at Shalwy as an example.

Sheridan (1972) studied the Donegal Basin as part of his compilation work on the 'Upper Old Red Sandstone and Lower Carboniferous of the Slieve Beagh Syncline and its setting in the Northwest Carboniferous Basin'. He contributed to the stratigraphy and palaeontology of the Donegal Basin succession, mainly through foraminiferal work. He divided the sequence into a number of large intervals, some of them overlapping, based on the Geological Survey's original subdivisions and presented the results in a series of facies and isopach maps.

Several other doctorate theses have concentrated on various aspects of the Carboniferous rocks of Donegal. Al-Rawi (1972), Nevin (1973) and Avbovbo (1973) worked on the stratigraphy and sedimentation of the 'Basal Clastics' of the area. Al Rawi (1972) proposed a new stratigraphical nomenclature for the Donegal Basin, differing from George and Oswald's nomenclature (1957). He outlined a detailed stratigraphic analysis for the western part of the basin (refer to Figure 6). Chandra (1974) and Buckman (1992) studied the ichnology of the Viséan sandstones in the Northwest Basin, with reference to the Donegal Basin. Chandra (1974) also interpreted the pattern of sedimentation and outlined different depositional environments for the eleven facies, which he proposed for the Northwest Basin. Buckman (1992) reviewed the stratigraphic nomenclature of the Northwest Basin and proposed member status to the units at Shalwy, assigning them to the Ballyshannon Limestone Formation.

The Geological Survey of Ireland conducted a review of the 'Geology of the Petroleum Prospecting Licence 2/80' in 1983. The Donegal Basin was part of this research, which concentrated on the regional geology, Carboniferous stratigraphy and the structure of the Northwest Basin (refer to Higgs and Sevastopulo 1983, MacDermot *et al.* 1983). Philcox (1983 Unpublished report) reported on the Lower Carboniferous succession from the Penarroya Borehole DN-69-17 drilled near southeast of Lough Eske. Philcox (1986) reviewed the 'Carboniferous Stratigraphy of N.W. Ireland' based on previous work and his own work on the lithostratigraphy.

Millar (1990) examined parts of the Donegal Basin in his study on fracturing in the Northwest Carboniferous Basin. Mesofracture analysis on rocks along the Doorin Peninsula and St. John's Peninsula contributed to a tectonic sequence for the Northwest Basin, which he interpreted as spanning from the Dinantian to the Tertiary.

Higgs (1984) contributed to the stratigraphic palynology of the Northwest Basin. Miospore assemblages were recovered from various areas, including samples from the Donegal Basin. Graham & Clayton (1994) published work on the Edergole Formation (a fault-controlled conglomeratic sequence which is exposed in streams in the northeast of the study area).

Nichols and Jones (1992) reported on the fusain deposits within shallow marine rocks in the Shalwy Syncline. They discussed the sedimentological effects of a palaeowildfire in a land area to the northwest of Donegal. Scott and Jones (1994) summarised the nature and influence of fire in the Carboniferous ecosystems, citing the previous authors' work on the fusain unit in Shalwy. Jones (1994) investigated the carbon isotope constraints on taphonomy, diagenesis and palaeoenvironment on ^{13}C enriched fossil plants from the succession at Muckros Head.

Graham (1996) studied the Shalwy Basin in his work on 'Dinantian river systems and coastal zone sedimentation in northwest Ireland'. Depositional environments were deduced from the various fluvial and coastal marine facies. The nature of the fluvial systems and the main controls on sedimentation were also discussed. He also commented on the size of the drainage basin operational in the Donegal area during the Dinantian as proposed by Nichols and Jones (1992). This present study on the Donegal Basin was initiated by Graham's work on the Shalwy area.

1.5 LAYOUT OF THE THESIS

This thesis has focussed on the Donegal Basin, which is situated in the southern part of County Donegal and is the most northwesterly of the sub-basins within the NW Basin of Ireland (refer to Figure 3). The stratigraphy of the Donegal Basin is confined to Tournaisian/Arundian or possibly Holkerian rocks. The general distribution of rock units is shown in Figure 2.

Chapter 2 presents a generalised stratigraphical succession of the NW Basin, and incorporates the Donegal succession within this Dinantian framework. Chapter 3 outlines the various facies that have been recognised within the Donegal succession. Where possible, depositional environments are interpreted for the rock units based on the evidence collected during the study. Chapter 4 comprises a detailed description of the western succession within the main outcrop of the Donegal Basin and in the smaller outliers to the west. Chapter 5 discusses the eastern succession (in the Donegal Town to Lough Eske area). The Bundoran Shale Formation and its associating clastic members are discussed in Chapter 6 and the youngest preserved strata, the Mullaghmore Sandstone Formation is described in Chapter 7. Chapter 8 examines the

biostratigraphical information and a correlation across the basin is presented, while Chapter 9 gives a structural outline of the area. Chapter 10 discusses the overall basinal development of the Donegal Basin.

1.6 METHODS

1.6.1 PRODUCTION OF A GEOLOGICAL MAP

Aerial photos were initially examined in the Geological Survey of Ireland to determine the structural grain and to delineate the main faults. However, the Quaternary cover, especially towards the core of the Donegal Basin (Inver area) obscures many of the trends. Extensive field mapping of the clastic and carbonate rocks within the Donegal Basin was carried out, using 6 inch to one mile field sheets. Many original aspects from the map by George and Oswald (1957) are retained, including the main lithologic boundaries along the more exposed areas. However, following greater examination of the less exposed inland rocks in this study, a more refined stratigraphical and structural compilation map has been completed. Since the study area comprises 200 km^2, it was not feasible to examine all areas in great detail. Thus, an initial survey was carried out to determine the key areas of interest.

These main areas of interest were:

- the McSwyne's Bay area to St. John's Point and inland from Bruckless to Croagh Lough (Oily River Conglomerate Formation to St. John's Point Sandy Limestone Formation),
- the Lough Eske area (Lough Eske Sandstone Formation to Banagher Sandstone Formation),
- the Doorin Peninsula (Bundoran Shale Formation and Ramp Hole sandstone Member)
- the quarries at Mountcharles (Mullaghmore Sandstone Formation).

1.6.2 DETAILED FIELD RECORDING

Logging of key areas (generally confined to coastal exposures) to examine the main facies characteristics within the various formations, allowed firmer construction of the various depositional environments. Logs were drawn to scale on graph paper and

transferred to a CorelDraw drawing package. Palaeocurrents are shown on these logs and summary rose diagrams were produced of the main clastic formations.

1.6.3 SAMPLING STRATEGY

Approximately 300 hand samples were collected during fieldwork, with 230 of these being utilized for thin-sectioning, conodont processing and palynological processing. During the first fieldwork season, the sampling was not intensive as more emphasis was put on facies analysis and recognition of the key units within the Donegal Basin. During the second fieldwork season, two key areas of the Rinn Point Limestone Formation (Shalwy Syncline and the St. John's Peninsula) were intensively sampled and thin-sectioned, in order to examine the biostratigraphy of this unit. Key areas associated with the Bundoran Shale Formation were sampled during the third field season (including the Doorin Peninsula, the Donegal Town area and inland from Inver to Banagher Hill).

1.6.4 BIOSTRATIGRAPHICAL TOOLS

1.6.4.1 THIN-SECTIONS

During the course of the study, 191 thin-sections were made by the author in the Geology Department laboratory for microfacies and biostratigraphical examination (refer to Appendix 1). The yellow, blue and green colour coding refers to thin-sections, conodont sampling and the hand samples, respectively, which still exist from the study. The majority of these samples were from the limestone units of the Rinn Point Limestone Formation and St. John's Point Sandy Limestone Formation.

The samples were cut to size (the normal is 2-3 mm thick to fit a 3x1 inch slide) and lapped on 600 grit silicon carbide until flat, using Logitech LP40 autolap machine. The carbonate sections were half-stained. Plaquettes were then mounted onto pre-ground glass (normally to 1200 microns thick) using Araldite 2019 -2 part epoxy resin. Heat and pressure were applied to achieve a good bond and the mounted specimen was then trimmed using a logitech CS10 saw, leaving a circa 100 microns rock specimen on the glass surface. The Lp40 and Vacuum jigs were set to render the specimen to desired height (the norm is 30 microns or 35-40 microns if polish is required). The thin-

sections in this study were all polished. Buehler Petropol and Aluminium Oxide (alumina-1micron particle size) were used to achieve a good polish.

1.6.4.2 CONODONT EXTRACTION

Twenty-one limestone samples were processed by the author for conodont extraction (Appendix 2). Refer to Austin (1987) and Geraghty (1996) for a more detailed discussion on conodonts. Below is a summary of this processing method, which is the common procedure within the Department of Geology, University of Dublin.

Limestone samples of greater than a kilo were taken from site. The samples were weighed, placed in a clean polythene bucket, and supported by a plastic sieve half-way up the bucket. This allowed the conodonts to fall freely from the sample to the bottom of the bucket and helped prevent mechanical damage and also increased circulation. The bucket was appropriately labelled. Three pints of calcium formate (the buffer) and nine pints of water were added to every sample. Formic acid was used (85%) concentration) at a ratio of one pint to one kilogram. No more than 1.75 pints of acid was ever used (regardless of the sample weight), as this made the solution too acidic and would result in etching of the conodonts. The buckets were placed in a fume cupboard for variable lengths of time, depending on the time taken to breakdown the rock. Large samples and samples with a high percentage of clay material took longer for the acid to act. In general, the buckets were sieved every two days.

The contents of the bucket (minus the undissolved block, if present) were washed through sieves (125 μm, 250 μm and 500 μm) until no more clay washed through. Undigested rock material was placed back in the bucket along with the undissolved part of the sample. These were re-weighed, and water, buffer and acid were added accordingly, before placing the bucket in the fume cupboard again. The washed contents within the finer meshes were emptied into labelled filter papers, and placed in an oven for several hours. The samples were ready for picking when dry. However, some residues were too large; thus, the conodonts had to be separated. Density separation in heavy liquid (sodium polytungstate) was used. The specific gravity of conodonts is 2.84 to 3.10 g/cm^3, which is denser than other common minerals. Thus, they can be concentrated by density separation in a heavy liquid. The heavy liquid form was placed in a plastic funnel, to which the residue was added, and left for six hours,

stirring regularly. After six hours, the clamp was opened to release the heavy residue on a filter paper. The residue and filter papers were washed through with de-ionised water to remove the sodium polytungstate, and dried out. The conodonts were then picked from the residues (under a light microscope) and placed on labelled cavity slides lightly covered with a semi-permanent glue (tragacanth).

The biostratigraphic age of several key carbonate sequences were constrained through this extensive foraminiferal and conodont analysis. This permitted the clastic sequences beneath and above these carbonates to be placed in a more logical order.

1.6.4.3 PALYNOLOGY

Fourteen palynology samples from clastic sequences were submitted for palynological processing (Appendix 3).

Three separate processes were applied:

- Nitric acid and Potassium Chloride
- Fuming
- Nitric acid (10 minutes)

Nitric acid is the weakest form of oxidising agent and the samples disintegrated after five minutes of oxidation in this solution. These samples are very rich in woody material, allowing for possibilities of Vitrinite studies. Some spherical objects (mostly indeterminate miospores) were present within the processing liquid. The edges of the miospores displayed splits, which enlarge during any of the processes above, destroying the samples. Although some spores were recognised in other samples, the preservation quality was too poor for use. Thus, it was not possible to add to the limited data presented by Higgs (1984).

1.6.5 PETROGRAPHY

Petrographical analysis was conducted on the carbonate samples, where limestone components were identified. Individual grain types are included in Appendix 4. The main aim of this analysis was to investigate the foraminiferal assemblages in order to clarify biostratigraphical problems within the area. Additionally, the presence of distinctive grain types such as ooids and algae assisted in the interpretation of

depositional environments. Microfacies analysis was conducted, whereby each sample was allocated descriptive limestone terminology under the classifications presented by Folk (1962) and Dunham (1962).

CHAPTER 2 THE STRATIGRAPHICAL SUCCESSION

2.1 CARBONIFEROUS SUCCESSION OF THE NW BASIN OF IRELAND

For an updated review of the entire Dinantian sequence within Ireland, the reader is referred to Sevastopulo and Wyse Jackson (in press). Below is a short summary relevant to the Northwest Basin of Ireland, which is extracted mainly from the work above and earlier work by Sevastopulo (1981a).

Ireland lay in tropical latitudes during the Lower Carboniferous. The onset of the Dinantian is marked by a marine transgression extending northwards across Ireland. The Dinantian succession characteristic of the Sligo Syncline and the Lough Allen Basin has been divided into two groups: a lower Tyrone Group (Lower Viséan-Asbian) and an upper Leitrim Group (Asbian-Namurian) (Brandon 1972, 1977). Rocks only within the Tyrone Group are of relevance to this present study. During the Courceyan, the sea had transgressed across the alluvial plain of central Ireland, reaching Ulster by late Courceyan times (Sevastopulo 1981a). Northward migration of the basal clastic facies and succeeding peritidal and marine sediments was controlled by successive syn-sedimentary extensional rift faults (Mitchell and Owens 1990). Each fault coincided with an expansion of the depositional basin. Non-marine conglomerates and sandstones were deposited within the eastern part of the Donegal Basin during the Tournaisian (Graham and Clayton 1994). Viséan rocks are widely distributed north of a line from Clew Bay to the western end of the Lower Palaeozoic Longford-Down inlier. Within this northern region, major facies and thickness changes reflect fault-controlled differential subsidence and relative proximity to the source of siliciclastic sediment. Its northern part lay close to, or included, the margin of marine deposition from early Viséan times onwards.

During Lower Viséan[1] to Arundian times, the northwest of Ireland was a centre of carbonate deposition (i.e. Ballyshannon Limestone Formation), with the thickest deposition occurring between the Ox Mountains and the Armagh Shelf Area. Terrigenous sediments, derived from the metamorphic highlands to the north and

[1] The Viséan part of former Chadian stage is informally termed Lower Viséan (Wyse & Sevastopulo, in press)

northwest dominate the northern edges of this palaeo-shoreline (i.e. the Donegal Basin). The Largymore Syncline in south Donegal (referred to in this study as the Shalwy Syncline, after Graham 1996) records a Lower Viséan marine transgression. Its succession resembles the rocks that outcrop in the western parts of the main Donegal outcrop, although the latter area comprises a greater thickness.

The Bundoran Shale Formation (Arundian in age) overlies the Ballyshannon Limestone Formation in the Sligo Syncline and the Donegal Basin. The Bundoran Shale Formation was the prelude to an influx of siliciclastic sand, which formed the Mullaghmore Sandstone Formation. A deltaic environment is inferred for the finer-grained sediments within this latter succession and much of the sandstone is likely to be of marginal marine origin. Miospore assemblages from the formation have been assigned to the TS Biozone (late Arundian to Holkerian) by Higgs (1984).

2.2 STRATIGRAPHICAL NOMENCLATURE OF THE DONEGAL BASIN

The stratigraphical nomenclature of the Donegal Basin employed in this study (Figure 5) is based on initial work from George and Oswald (1957) and Graham (1996) – refer to Figure 6. Many of the lithostratigraphic boundaries that were presented by George and Oswald (1957) are still recognisable in the field today. However, as noted previously, their stratigraphy does not conform to modern nomenclature (Holland *et al.* 1978). Thus, the 'Rinn Point Beds' are amended to Rinn Point Limestone Formation and the 'Calhame Limestone' to Calhame Limestone Member. Graham (1996) presented a revised nomenclature of the Shalwy area, which is adhered to in this study.

Where units are comparable with those recognised within the Sligo Syncline, the most widely employed names in the literature were used (for example, the Bundoran Shale Formation in the Doorin area and the Mullaghmore Sandstone Formation in the Mountcharles area). This permits better correlation across the Donegal and Sligo sub-basins.

Several of the basal units recognised in this study could not be correlated accurately to the Sligo sequence. This is due to the variability of depositional environments between the type area of the 'Ballyshannon Limestone' in the Sligo Syncline and the exposed localities within the Donegal Basin. During the Lower Viséan, the Sligo area

(comprising predominantly carbonates) represented a more distal to basinal depositional environment. In contrast, the Donegal area lay close or formed the coastal zone. Lateral north to south facies changes resulted from this more proximal regime. Thus, within the Donegal Basin, the local names revised by Graham (1996) were used in the discussion on the outliers to the west of the main Donegal Basin. Where possible, this present study then correlates the Shalwy stratigraphy to that within the main Donegal Basin, although some additional names are integrated. It is more difficult to erect a clear stratigraphy for the eastern part of the main Donegal Basin. As this latter area displays more influence of marine conditions, problems arise in correlating the more established stratigraphy of the western limb onto the eastern limb of the syncline. Again, names already employed in the literature were applied and revised to fit modern nomenclature. Some new unit names were introduced (i.e. Lough Eske Sandstone Formation in place of the 'Basal Clastics' and the Donegal Limestone Member for the early Ballyshannon Limestone Formation succession in the eastern part of the basin).

2.3 BRIEF INTRODUCTION TO THE DONEGAL BASIN STRATIGRAPHY

A summary of the stratigraphy of the Donegal Basin is presented in Figure 6, where it is compared with the nomenclature employed by earlier schemes. A more detailed discussion on biostratigraphy is included in Chapter 8.

The only proven Tournaisian strata in the Donegal Basin are non-marine conglomerates in the Edergole area (Graham and Clayton 1994). Earlier Tournaisian assignments by Sheridan (1972) have not been substantiated (Higgs and Sevastopulo 1983).

A large section of the rocks within the Donegal Basin is assigned a Lower Viséan age (previously late Chadian – discussed in later sections). These formations extend from the Roelough Conglomerate Formation, the Oily River Conglomerate Formation, the Largysillagh Sandstone Formation, the Shalwy Formation, and the Rinn Point Limestone Formation in the west, to the Lough Eske Sandstone Formation, the Clady Limestone Member and the Donegal Limestone Member.

Doubts exist over the assignment of the clastic units, the Muckros Sandstone Formation, the St. John's Point Limestone Formation and the Banagher Sandstone

Formation. Sevastopulo (in George *et al.* 1976) identified *Permodiscus* (now termed *Uralodiscus)* (Sevastopulo 1999, pers. comm.) within the Muckros Sandstone Formation, indicating an Arundian age. This record would require confirmation. However, this study has not retrieved Arundian fauna within the extensively sampled St. John's Point Sandy Limestone Formation. On this basis, these three clastic units are placed within the Lower Viséan.

The Bundoran Shale Formation marks the first unequivocal identification of Arundian fauna within the Donegal Basin. The Mullaghmore Sandstone Formation comprises the youngest sequence within the Donegal Basin. It is inferred to be Arundian to Holkerian in age, although the evidence for a Holkerian age is slight (Sevastopulo 1981a). This present study did not yield any dates for the Mullaghmore Sandstone Formation.

CHAPTER 3 FACIES ANALYSIS

3.1 INTRODUCTION

This chapter is divided into three components. This section introduces the concept of sedimentary facies. Section 3.2 gives a brief outline to the grain components and textures recognised within the carbonate thin-sections processed during this study. Section 3.3 presents the eighteen sedimentary facies recognised within the Dinantian Donegal Basin.

A sedimentary facies is defined by a distinctive assemblage of depositional and/or post depositional characteristics. These are generally interpreted to form under certain conditions of sedimentation, which reflect a particular assemblage of process(es) that is often interpreted in terms of environment. Facies may be subdivided into sub-facies or grouped into facies associations or assemblages. It is important to keep descriptions and interpretation of facies separate as non-unique interpretations commonly apply. Walther's *Law of Succession of Facies* (1894) indicates that facies occurring in vertical contact with each other must be the product of spatially neighbouring environments, providing they are in a conformable vertical sequence. A major pulse of modern facies analysis occurred in the 1960's when Walther's warnings about conformable contacts were not always heeded. The more recent advent of sequence stratigraphy has emphasised the importance of discontinuities and marked facies shifts.

Facies changes occur due to changes in subsidence, sediment supply and eustatic sea level movement. Within the Donegal Basin, individual facies outline the overall changes that occurred within the basin. Transgressive facies are deposited when sea level rise was greater than the sediment supply or subsidence rate. Regression and progradation occur when the sea level rise is less than sediment supply.

3.2 BRIEF INTRODUCTION TO GRAIN-TYPES IN CARBONATE FACIES

Appendix 4 contains an analysis of the grain components present within the carbonate thin-sections. The thin-sections within Appendix 4 were chosen to reflect the most characteristic components within the individual carbonate units.

The components of limestones can be divided into four groups; non-skeletal grains, skeletal grains, micrite and cement (Tucker 1991). Recognition of skeletal structure in thin-section is based on descriptions and criteria in Milliman (1974), Bathurst (1975), Flügel (1982), Scholle (1978), Adams *et al.* (1984), Scoffin (1987) and Dehantschutter (1995).

Non-skeletal grains include ooids, peloids and intraclasts. Several limestones within this analysis contain variable amounts of quartz and feldspar debris. The most abundant skeletal grains in this study are echinoderms, crinoids, brachiopods, bivalves, bryozoa, foraminifers, ostracods and calcispheres. Minimal amounts of gastropods, corals, algae (*Koninckopora* and *Girvanella*), conodont, worm tubes, moravamminids and sponges are also present. The reader is referred to Scoffin (1987), Tucker (1991) and Dehantschutter (1995) for a description of these grain components. The matrix of the limestones is generally composed of fine-grained detrital matrix or *micrite* (Scoffin 1987). The cement occupying the majority of the original pore space in many limestones is a clear equant calcite referred to as *sparite* or calcite spar (Tucker 1991), which precipitates from solution after deposition in intergranular pores (Folk 1962).

In this study, classifications by both Folk (1962) and Dunham (1962) were used. These classifications subdivide limestones according to a blend of descriptive and genetic parameters. Folk's classification is based on the principle that carbonate sedimentation is comparable to that of sandstone sedimentation and that most carbonates comprise the three end members of grains, matrix and cement. Dunham's limestone classification is also based on the depositional texture of the limestone. However, emphasis is placed on the nature of the framework of the sediment, that is, whether it is 'mud-supported' or 'grain-supported'. The former generally implies low hydraulic energy of deposition, the latter is of high energy (Tucker 1991). Although the classifications by Folk and Dunham have their disadvantages, it was necessary to classify the limestones in this

FACIES	BRIEF DESCRIPTION	FORMATION	INTERPRETATION
A	Variably coloured conglomerates	Roelough Cong. Fm., Oily River Cong. Fm., Banagher Sst. Fm.	Shallow bedload rivers with flashy discharge
B	Non-calc, tab, wedge, planar, trgh X-bded ssts	Largysillagh Sst Fm, Shalwy Fm, Roelough & Oily River Cong. Fms.	Bedload channels with common channel switching
C	Med-co. gr., buff calc. herring-boned X-st.	Shalwy Fm., Muckros Sst. Fm., Lough Eske Sst. Fm.	Tidally influenced reach of bedload rivers
D	Variegated mudsts, dessic. cracks, palaeosols	Largysillagh Sst Fm, Shalwy Fm, Roelough & Oily River Cong. Fms.	Non-marine floodplain with exposure & soil forming processes
E	Grey mudrks & siltst. with plant debris	Largysillagh Sst. Fm, Shalwy Fm., Oily River Cong. Fm	Flood deposits in abandoned channels
F	IHS comprising mudstones, mudsts/sst & sst.	Largysillagh Sst. Fm, Shalwy Fm.	Lateral accretion - migrating pt bars in tidal & fluvial channels
G	Well std, med.-gr., tab, biotur. ssts	Shalwy Fm, St J.Pt Sdy Ls Fm, Muckros Sst Fm, Ramp Hole Sst Mbr	Shallow marine sandflats dominated by wave action
H	Unsorted pbly calc. ssts & sandy limestones	Shalwy Fm, base of Rinn Pt Ls Fm, Clady Ls Mbr, Ramp Hole Sst Mbr	Deposits of surf zone, especially during coastal retreat
J	Black mudsts w. micrite, gastrop. & ostrac.	Shalwy Formation, Bundoran Shale Formation	Coastal swamps & brackish bays, variable marine influence
K	Compact argillaceous bioturbated limestones	Rinn Pt. Ls. Fm., Donegal Ls. Mbr., Bundoran Shale Fm.	Normal open marine platform with high mud content
L	Crinoidal grainstone	Rinn Pt. Ls. Fm.	Debris beds within shelfal area w. varied energy conditions
M	Wavy, thin bedded sandy/argill. ls	Rinn Pt. Ls. Fm., Rabley Limestone Member	Shelfal conditions beneath wave base - intensive bioturbation
N	Intbdded sandy ls., ool. ls., calc. ssts.	Gullhuch Sandy Ls. Mbr., Clady Limestone Member	High energy, shoaling marine shelf
P1	Bioturbated, fossiliferous calcareous shales	Rinn Point Ls. Fm., St. John's Pt. Sandy Ls. Fm., Donegal Ls. Mbr	Suspended deposition within normal marine conditions
P2	Thick, non bioturbated calcareous shales	Bundoran Shale Fm., Donegal Ls. Mbr, rare in Rinn Pt. Ls. Fm.	Suspended deposition in prodelta area, partially anaerobic
Q	Thin bded, lamin., rippled, var. foss. calc. siltsts.	Bundoran Shale Fm., Donegal Ls. Mbr, rare in Rinn Pt. Ls Fm.	Suspended deposition, current activity, variably oxygenated
R	Massive bedded sandstone	Mullaghmore Sst. Fm.	Unclear fluvial or marine - possibly distributary mouth?
S	Tab., X-st. well sorted sst. with shells	Mullaghmore Sst. Fm.	Shallow marine, variable energy - tidal sandflat or delta front ?
T	Thin siltst. & f.-gr. mic. sst. w. plant debris	Mullaghmore Sst. Fm.	Terestrially influenced coastal area - distributary mouth ?

Table 3.1 Facies recognised within the Dinantian Donegal Basin

study into assemblages, to give some insight into the characteristics of the variable depositional settings. For example, micrite may be generally linked to lower energies of deposition than most sparites (Scoffin 1987).

3.3 FACIES ANALYSIS

The eighteen facies outlined below (refer to Table 3.1) are defined largely on the succession in the Shalwy Syncline and the western margin of the main Donegal Basin. This is primarily due to the quality of exposure in this area. Although many of these facies can also be recognised in the eastern area (in the vicinity of Lough Eske), a complete facies profile is less easy to generate here. This is due to difficulties of examining junctions between individual facies, which are rarely seen due to incomplete exposure. Due to the overall transgressive nature of the Donegal succession, giving a bulk change from non-marine to shelf environments, several facies are only common in one area and confined to particular stratigraphic units.

Each facies is designated an alphabet letter for easy reference, instead of quoting the description name. To avoid confusion, the letters I and O have not been used. Table 3.1 presents all the facies with brief descriptions and interpretations on their depositional environment.

3.3.1 FACIES A Conglomerates

Facies A has been divided into three components on the basis of colour and sorting characteristics: A1, A2, and A3. It would appear that although each subfacies comprises predominantly conglomerates, they display enough differences to merit separate subfacies.

3.3.1.1 FACIES A1 Buff, clast-supported conglomerates

Facies A1 comprises buff coloured, relatively well sorted, clast-supported conglomerates (Plate 1). Matrix-supported conglomerates are observed within some sandstone-rich lenses towards the top of the facies sequence. Clasts within the conglomerates are dominated by psammite, quartzite and white vein-quartz (Plate 2). A

large percentage of the quartzite clasts are sub-rounded. The smaller grain sizes (especially quartz) display a more angular morphology. Maximum particle size (mean of five largest clasts) ranges from 21 cm to 47 cm, with isolated clasts up to 80 cm in diameter (Graham 1996). Imbrication is common, indicating current flow to the south. Many cross-strata have set thicknesses typically less than 50 cm. Palaeocurrent directions from the cross-strata consistently display current flow to the south. Some conglomerates beds (especially west of Shalwy and at Pollacurry) display horizontal stratification within the sheeted geometries (Plate 3). Plate 4 displays clasts cutting into and disturbing the parallel bedding within the underlying coarse-grained sandstones.

Isolated *Taenidium barreti* (after Keighley & Pickerill 1994) (formerly termed *Beaconites barreti*) trace fossils are displayed on some surfaces. These are generally a series of overlapping concentric forms, which are three to five centimetres in diameter.

In association with:

Facies A conglomerates are associated with buff coloured, coarse-grained sandstone lenses and irregular beds of Facies B. Subordinate to rare grey coloured siltstone and mudstone lenses of Facies D often infill channel bases.

Recorded in:

Roelough Conglomerate Formation

Best exposed at:

- Roelough (west of Shalwy Syncline) above an unconformable contact with the Dalradian rocks (GR16534 37419)
- West of Shalwy beach within the Shalwy Syncline (GR16445 37482)
- Pollacurry (west of Shalwy Syncline – GR16403 37477)

3.3.1.2 FACIES A2 Red, poorly sorted conglomerates

Facies A2 comprises red, purple to brown coloured, variably stratified to unstratified conglomerates (Plate 5). The stratified sections are generally separated by coarse-grained sandstones. Internal structures are often lacking in the conglomerates. Both

clast- and matrix-supported conglomerates are observed within this sub-facies, the latter being generally dominant (Plate 6). This variation in support fabric is probably due to the poor sorting within the conglomerates, implying limited segregation of grain sizes. The clasts are predominantly of quartzite and psammite, with subordinate schist, pelites and metadolerites. Irregular clasts of reworked red, green and grey sandstone and siltstone are also observed. The clast size ranges from 30 cm down to pebble size, although most clasts are in the 3 to 7 cm category. The sphericity of the clasts is generally low. Most of the clasts are sub-rounded, with the smaller grain sizes showing quite angular morphology. Sorting is generally poor. Imbrication has been noted and tabular cross-strata are observed in the less coarse-grained lithologies. Some graded sequences have been observed (Ballyloughan – GR17381 37596).

Facies A2 appears more heterogeneous than Facies A1, due to the common presence of beds and lenses of sandstones and mudstones in association with the conglomerates. In addition, the type of clasts within this sub-facies is more varied, compared to the quartzite-dominated clasts in Facies A1. One variant of Facies A is observed at a small (approximately 3 metre thick) exposure towards Croagh Lough – GR17610 38275 (Plates 7 and 8). Here, a clast supported, purplish conglomerate is exposed close to a faulted boundary with Dalradian rocks. The clasts are again predominantly quartzitic, although psammites and pelitic clasts are also quite common. The rounded nature of the clasts seen elsewhere in this facies is replaced by very angular clasts with very low sphericity.

In association with:

The A2 conglomerates are commonly associated with Facies B red coloured, variably bedded to lensoid sandstones, siltstones, and Facies D variegated red and green mudstones. These latter mudstones vary from irregular lenses which infill irregular channels to thick (up to 1.3 metres), tabular, laterally continuous beds, which display an abrupt contact with overlying conglomerates. Fining-up sequences from conglomerates to pebbly sandstones, coarse- to fine-grained sandstones and mudstones have been noted in this facies assemblage at Ballyloughan Strand.

Recorded in:

- Oily River Conglomerate Formation

- Subordinate in Largysillagh Sandstone Formation

Best exposed at:

- Ballyloughan Strand (southwest of Bruckless – refer to Enclosure 4.3), along the Oily River (refer to Enclosure 4.4) and to a lesser extent at Bruckless Harbour.
- Present as minor beds, lenses and conglomerate lags within the Largysillagh Sandstone Formation in the Bruckless area.

3.3.1.3 FACIES A3 Grey conglomerates and pebbly sandstones

A third subdivision of Facies A is the uniformly grey, predominantly matrix-supported, conglomerates (Plate 9) and pebbly sandstones, which constitute most of the Banagher Sandstone Formation at Banagher Hill. The clasts are dominated by quartzite and vein-quartz with subordinate psammite. Bed geometries appear to vary from tabular to lensoid and irregularly bedded. Cross-stratification is apparent (Plate 10).

Interpretation of Facies A

The presence of unidirectional, variably clast to matrix supported, generally unsorted conglomerates of Facies A are indicative of deposition from a bedload river (as discussed by Miall 1978, Vincent 1999). Conglomerates occupy the lowest parts of channel sequences and are the first products to be deposited from the fluid medium, whilst substantial volumes of sand is kept in suspension, especially during floods. In a river channel, the heavier gravels and pebbles lag behind, while the smaller grains of sand and silt continue further downstream. The coarse gravels accumulate as discontinuous, lenticular patches in the deeper parts of the channel. This is especially noted at Shalwy, where invariably discontinuous, clast-supported conglomerates dominate the sequence.

At Ballyloughan (Bruckless area), the Facies A2 conglomerate sequences generally comprise much less well-sorted sediments, which would probably indicate fluidal flow but with short transport distance. As flow velocity over a bar reduces, sand, which during high stage is carried in rapid saltation or suspension, becomes deposited on already static gravel, thereby allowing sand to infiltrate between the framework

particles and accumulate on the surface. Fluctuations of discharge result in alternating layers of matrix-filled and clast supported conglomerates within the bar. The imbrication within Facies A is associated with periods of high discharge and display a unimodal, low variability within single bar or channel elements. Vincent (1999) noted similar bedload-dominated streamflow processes in Tertiary fluvial systems of the Tremp-Graus Basin, in the south central Pyrenees.

The sheet-like conglomerate geometries noted at Shalwy within Facies A are suggestive of wide shallow rivers with coarse-grained banks with poorly channelised flows (Friend 1983, Fillmore 1993). In these cases, any erosion surfaces tend to be difficult to detect and are often subparallel to bedding. There is no evidence of the conglomerate lenses representing individual bars within a larger channel belt (i.e. of a braided river). There is a lack of distinguishing features such as trough-shaped erosional base and fine-grained sediment spreading across the whole upper surface of the coarser-grained deposits etc. (Moody-Stuart 1966). The scale of the clasts (up to 50 cm in diameter) within the conglomerate facies, would indicate the presence of a relatively high velocity in order to move clasts of this size. Reading (1996) maintains that the larger clasts are commonly transported only during floods. The localised presence of thin and laterally continuous sandstones and muddy lenses at the bases of channels would indicate that flows were very flashy in the area at this time (Graham 1996). Coarse-grained bedload streams tend to show low sinuosity and moderate or strong braiding. The fining-up sequences, which have been observed within the clastics at Ballyloughan, are indicative of deposition under waning flow.

Red colouration in alluvial sediments is often general and pervasive and unconnected with soils. It occurs most commonly in sediments deposited under hot, semi-arid or strongly seasonal conditions. The colour results from diagenetic hematite coatings on detrital grains (commonly quartz).

It is postulated that the reddish-purple coloured conglomerate exposed towards Croagh Lough represents an isolated, immature deposit, which is possibly fault-related. Facies A3 (which constitutes the Banagher Sandstone Section) is discussed in more detail in Section 5.4. A fluvial deposition is inferred with relatively large dunes.

3.3.2 FACIES B Non-calcareous, planar laminated to cross-bedded sandstones

Facies B comprises predominantly buff coloured sandstones (Plate 11), although reddish brown, feldspathic sandstones are more common in some localities. This reddening feature is especially noted in the basal units of the western part of the main Donegal Basin where the red sandstones are closely associated with the red conglomerates of Facies A2. The sandstones are generally medium- to coarse-grained and predominantly feldspathic (less commonly quartzitic).

Facies B sandstones display generally tabular to lensoid geometries (Plate 12). These sandstone units are dominated by cross-stratification, the most common being large scale tabular to wedge shaped cross-strata. Both angular and tangential bases are observed. Preserved set thickness of cross-strata is also variable (generally 15 cm to 1 m). Trough cross-stratification is also observed within these sandstones. The hollows between the troughs are often filled with variegated mudstones and siltstones. Unidirectional palaeocurrent indicators are common both within the trough- and the tabular- cross beds. Flat to gently inclined strata are generally less common. Bed thickness is extremely variable within this facies (ranging from several centimetres to approximately two metres in thickness). The latter units are generally massive in appearance and are frequently associated with channel fills (Plate 11). Many other beds are laterally restricted and pinch out within ten to twenty metres. Beds often rest on concave erosion surfaces, resulting in very irregular geometries. As three-dimensional exposure is relatively uncommon, the visual result is a multitude of irregular lenses of sandstone, each separated by erosional surfaces (Plates 13 and 14) - as observed in the sequence beneath the ruins of McSwyne's Castle at Bruckless.

Facies B comprises variable single to complex channels (as described above), the latter being constructed from several intercutting channels. Individual channel beds are also variable, often reflecting the shape of the underlying erosional base. Thus, individual units are structureless, cross-bedded or parallel laminated in nature. In general, u-shaped to rounded cross-sections of channels are the most common, with subordinate v-shaped geometries. In general, channel widths range from 1 to 8 metres wide, although some appear to extend to 20 to 25 metres wide. Many of the channels display conglomeratic to pebbly lags and are commonly filled with coarse- to medium-grained

sandstone. Other channel fills include fine-grained sandstone, siltstone and variegated mudstones.

Drifted plant debris (stems, plant fragments, coalified wood etc.) are observed on exposed surfaces of Facies B sandstones. The trace fossil *Taenidium barreti* has been observed on some sandstone surfaces.

In association with:

Conglomerate lenses and pebbly beds of Facies A are often associated with Facies B sandstones, especially in the lower parts of the Largysillagh Sandstone Formation. Local preservation of thinly bedded to laminated mudstone lenses with plant debris (Facies E) are found lining concave scours within the sandstone. Facies D variegated green, red and buff coloured mudstones, siltstones and sandstone lenses are also associated with Facies B. The former commonly contains rootlet horizons and desiccation cracks.

Recorded in:

- Largysillagh Sandstone Formation at Largysillagh, Shalwy and Muckros, and from Bruckless towards the Garrafada area
- Minor presence within the Roelough Conglomerate Formation
- Associated with Facies A2 within the Oily River Conglomerate Formation

Best exposed at:

Facies B sandstones are well-exposed on the western side of Shalwy Beach within the Shalwy Syncline. An approximately eight metre wide erosional surface is displayed at this locality. Facies B is also seen to the east of Shalwy beach, within both the Largysillagh Sandstone Formation and in the basal sections of the Shalwy Formation. Within the main Donegal Basin, the section from Bruckless Harbour to McSwyne's Castle (refer to Enclosure 4.3) shows abundant examples of Facies B, in addition to inland areas (Enclosure 4.4).

Interpretation of Facies B

Facies B sandstones are interpreted to have been deposited in sandy bedload channels with common channel switching, as noted by the numerous erosional surfaces within the facies (Friend 1983, Dade and Friend 1998). The river pattern is a reflection of channel adjustment to channel gradient and cross-section and seems to be strongly controlled by the amount of sediment load and its characteristics, and the amount and nature of discharge (Bridge 1993, McCarthy *et al.* 1997). Conglomerates are often dispersed within the sand or as winnowed lags on scoured surfaces.

Bars and dunes are the dominant structures of these channels, as reflected by the dominance of the tabular and trough cross-strata (Doyle and Sweet 1995). Trough and planar cross-bedding are commonly observed features in channel-fill sequences and record deposition from sinuous crested dunes and straight crested dunes, respectively (Tucker 1982, Friend 1983, Collinson and Thompson 1989). Dunes occur on riverbeds at a wide range of scales from around two metre spacing and a few tens of centimetres height to spacing of hundreds of metres and heights up to several metres. They are most active during floods and shift rapidly or are created and destroyed over short time intervals. Several scales of dune may coexist, especially where water depth changes rapidly, and superimposed relationships reflect disequilibrium (Neill 1969, Allen & Collinson 1974). Horizontally bedded sandstone records deposition under upper-flow regime conditions that developed locally on point-bar surfaces (LePain, Crowder and Wallace 1994). Reading (1996) maintains that the larger dune forms, which are termed 'macroforms' or 'bars', are the main sites of longer-term bedload storage.

3.3.3 FACIES C Herringbone cross-stratified, calcareous sandstones

Facies C comprises buff to brown coloured, quartz-rich, medium to coarse-grained, commonly pebbly sandstones (Plate 15). Small ripple bedding is observed within the thinner bedded examples. Asymmetrical ripples with a preserved mud drape are preserved (at Shalwy) within Facies C sandstones. Wavelength is 3 to 4 cm and height is less than one centimetre (Plate 16). The sandstones are variably non-calcareous to calcareous. Many of the inland exposures of this facies (Plate 17 – at Gilbertstown and also west of Lough Eske) display a weathering effect resulting in a honeycomb, pocked,

dolomitised appearance. This observation is not noted in the coastal exposure at Shalwy. This is most likely due to the less calcareous nature of the Shalwy exposure.

Facies C is generally quite similar to Facies B in morphology (grain size and colour). However, the former is commonly distinguished from the latter by the presence of herringbone cross-strata, where northerly directed palaeocurrents oppose the local fluvial flow (currents to the south). Foreset laminae within Facies C vary from less than one to three centimetres thick. The angles are commonly steep and display tangential bases. Preserved set thicknesses commonly range from 10 to 30 cm. Pebble-sized, white vein-quartz grains are common within some exposures (Plate 18). The presence of these pebbles vary from being scattered randomly throughout the outcrop, to pebbly lags, or are lined along bedding and foresets. The bases of set boundaries are generally distinctive, due to the pebbles being aligned down the slope of the foreset and commonly settling along the bases of set boundaries. As discussed above, pebbly grains appear to be confined to irregular basal lags, and conglomerate units are generally rare. However, at one location (Gilbertstown, north of Bruckless), a 35 cm thick, clast-supported conglomerate is exposed beneath the sandstones (Plate 17). The quartzite clasts in the conglomerate (generally 2 to 5 cm in size) vary from sub-angular to very well rounded.

In association with:

Facies C sandstones are commonly associated with the non-marine Facies B sandstones; thus, indicating the relative proximity of the coastline during deposition. At Shalwy, Facies C is also associated with Facies F Inclined Heterolithic Strata.

Recorded in:

- Shalwy Formation
- Lough Eske Sandstone Formation

Best exposed at:

- Shalwy Syncline (Shalwy Formation)
- Gilbertstown area (Locality177, GR17528 37983) – north of Bruckless (Shalwy Formation) – refer to Enclosure 4.4

- In the Greenan area between Lough Eske and Banagher Hill (Lough Eske Sandstone Formation)

Interpretation of Facies C

As discussed above, Facies C shows some general similarities to Facies B sandstones, the latter being non-marine in character. Thus, it is assumed that Facies C sandstones are also primarily deposited by bedload rivers. However, this facies differs from Facies B in its influence from tidal processes. One important criterion for the distinction of tidally influenced river from non-tidal river point-bar deposits, is the presence of evidence for reversals of flow in the former (Cuevas Gozalo and de Boer 1989, Rossetti 1998). The possible reactivation surfaces observed within the calcareous sandstones west of Lough Eske may represent short-term changes in the flow conditions, which caused modification to the shape of the bedform. Bipolar currents can occur in tidal sand deposits through tidal current reversals, where the current of one direction is of insufficient strength to cause much sediment movement in that direction (Tucker 1982, de Mowbray and Visser 1984). Bipolar cross bedding can be produced where there are reversals of the currents, causing dunes and sand waves to change their direction of migration. Small ripple-bedding is formed under conditions where relatively less sediment is available and reworking is stronger.

The clast-supported conglomerate bed with some finer material exposed beneath the bipolar cross-stratified sandstones (at Gilbertstown) probably equates with deposition from a gravelly bar. It is unlikely to equate with beach gravel as these would comprise solely of pebbles or cobbles without fines.

3.3.4 FACIES D Variegated mudstones (siltstones and sandstones) with palaeosol features

Facies D comprises predominantly mudstones, which are interbedded with thin bedded, silty sandstones. These lithologies vary from buff, grey, red, green or variegated coloured units. Thicknesses are variable ranging from less than a centimetre up to 1.3 metres (Plate 19). The silty sandstones (commonly buff in colour) vary from laterally continuous over more than 20m (Plate 20) to strongly lenticular, which pinch out over tens of centimetres. Some small-scale, trough cross bedding with tangential bases (Plate

21) and erosional surfaces have been noted with the coarser grain sizes of this facies. Facies D commonly lines depressions and hollows formed by the sandstones and conglomerates (Plate 22). One diagnostic feature of Facies D is the presence of polygonal desiccation cracks and pedogenic carbonate glaebules. Rootlets have also been observed (Plate 23). Plant fragments are present within this facies, but they are not as common as within Facies E. This factor may be largely due to greater oxidation.

In association with:

Facies D is commonly associated with Facies B fluvial sandstones, infilling irregular scours. Along McSwyne's Bay, these red/green mudstones (with thin, irregular fine-grained sandstone lenses) are also associated with plant-bearing, grey siltstones (of Facies E). Facies D is subordinately associated with Facies A2 conglomerates (within the Oily River Conglomerate Formation).

Recorded in:

- Subordinate to rare within the Roelough Conglomerate Formation
- Common within the Oily River Conglomerate Formation
- Common in the Largysillagh Sandstone Formation
- Subordinate to common within the Shalwy Formation

Best exposed at:

- The Ballyloughan to Castle Port area (along McSwyne's Bay – Enclosure 4.3) provides numerous examples of Facies D
- Desiccation cracks are observed along the Shalwy coastline, and at some localities (Locality117 - GR17526 37526, and Locality144 - GR17490 37559) along the Killaghtee coastline. Pedogenic carbonate glaebules are also observed at the former locality.
- Muckros Head

Interpretation of Facies D

The variegated siltstones and mudstones of Facies D commonly line erosional bases and hollows within Facies B sandstones. By this association, they are interpreted to have been deposited within a non-marine floodplain. Flood plains act as settling basins in which suspended fine-grained sediment settles down on the over bank areas of the

river's floodplain, when the river breaks its banks. Sediments of a flood basin normally contain the finest grains of all the alluvial sediments. There is a tendency for deposits to fine away from the channel (Reading 1996). In general, finely laminated muds are present, interrupted by some sandy or silty intercalations. Sometimes, small channels with sandy-silty sediments may also be present. Rootlet horizons, soil horizons and caliches with disturbed bedding are common along with organic debris and mottled structures (Aitken and Flint 1995, McCarthy *et al.* 1997, Retallack 1988, 1997). Floodplain sediments dry out between floods. Thus, due to exposure, the flood plains are subjected to desiccation. Evidence of sub-aerial exposure is noted from the presence of polygonal desiccation cracks and pedogenic carbonate nodules. Colour mottling is the result of local variations in oxidation and reduction processes (Retallack 1988 and 1997, Vincent 1999). It is often related to vegetation and to variations of moisture. It can also be produced by the action of animals introducing air and/or organic matter into the sediment (Cuevas Gozalo and de Boer 1989). The red coloration results from diagenetic hematite, which probably results from maturation of iron hydroxides. The green colour is related to the reduction of the sediments, which almost certainly would have occurred later than the oxidation phase. Palaeosol profile and mottle development resulted from fluctuations in the water table height due to intermittent flooding (Vincent 1999).

3.3.5 FACIES E Grey mudstones & siltstones with plants fragments

This facies comprises thin beeded, variably light to dark grey mudstones, and grey silty sandstones. The finer grained sediments are commonly arranged as dark and light grey laminated (several millimetres thick) to thinly bedded (several centimetres thick) bands (Plate 24). They may be observed as laterally extensive beds, bounded by Facies B sandstone and Facies D siltstone/fine sandstone units, or infilling irregular hollows caused by erosional scours on Facies B sandstones (Plate 25). The latter are not laterally extensive. Both the mudstones and the fine-grained sandstones are commonly rich in plant debris, present as comminuted or as larger more complete stem forms (Plate 26). Bioturbation is variable, with burrows often disturbing the laminations.

In association with:

Facies E is commonly associated with Facies B non-calcareous sandstones and Facies D variegated mudstones. It is subordinately to rarely associated with Facies A1 conglomerates.

Recorded in:

- Largysillagh Sandstone Formation
- Shalwy Formation

Best exposed at:

- Ballyloughan to Kiln Port area along the McSwyne's Bay coast in the western part of the Donegal Basin. It has been observed that Facies E is more common towards the upper part of the Largysillagh Sandstone Formation along McSwyne's Bay.
- Similar beds are observed in the Shalwy and Largymore areas.

Interpretation of Facies E

The presence of plant bearing, fine-grained, grey siltstones and mudstones, with a lack of marine faunas or any sign of marine influence suggests deposition within a terrestrially influenced environment. Laminations are formed when the finer particles carried in suspension are deposited due to a reduction in the level of turbulence. This is usually achieved when a flow carrying a load of suspended sediment slows down on entering a larger body of water. The laminated siltstones and mudstones commonly overlie and drape erosional scours within channelled sandstones, which would most likely imply flood deposits in abandoned channels. Channel choking and switching may cause channel abandonment, as shown by the erosional scours within the Facies B sandstones. The rate of abandonment will partly determine the lithofacies of abandoned channel fills (Bridge 1984).

3.3.6 FACIES F Inclined heterolithic stratified ssts and mudstones

Facies F comprises sets of 'Inclined Heterolithic Strata' (IHS). The term 'Inclined Heterolithic Strata' has been proposed by Thomas *et al.* (1987) 'to characterise.... large scale, water lain, lithologically heterogeneous ... siliciclastic sedimentary sequences, whose

constituent strata are inclined at an original ("depositional") angle to ... the palaeohorizontal. Deposits of such strata typically range in thickness from 1 to 30 m, exhibit initial dips of 1-36^0, and, given suitable exposure, may be traceable along their strikes for many tens of metres'. IHS deposits consist of inclined units of variable grain sizes. The varieties recognised during this study are:

(i) sandstone-dominant types with unidirectional palaeocurrents (Plates 27, 28)

(ii) muddier sets with bipolar strata (Plate 29)

(iii) very muddy examples with common shell debris (Plate 30)

Dips of the inclined bed-sets range from a few degrees to twenty degrees, but the lower dips are more common. This is probably a function of the grain size as the muddier forms display shallower dips. Collinson and Thompson (1982) state that the thicker the unit, the lower the inclination. Lateral extent of individual inclined strata are generally 10 to 25 metres. Ripples and small dunes have been noted in the finer grained and sandstone varieties, respectively. These are strongly oblique to perpendicular to the IHS dip. These structures indicate that flow was subparallel to the strike of the inclined surfaces. Some of the muddier examples are rich in fusain (fossil charcoal) which are commonly concentrated into distinctive layers. The fusain units are commonly rich in angular quartz and shell fragments in a muddy limestone matrix, and are not generally well sorted. Fusain is discussed in more detail in Section 4.5.4.1 A classical point bar example (dominated by sandstones) is exposed 11.5 metres above black mudstones with micrite lenses in the lower part of the Shalwy Formation (western part of the Shalwy Syncline (refer to Section 4.5.4.1).

In association with:

The non-marine example of Facies F is associated with a thin lens of grey siltstone (Facies E) and extensive Facies B sandstones. The marine influenced examples are in association with herringbone cross-stratified sandstones of Facies C, well sorted, calcareous sandstones (Facies G), black mudstones with micritic bands and plant debris and some fusain rich horizons (Facies J).

Recorded in:

- Largysillagh Sandstone Formation
- Shalwy Formation

Best exposed at:

- Facies F is observed at several localities along the section east of Shalwy beach, within the Shalwy Syncline. This facies does not appear to be exposed within the McSwyne's Bay area.

Interpretation of Facies F

The distinctive 'epsilon' bedding displayed in Facies F is indicative of lateral accretion of migrating point bars (Tucker 1982, Thomas *et al.* 1987, Nio and Yang 1991, Shanley *et al.* 1992, Bridge 1993). The internal structures (cross-strata) infer flow subparallel to the strike of the inclined surfaces. Thus, the inclined depositional surface migrated laterally. These bedforms occur in both tidal and fluvial channels, the former being much more common. Thomas *et al.* (1987) and Shanley *et al.* (1992) include the following characteristics as indicative of ancient tidally influenced point bar IHS:

- Evidence for flow reversals
- Macro or micro-fossils of marine or brackish water species
- Sigmoidal bedding
- IHS exhibiting marked rhythmicity and regularity in terms of constituent sand- and mud-layer frequency and thickness.

The non-tidal IHS example (observed towards the top of the Largysillagh Sandstone Formation at Shalwy) suggests deposition within the fluvial part of a laterally migrating channel, possibly out of the reach of tidal influences. The remaining examples are all associated with lateral migration of a point bar within the tidal reaches, due to the presence of herringbone cross-strata and shelly debris. The curved plan view of the dipping beds (as seen in Plate 28) suggests a curved channel side, and a meandering plan view. Nio and Yang (1991) maintain that the formation of tidal point bars within the Eocene Roda Sandstone in the southern Pyrenees is related to the fourth-order eustatic changes, linked to abundant sediment supply and an increased tidal discharge. Following work in Cretaceous tidally-influenced fluvial strata in Utah, USA, Shanley *et al.* (1992) suggest that although tidally-influenced fluvial deposits may be difficult to recognise, they can be temporally equivalent to marine maximum flooding surfaces in marine strata.

3.3.7 FACIES G Well sorted, x-stratified, bioturbated fine-grained ssts

Facies G comprises well sorted, fine- to medium-grained, buff coloured, quartzose sandstones forming relatively tabular beds (Plate 31). The beds may show traces of both parallel lamination and subordinate ripples (Plate 32). Low-angled cross-strata have been observed. The surfaces of some sandstone beds display 'rib and furrow' micro cross-lamination (Plate 33 - refer to Section 4.5.4.2.2). Hummocky cross-stratification was observed within well-sorted sandstones, whilst trough cross-stratification were noted within some of the coarser-grained units. Bed thicknesses are variable, ranging from 30 cm to 70 cm thick. Bioturbation is generally extensive (Plate 34).

In association with:

The parallel sandstone beds of Facies G are commonly associated with Inclined Heterolithic Strata (Facies F), black mudstones with micrite bands (Facies J), and coarse-grained to pebbly, unsorted, calcareous sandstones (Facies H).

Recorded in:

- Shalwy Formation
- Cavan Sandstone Member
- St. John's Point Sandy Limestone Formation
- Ramp Hole Sandstone Member

Observed at:

- Castle Port to Kiln Port area along St. John's Peninsula (Shalwy Formation)
- East coast of Dunkineely (Cavan Sandstone Member)
- Shalwy Point area within the Shalwy Syncline (Shalwy Formation)
- Portachurry, Doorin Peninsula (Ramp Hole Sandstone Member)

Interpretation of Facies G

The fine-grained, relatively well-washed nature of Facies G sandstones and the presence of hummocky cross-strata would indicate deposition during periods of high wave activity. Oscillatory flows would have been often dominant in order to produce hummocky cross-stratification. HCS structures are thought to form in the area between fair-weather wave-base and storm wave-base and are intimately associated with storm processes (Harms *et al.* 1984, Tucker 1991). Driese *et al.* (1991) infer hummocky megaripples (within Silurian shelf sandstone sequences in the southern Appalachians), generated by combined-flow storm currents as being deposited within the inner shelf, in water depths of 10 to 50 metres.

Low-angle, inclined lamination in marginal marine deposits have been widely accepted as indicating deposition in the surf zone on beaches (Reinson 1984, Elliot 1986b). Thus, deposition within shallow marine sandflats/tidal flats is envisaged for these Facies G sandstones. During storms, a lot of sand is eroded on the upper part of the beach (foreshore and upper shore-face) and is taken into suspension by turbulent water. The suspended sand is brought to the lower shoreface and deposited as evenly laminated sand (Reineck & Singh 1973). This process would have resulted in the good sorting that is characteristic of this facies.

Craft and Bridge (1987) describe a similar facies within the Late Devonian Catskill Sea in New York State as having been deposited within a shallow marine area, episodically influenced by intense tropical storms. A modern analogue is the North American Atlantic shelf, where strong offshore-directed storm currents modified and shaped the shelf sand sheet into a complex system of sand waves and megaripples (Driese *et al.* 1991).

3.3.8 FACIES H Unsorted, pebbly calcareous ssts and sandy limestones

Facies H is dominated by medium- to coarse-grained, calcareous sandstones and sandy limestones (Plate 35). Quartz granules and small pebbles are locally common (Plate 36). Structures are dominated by flat and undulose lamination, but several thin sets of high-angled cross beds are also noted. There are variable amounts of bioclastic debris present, especially *Syringopora* and crinoids. One of the main characteristics of Facies

H is the high degree of bioturbation. Both vertical and horizontal burrows are usually observed.

In association with:

Facies H is generally associated with beds of well-sorted, predominantly parallel laminated sandstones (Facies G) and Facies K argillaceous, bioturbated limestones.

Recorded in:

- Shalwy Formation
- At the base of the Rinn Point Limestone Formation.
- St. John Point Sandy Limestone Formation
- Ramp Hole Sandstone Member
- Top of Clady Limestone Member

Best exposed at:

- Castle Port to Kiln Port area along St. John's Peninsula (Shalwy Formation)
- Shalwy Point area (Shalwy Formation)
- Ramp Hole and Portachurry, Doorin Peninsula (Ramp Hole Sandstone Member)
- Clady River (eastern part of the Donegal Basin)

Interpretation of Facies H

The presence of unsorted, calcareous coarse-grained to pebbly sandstones with shell debris indicates deposition within a marine environment. Sediments of the lower part of a foreshore are generally poorly sorted and contain much broken shell, mica and organic debris etc. The degree of bioturbation normally increases with increasing water depth. Facies H is interpreted as the deposits of the surf zone area. In the surf zone, the undertow of backwash transports coarser sediment toward the breaker zone, where the coarsest sediment is more abundant (Wang *et al.* 1998). Simultaneously, sediment is brought from the open sea into the breaker zone. During storms and with longer waves, the effective wave-base reached deeper parts of the shoreface profile than during calm sea and short waves. The presence and width of a surf zone is controlled mainly by the angle of slope of the beach and the tidal phase. Beaches with steep slopes seldom show a surf zone, whereas gentle beach slopes are characterised by wide surf zones.

Swift and Thorne (1991) discuss a model for shelf sedimentation on continental margins. Accommodation-dominated regimes are characterized by transgressions, in which river mouths become sediment trapping estuaries. The shoreface undergoes erosional shoreface retreat so that shoreface bypassing becomes dominant. The two bypassing modes result in two basic classes of sediment provenance. River mouth bypassing results in *allochthonous* sedimentation, whereas shoreface bypassing results in *autochthonous* (of *in situ* origin) sedimentation. These latter sediments (interpreted as Facies H in this study) are derived primarily from erosional shoreface retreat.

The geometry of shoreface translation, in response to rising sea level was first described by Bruun (1962). He argued that if the coastal profile was accepted as an equilibrium response of the sea-floor to the hydraulic climate, the effect of sea level rise must be a landward and upward translation of the profile. Thus, the shoreface undergoes erosional retreat, while accommodation space is created for the resulting debris beneath the rising seaward limb of the profile (Swift and Thorne 1991).

Thin, laterally persistent pebble conglomerates have been described from high-energy beach and nearshore settings by Clifton (1973), DeCelles (1986) and Massari and Parea (1988). This facies is formed particularly during periods of local coastal retreat when coarse sediment is transported landward while finer sands and silts are suspended briefly.

3.3.9 FACIES J Black, commonly sulphurous mudstones

Facies J comprises black mudstone units (Plate 37), which are commonly sulphurous and plant rich. Carbonate nodules (Plate 38) are commonly present, and septarian nodules and thin (3 cm to 8 cm) micritic limestone beds and lenses are also observed. Ostracods and gastropods dominate the fauna, but some examples contain subordinate marine shells, including brachiopods. Bioturbation and burrows (more frequently vertical) are prevalent. Black fissile mudstones with microfolds, which contain abundant ostracods are a variant to Facies J. This latter sequence is observed within the

Ramp Hole Sandstone Member at Ramp Hole (Doorin Peninsula - refer to Section 6.4.3.1).

In association with:

Facies J mudstones are associated with non-marine Facies B sandstones at Shalwy. At Ramp Hole, Facies J is associated with Facies H coarse-grained to pebbly sandstones with subordinate marine fossils and also with Facies P2 deltaic shales.

Recorded in:

- Shalwy Formation
- Ramp Hole Sandstone Member of the Bundoran Shale Formation

Observed at:

- Shalwy Point area
- Less common at Castle Port (McSwyne's Bay)
- South of Kiln Port (St. John's Peninsula) within the faulted Shalwy Formation
- Portachurry, Doorin Peninsula (Ramp Hole Sandstone Member)

Interpretation of Facies J

The fine-grained muddy sediments of Facies J would imply settling out of suspension. The presence of subordinate brachiopods and micrite bands indicate marine influence. The shallow water areas of lagoons are generally protected from the sea by barrier islands (Shepard and Moore 1960). It is here that fine-grained terrigenous sediments accumulate from suspension and/or carbonate sediment. These clays and silts may be finely laminated, but more commonly are structureless due to bioturbation. In humid and temperate lagoons, the muds are often rich in organic matter, including plant debris washed in by rivers (Reading 1996). The mudstones of Facies J are interpreted to have been deposited within coastal swamps and brackish bays with variable degrees of marine influence. Waterbodies within lagoons, estuaries and bays are shallow (<5 metres and often less than 1 metre), yet the energy level is low and clays, silts and fine sands predominate.

On transgressive coasts, the immediate source of fine sediment is the nearshore turbid zone on the adjacent inner shelf, where it is kept in suspension by wave stirring (Swift *et al.* 1985a, Swift *et al.* 1991). Local rivers also contribute fine sediment, but within

the back-barrier region, mud deposits unusually contain open marine microfossils, suggesting that most of the material has been derived recently from the shelf (Nichols 1989). The salinity depends on the degree of communication with the open sea, the amount of river input and tidal range. Reduced salinities result in prolific but low diversity faunal assemblages, whereas normal salinity, as found in tidal inlets, favours high diversity (Selley 1996). The former is indicative of Facies J, as a predominantly brackish assemblage of ostracods and gastropods were observed, with the general absence of open marine fauna (apart from subordinate brachiopods).

A similar facies (dark to medium grey muds with plants, bivalve and gastropod assemblages) has been recognised by Dominguez and Wanless (1991) in the Doce River strandplain in Brazil. Deposition within a brackish water pond/open lagoon environment is referred.

3.3.10 FACIES K Argillaceous, bioturbated, fossiliferous limestones

Facies K comprises compact (as opposed to fissile), tabular bioturbated, argillaceous limestones (Plate 39). Bed thickness varies from approximately 20 cm to 100 cm. Fossiliferous content is generally high, with a diverse assemblage including brachiopods (spiriferids and large *Delepinea* shells), crinoid ossicles, *Syringopora* and caninioid corals, bryozoa and echinoids plates (Plate 40). These fossils (especially the echinoid plates and crinoid ossicles) are commonly observed as tightly packed into debris horizons. Most of the argillaceous units show a high degree of bioturbation, with both vertical and horizontal burrows present. *Zoophycus* and *Palaeophycus* burrows have been observed on the more argillaceous surfaces. Although Facies K is dominated by argillaceous carbonates, some less argillaceous units have also been assigned to this facies on the basis of similar fossil content and bioturbation. These latter lithologies are differentiated on logs as having a normal limestone pattern fill and a lighter blue corresponding colour. Facies K is classified under Folk's (1962) scheme as predominantly biomicrites and biosparites (depending on the micritic and spar content). Under Dunham's (1962) classification they are wackestones and packstones.

In association with:

Facies K limestones are most commonly associated with Facies P1 fossiliferous, bioturbated, calcareous shales. The limestones are subordinately associated with wavy bedded, bioturbated sandy limestones of Facies M and tabular beds of fossiliferous sandy limestones and calcareous sandstones of Facies N. Facies K limestones are also associated with some sections which contain Facies P2 calcareous shales (e.g. Ballyederlan - refer to Section 4.6.4.3.13).

Recorded in:

- Rinn Point Limestone Formation
- Rabley Limestone Member (St. John's Point Sandy Limestone Formation)
- Subordinate within the Gullhuch Sandy Limestone Member (St. John's Point Sandy Limestone Formation)
- Donegal Limestone Member and Clady Limestone Member

Best exposed at:

- Kiln Port to Rabley Hill (western St John's Peninsula) (Rinn Pt. Ls. Fm.)
- Rinn Point to Shalwy area within the Shalwy Syncline (Rinn Pt. Ls. Fm.)
- Cassan Sound to Cavan Point area (eastern St John's Peninsula)
- St. John's Point
- Lough Eske area – eastern part of the Donegal Basin (Donegal and Clady Ls. Mbrs)

Interpretation of Facies K

The amount of bioturbation within the argillaceous limestones is relatively intense; thus, deposition of these carbonates would have occurred below the storm wave base to further offshore, in areas free of turbidity currents. Offshore deposits typically comprise bioturbated packstones and wackestones. Distinct burrow traces within these units are either horizontal or branching and reflect prevailing lower energy conditions in offshore areas (Shinn 1983). The fossils are indicative of normal salinities. *Zoophycus* and *Palaeophycus* trace fossils are from typical benthic environments. Relatively low energy areas are inferred due to the high mud content. A relatively shallow, open marine environment is inferred for Facies K limestones.

A similar carbonate facies has been observed by Okhravi and Lahijani (1994) within the Dorud Formation, in the Alborz Mountains of Iran, which was also assigned a relatively low energy environment. As discussed later in Section 4.6.7, the argillaceous content within the limestone successions is likely to be supply related (Fewtrell 1979).

3.3.11 FACIES L Crinoidal grainstones

Facies L comprises a crinoidal limestone unit, packed almost wholly with crinoid ossicles and bounded with sparry cement (Plate 41) – otherwise classified as a biocalcarenite. The crinoidal beds vary from tabular to irregular to strongly lensoid with variable bed thickness. Under Dunham's (1962) scheme, it is classified as a grainstone. No complete crinoids were found; however, there are abundant highly fragmented crinoid ossicles (Plate 42). Large *Syringopora* coral colonies have also been observed within this facies. The grainstone is interbedded with minor, fissile, silty-muddy limestones (packstones).

In association with:

This facies is associated with Facies K (argillaceous bioturbated limestones - packstones) and Facies P2 calcareous shales.

Recorded in:

- Rinn Point Limestone Formation
- Facies L grainstones are also recognised within parts of the Bundoran Shale Formation in the Sligo Syncline – outside the area of study.

Best exposed at:

This facies was observed only within the Rinn Point Limestone Formation at Ballyederlan, on the eastern coast of St. John's Peninsula. It has not been recorded elsewhere in the field within the area of study, although some of the carbonate thin-sections are classified as grainstone.

Interpretation of Facies L

The presence of crinoids and *Syringopora* corals suggest an open marine assemblage. All the crinoids show a high degree of fragmentation, which together with the

predominant grainstone texture suggest a high-energy environment and frequent reworking. However, as some micritisation is observed, low sedimentation rates are possible. Changes in texture from wackestone to packstone to grainstone occur from basin centre to basin margin (Selley 1996). The association of this facies with argillaceous limestones (packstones) in the Ballyederlan area may be attributed to infiltration of carbonate mud through the sediment, following a change to lower energy conditions. This association of grainstones and packstones has also been noted on late Dinantian platform margin bioclastic shoals in Derbyshire, UK (Gawthorpe and Gutteridge 1990). Okhravi and Lahijani (1994) interpreted grain-supported biocalcarenites with sparite cement as having been deposited above the wave base level and below the low tide level.

3.3.12 FACIES M Wavy, thin bedded, sandy to argillaceous limestones

Facies M comprises wavy bedded, sandy to argillaceous limestones (Plate 43). The beds are generally thin (10 cm to 35 cm thick). Subordinate interbeds and lenses of calcareous shale are observed. Fossil material within Facies M is variable, consisting mainly of crinoidal debris. Other fossils include small brachiopods and echinoids fragments and occasional rich *Syringopora* coral horizons. The rubbly, nodular appearance is most likely a feature of bioturbation, although only a few obvious burrow forms are preserved. Several *Zoophycus* trace fossils have been noted on surfaces. Facies M limestones are classified as predominantly packstones with some wackestones (Dunham 1962) and biosparite with micrite coated grains (Folk 1962).

In association with:

Facies K argillaceous limestone and Facies P1 calcareous shales.

Recorded in:

- Rabley Limestone Member (St. John's Point Sandy Limestone Formation).

Best exposed at:

- From Portnaman to Rabley area on St. John's Point
- North of Dough Cove fault on St. John's Point

- Cassan Sound on St. John's Point

Interpretation of Facies M

The fossils listed above and *Zoophycus* trace fossils are common within normal marine conditions. The intensive bioturbation indicates depositional areas generally unaffected by normal wave reworking; thus, situated on the inner shelf to offshore. The distinctive undulose planes that result in a wavy bedded appearance are indicative of shelfal environments (Wilson and Jordan 1983). The subordinate amount of sand present within this facies probably indicates a proximal position, towards the inner shelf setting. Rather than being unaffected by waves, the possibility exists that the wave-generated structures are not preserved due to bioturbation.

3.3.13 FACIES N Tabular sandy limestone, oolitic ls and calcareous ssts

Facies N comprises grey coloured interbeds of sandy limestone, fine- to medium-grained, calcareous sandstone, oolitic limestones and subordinate grainstone (Plate 44). These lithologies have all been grouped together due their overall common appearance, similar fossil content and their close association with each other in outcrop. Several of the sand rich beds are light brown in colour due to some dolomite alteration. Some of the beds appear wavy and irregular, although not as wavy as Facies M. Tabular bed geometries are predominant in this facies. Parallel laminations and subordinate cross-stratification are observed in the calcareous sandstones. Some erosional surfaces are observed within the more clastic units and possible hummocky cross-stratification. Calcareous shale beds are subordinate to rare and are generally confined to thin horizons, lenses or flasers separating the limestone units. The bed thickness varies from 30 to 60 cm. Sandy limestone beds up to a metre thick have been noted along St. John's Point. Stylolites and pseudo-bedding are quite common within this facies. Oolites have been observed in limestones along St. John's Point. Fossils include crinoids, brachiopods, bivalves, echinoids and *Syringopora* corals. Within one sandy limestone sequence, a zone of abundant horizontal burrows has been observed. Under Folk's (1962) scheme, thin-sections of these carbonates are classified as oo-, pel-, or intra-biosparite depending on the presence of ooids, peloids and/or intraclasts along with the basic bioclasts and spar cement. Biomicrites are subordinate with most of the micrite

present as coating on grains. This facies comprises packstones, grainstones and subordinate wackestone under Dunham's classification.

In association with:

Facies N sandy limestones are associated with Facies K argillaceous, bioturbated limestones and Facies P1 bioturbated calcareous shales.

Recorded in:

- Gullhuch Sandy Limestone Member (St. John's Point Sandy Limestone Formation)
- Muckros Sandstone Formation
- Clady Limestone Member

Best exposed at:

- St. John's Point (Gullhuch, Boatslip area, south of Trabane)
- Inland from Cavan Point (northeastern part of St. John's Peninsula)
- Ballycroy inlier along St. John's Peninsula
- Muckros Headland and core of Shalwy Syncline (Muckros Sandstone Formation)
- Eastern slopes of Banagher Hill, Clady River (Clady Limestone Member)

Interpretation of Facies N

The carbonates of Facies N contain faunas indicative of normal marine conditions. However, the fossils are generally in a fragmented condition and in addition to the presence of well-washed sandy material, parallel laminations and ooids, it is likely that deposition occurred within a high-energy, shallow marine environment with frequent reworking and winnowing (MacNaughton *et al.* 1997). Ooids tend to form where waters of different salinity or temperature mix (i.e. edges of banks as in the Bahamas – Selley 1996). The occurrence of intraclasts also suggests input of reworked sediment from surrounding areas. Micritisation and peloid presence would suggest that sedimentation rates were probably low. Facies N is associated with the muddy packstones of Facies K and calcareous shales of Facies P1. The latter two facies are attributed to infiltration of carbonate mud through the sediment following a change to lower energy conditions.

Gawthorpe and Gutteridge (1990) have observed similar facies in platform-margin shoals in late Dinantian carbonate sequences in Derbyshire, UK. Carbonate sand shoals occur in a number of depositional systems such as ramps, rimmed shelves and epeiric platforms (Tucker 1985). It is inferred that Facies N formed within areas of shoaling extending from a platform environment to a more proximal position closer towards the shore.

3.3.14 FACIES P Calcareous shales

Facies P comprises grey, calcareous shales and is subdivided into Facies P1 and P2. This subdivision is based on their different characteristics and associations with different facies assemblages.

3.3.14.1 FACIES P1 Bioturbated, fossiliferous calcareous shales

P1 comprises dark grey, calcareous shales, which are nearly always interbedded with Facies K (compact beds of argillaceous, bioturbated limestones). The bed thickness of these shales varies from 20 cm to a maximum of 2.6 metres. The shales are predominantly fossiliferous and bioturbation, although variable, is commonly extensive. Some of the shale beds are completely bioturbated so as to remove any original laminations. The most characteristic fossils within this subfacies are caninioid corals. The corals are located parallel on the bedding planes and commonly appear crushed (Plate 45). Other fossils within P1 calcareous shales include fragments of echinoderm plate, spiriferid brachiopods, horn corals, bryozoans and shell fragments.

In association with:

Both Facies P1 calcareous shales and Facies K argillaceous limestones are arranged in a cyclical order throughout the Rinn Point Limestone Formation and parts of the Donegal Limestone Member. The contact between the limestones and shales is generally gradational, although erosion along cliffs has resulted in the more compact, argillaceous limestone beds protruding more than the calcareous shales. At Ballyederlan (eastern part of St. John's Peninsula), Facies P1 shales are very common (along with Facies K

limestones) within the lower part of the logged section (Figures 36a and 36b). However, within the upper part of the section (from 54.7 metres upwards), Facies P1 is also interbedded with Facies P2: unbioturbated, laminated calcareous shales and the Facies K limestones. The Facies P1 shales are distinguished from the Facies P2 shales in containing more fossiliferous debris and intensive bioturbation.

Recorded in:

- Rinn Point Limestone Formation
- Donegal Limestone Member
- Clady Limestone Member

Best exposed at:

- Shalwy Syncline
- St. John's Peninsula
- Lough Eske area (Donegal and Clady Limestone Members)

Interpretation of Facies P1

The association of Facies P1 shales with Facies K argillaceous limestone and the fossils outlined above (corals, crinoids, echinoids) would imply marine conditions with normal salinities. The amount of bioturbation is generally intense; thus, an offshore environment, unaffected by wave reworking is inferred. Deposition of the shales took place under low energy with the material depositing out of suspension. Some of the fossiliferous material is interpreted as forming from death assemblages.

3.3.14.2 FACIES P2 Variably fossiliferous laminated, calc. shales

Facies P2 comprises light grey coloured, calcareous, laminated shales (Plate 46), and differ from P1 shales by the former's overall uniformity. Facies P2 varies in thickness from tens of centimetres up to five metres thick. Metre thick beds are common (along Doorin Peninsula). The grain size within the P2 shales is very fine. Laminations are very thin and do not appear to be disturbed by bioturbation to a great extent. The fossil content varies within different locations. Fossils are absent within the shales in the lowermost beds of the Doorin Peninsula (Jack's Quay to Burn Foot area) and at

Rossylongan (southwest of Donegal Town). Fossils are limited to solitary corals and small brachiopods within some beds along the main part of Doorin Peninsula. Towards the top of the sequence at Doorin Point, fossils are abundant (including crinoids, brachiopods, bryozoa, solitary horn corals and bivalves). The calcareous shales above the Banagher Sandstone Formation (west of Banagher Hill) are relatively rich in fossils. Facies P2 displays slumped sections at the coast of Summerhill (GR19055 37665 - southwest of Donegal Town).

In association with:

Five to ten cm thick units of fine-grained, laminated siltstones (Facies Q) are interbedded with the shales along Doorin Peninsula and inland from Dunkineely in the Garrafada and Bunlacky River area. Facies P2 shales are also associated with the argillaceous, fossiliferous limestones of Facies K. At one location (Ballyederlan, eastern St. John's Peninsula), Facies P2 may be associated with Facies P1 shales. The latter is distinguished by the presence of bioturbation, relatively coarser-grain size and lack of laminations.

Recorded in:

- Bundoran Shale Formation
- Subordinate in Rinn Point Limestone Formation

Best exposed at:

- Doorin Peninsula
- Port Pier / West of Inver Bay
- Bunlacky River – north of Dunkineely Village
- Inland from Inver area
- Ball Hill, Rossylongan area (SW of Donegal Town)
- West of Banagher Hill
- Ballyederlan on St. John's Peninsula (Rinn Point Limestone Formation)

Interpretation of Facies P2

The fissility and fine laminations of the shales suggest an absence of burrowing, as burrowing would have disturbed the bedding (Riemersma and Chan 1991). Roep *et al.* (1998) infers the lack of burrowing as a result of oxygen depletion and/or abnormal

salinities. Where fossil material is absent within the shales, it may be assumed that conditions were not favourable for animal life to be sustained. It is most probable that the bottom of the water column may have been oxygen deficient during this time. However, these oxygen-lacking conditions may only have been present at the sediment-water interface. As fossils are noted in some of the sequences (e.g. Doorin Point), it is likely that oxygenated periods resulting from possible sediment gravity flows bringing in oxygenated waters, would have allowed a short-lived benthic community to survive (Byers 1977). This facies assemblage (P2 and Q) illustrates deposition within a low energy prodelta environment and is discussed in more detail in Section 6.8.

Avbovbo (1973) stated a depth of water up to 20 metres, in which the shales (of the Bundoran Shale Formation) were formed, although it is not clear how he arrived at this estimate. The absence of ripples and cross-strata are a factor of the smaller grain size, as ripples may only be observed in silt and coarser grains. Chandra (1974) deduced that these sediments within the prodelta association were deposited at a depth of 12 to 20 metres. The slumping noted at Summerhill (SW of Donegal Town) may indicate periods of high sedimentation rates leading to instability.

3.3.15 FACIES Q Laminated variably fossiliferous, calcareous siltstone

Facies Q comprises beds of thinly laminated, calcareous siltstone (Plate 47). Bioturbation commonly disturbs these parallel laminations. The best exposed units range from four to twelve centimetres thick and are interspersed randomly within the thicker sequences of Facies P2 calcareous shales. These calcareous siltstones can be picked out in the field as distinctive brown horizons within the grey shales (e.g. along eastern part of Doorin Peninsula). Ripple scale, cross-laminations are common, although they may be altered by burrowing action. Avbovbo (1973) noted *Teichichnus* and *Chondrites* trace fossils within this facies. Body fossils are relatively rare within the Doorin area, although archaediscid foraminifers and shell debris have been observed in thin-sections from inland areas (e.g. west of Banagher Hill and in the Garrafada area – north of Bruckless).

In association with:

Facies P2 calcareous shales and Facies K argillaceous limestones

Recorded in:

- Bundoran Shale Formation
- Rare occurrences within Rinn Point Limestone Formation
- Rare occurrences within Donegal Limestone Member

Best exposed at:

- Doorin Peninsula (Bundoran Shale Formation)
- Central parts of the Donegal Basin (Bundoran Shale Formation)
- West of Banagher Hill (Bundoran Shale Formation)
- Menamny area (eastern St. John's Peninsula) (Rinn Point Limestone Formation)
- Rossylongan Strand (SW of Donegal Town - Donegal Limestone Member)

Interpretation of Facies Q

The generally laminated fabric within the calcareous siltstones, and the lack of body fossils (as observed along the Doorin Peninsula) may indicate that conditions during sediment suspension were predominantly anoxic (Sageman *et al.* 1991). However in some localities, many of the sediments have been disturbed by bioturbation. This facies probably formed on a shallow marine shelf, below wave base, under low energy conditions. Biological reworking would have occurred during periods when the substrate was most stable; that is, during periods of low water agitation and turbulence. Conversely, recurring and frequent physical reworking would have taken place during periods of high agitation and turbulence (Krause and Nelson 1984).

To the west of Banagher Hill and Garrafada areas, the siltstones in the Bundoran Shale Formation contain more abundant fauna; thus, deposition commonly occurred within normal marine conditions, as indicated by the presence of foraminifers and shelly debris below. Near the delta front environment, the sediments are more silty, and parallel and lenticular laminations are common.

3.3.16 FACIES R Buff, massive bedded, coarse to pebbly sandstone

The buff coloured sandstones of Facies R comprise coarse-grained to predominantly pebbly sandstones. Sorting is moderate and the thickness of the individual beds range from 50 cm to more than a metre. These sandstones are generally non-calcareous, although some calcite cement, in addition to quartz cement is present. Beds are commonly tabular, although wedge-shaped beds with irregular surfaces are also observed (upper part of Plate 48). No internal structures can be detected within these sandstones. Some thin interbeds may comprise horizons and lenses of Facies T (siltstone to fine-grained sandstone). The pebbly sandstone of Facies R is termed 'Sugar Granite' by the locals in Mountcharles (where this facies is confined to). Quartz grains are dominant, although feldspars and muscovite are also present. No body or trace fossils have been noted within this facies.

In association with:

Facies R coarse-grained sandstones are associated with Facies S well sorted, parallel laminated, tabular to trough cross-stratified sandstones.

Recorded in:

Mullaghmore Sandstone Formation

Best exposed at:

This facies has only been observed within the Mountcharles area. It is well-exposed at Lower Drumkeelan (Monaghan), Upper Drumkeelan, west of Mountcharles and McMonagle A and B quarries (refer to Section 7.3). Massive beds of coarse-grained to pebbly sandstone form the 'roof' to the Lower Drumkeelan Quarry in Montcharles.

Interpretation of Facies R:

The coarse-grained nature of these sandstones and the lack of marine fossils and calcareous grains would suggest a non-marine environment. However, no channels or internal structures (cross-stratification or laminations), indicative of fluvial processes have been observed. The absence of dune forms may imply deposition within the lower part of the upper flow regime. An environmental interpretation can only be made by viewing this facies in an overall context with Facies S and T. As discussed later in Section 7.9, this facies (within the Mullaghmore Sandstone Formation) is inferred to have been deposited within a shallow water environment.

3.3.17 FACIES S Tabular, well sorted, variably fossiliferous sandstones

Facies S comprises buff coloured, generally tabular, well sorted, medium to coarse-grained, feldspathic, commonly micaceous sandstones (Plate 48, lower cross-stratified beds). Beds vary from five centimetres to more than one metre thick. Bedding planes are generally distinct, although not erosional. Thin micaceous and/or plant rich horizons may separate the sandstone beds. These horizons range from several millimetres to several centimetres thick. Subordinate thin horizons (approximately 1 cm) of coarse grained, pebbly material may also be present within the beds. In general, bedding within Facies S is laterally persistent, with only one small channel observed within the main exposures of this facies (refer to Section 7.3.5). This shallow channel is approximately 60 cm in depth (Plate 49). Some beds display more lensoid geometry due to wedge bedding. Ripples have not been noted within this facies. Cross-strata are generally subordinate to rare in most of the exposures. However, tabular solitary sets have been noted in some exposures (Plate 48). Set thickness within these cross-strata varies from tens of centimetres to a maximum of 1.6 metres. The base and top of the sets are generally flat. Foreset thickness within a 1.6 metre bed ranges from 20 cm to 45 cm. Dips of the cross-beds are predominantly rather shallow, ranging from 8 to 14^0.

The thinner tabular beds (2 cm to 10 cm thick) are distinctively flaggy in appearance (Plate 50). Laminations are often present within these flaggy sandstones, with separation planes comprising siltstone flasers and plant material. Isolated sets of cross-strata are observed within these thinner beds.

Body fossils are generally rare, although straight-hinged brachiopods (Plate 51), planispirally-coiled gastropods (Plate 52) and bivalves have been noted at one locality. The sandstones do not appear to be bioturbated, although horizontal and vertical trace fossils are present on or within bedding planes, respectively. An excellent example of *Chondrites* was noted between the bedding planes of a well sorted, buff sandstone at Murray Quarry (refer to Section 7.3.7). An unknown trace fossil (possibly *Phycodes*?) has also been observed on the surface of similar sandstones. Scattered plant debris is observed within the sandstones (Plate 53).

In associated with:

The Facies S sandstones are associated with Facies R (massive bedded pebbly sandstones) and Facies T (siltstone and fine-grained sandstone facies). Separation planes (mostly of micaceous, plant-rich siltstone) commonly exist between individual beds.

Recorded in:

Mullaghmore Sandstone Formation

Best exposed at:

Facies S is observed within all the quarries in the Mountcharles area (i.e. Drumbeagh Quarry, the west of Mountcharles Quarry and McMonagle A Quarry and at Lower Drumkeelan-Monaghan Quarry. Two beds of tabular cross-stratified sandstone are exposed at Upper Drumkeelan Quarry. This facies is exposed at the small northwestern quarry owned by the Monaghan family in Lower Drumkeelan. The facies is also seen towards the top of the exposure in McMonagle A Quarry and is associated with interbedded siltstones and fine-grained sandstones of Facies T. Refer to Chapter 7 for more detailed discussion on these localities.

Interpretation of Facies S

The presence of gastropods and brachiopod/bivalves suggests deposition within a marine depositional environment. Due to the absence of ripples, the relative importance of wave and current activity cannot be determined. The most characteristic element of this facies is that it is well sorted and well washed. Plant debris horizons (within the beds) indicate periods of proximity to terrestrial influence. The lack of channelling may be due to limited exposure. It is possible that that channels are present within this facies and are either wider than the exposure, or parallel to the quarry faces (Avbovbo 1973).

The large scale cross-stratification probably originated by the migration and vertical accretion of dunes. Similar facies within the Lower Pennsylvanian estuarine facies in the Illinois Basin, Indiana have been interpreted by Kvale and Barnhill (1994) as the product of a tidal channel fill that formed within a tidal sandflat environment. However, dissecting tidal channels are not observed within the Mountcharles area. The individual cross-beds may represent single sandwaves across the tidal sandflat. The general lack of

bioturbation may reflect high sediment mobility and current energy within the original depositional environment.

3.3.18 FACIES T Interbedded siltstone & fine-grained micaceous sst.

The interbedded non-calcareous siltstone and fine-grained sandstones of Facies T are generally dark grey, brown to black in colour, depending on the amount of clay and plant material present (Plate 54). The siltstones are quite micaceous and plant debris is abundant. Varying degrees of bioturbation and burrows may be present. Individual bed thickness varies from thin millimetre-sized silty partings to 20 cm.

In associated with:

This facies commonly occurs as thin horizons and interbeds associated with Facies S and is subordinate to rarely associated with Facies R. The Facies T siltstones and fine-grained sandstones are generally not laterally continuous, and are predominantly observed draping the irregular surfaces of the more lensoid sandstone beds.

Recorded in:

Mullaghmore Sandstone Formation

Best exposed at:

The quarry west of Mountcharles exposes the best examples of this facies, where abundant plant debris is observed (refer to Chapter 7). Thin silty partings occur along the sandstone beds of the quarry at Drumbeagh, whilst Upper Drumkeelan Quarry contains several beds of this facies along the lower exposed cliff. The top several metres of McMonagle quarry also contains several beds of Facies T. A small quarry east of Drumbaran School (locality 96-74 GR18596 38035) exposes interbedded, non-calcareous, fine-grained micaceous sandstones and siltstones with scattered muddy flasers. Plant debris and burrows are abundant.

Interpretation of Facies T

A fluvial depositional environment is interpreted for this predominantly plant-rich sandstones and siltstone facies. Facies T differs from Facies E in that it is generally

coarser-grained and distinctively micaceous. This may reflect short transport distances with less sorting. Facies T is associated with variably fluvially influenced and shallow marine sandstones (Facies R and S). de Raaf and Boersma (1971) suggested a tidally influenced, low energy marginal marine setting, situated seaward of unconfined sandy fluvial systems for interbedded organic rich mudstones and burrow mottled sandstones, with abundant well preserved plant fragments.

CHAPTER 4 LITHOSTRATIGRAPHY OF THE SHALWY SYNCLINE AND WESTERN LIMB OF THE DONEGAL SYNCLINE

4.1 INTRODUCTION

This chapter outlines the lithostratigraphy of the Shalwy Syncline and the western limb of the main Donegal outcrop (Figures 2 and 7). The main Donegal outcrop, the Shalwy Syncline, and the Muckros outlier are referred to as the Donegal Basin. The sequence commences with the basal sequences of the Roelough Conglomerate Formation and the Oily River Conglomerate (in the Shalwy Syncline and the western part of the main Donegal outcrop, respectively). A nearly identical sequence (Largysillagh Sandstone Formation, Shalwy Formation and Rinn Point Limestone Formation) overlies these basal units in both areas. The Muckros Sandstone Formation and the St. John's Point Sandy Limestone Formation are the youngest rocks preserved and overlie the Rinn Point Limestone Formation in the Shalwy Syncline and the main outcrop respectively (refer to Figure 7).

Five smaller Carboniferous outliers are contemporary with the main Donegal outcrop (Figure 1). These are situated to the west of Killybegs Town and the Killybegs Fault; thus, isolated from the main south Donegal outcrop.

- The largest of these outliers is the Shalwy Syncline, comprising an open syncline approximately seven km^2 in size.
- The Muckros outlier (approximately 1 km^2) in area is situated west of the Shalwy area and south of Kilcar village. It comprises a completely faulted succession, that is, no conformable formational boundaries are exposed within this area. However, its units more or less match the stratigraphy within the Shalwy Syncline.
- A conglomerate outlier at Roelough is 0.6 km^2 in size.
- Two smaller exposures of conglomerates (with less certain correlation to the other outliers) cap the summit of Slieve League, further west.

With the exception of the rocks at Slieve League, the various sequences in the Shalwy Syncline and Muckros area can be correlated across the Killybegs fault with the sequences from the western limb of the main Donegal Basin. Therefore, to avoid

introducing excess local names, the lithostratigraphy of these western areas generally follows the nomenclature used by Graham (1996).

4.1.1 THE SHALWY SYNCLINE

The Shalwy Syncline comprises a well-exposed and almost complete sequence within the lower parts of the Donegal Basin lithostratigraphy. The present nomenclature for the Shalwy area was proposed by Graham (1996), following earlier work by George and Oswald (1957). A correlation of terms used by Graham and George and Oswald, along with the unpublished scheme of Buckman (1992) is summarised in Table 4.1.

George & Oswald 1957	**Al-Rawi 1972**	**Buckman 1992**	**Graham 1996** **Ní Bhroin - this study**
Muckros Sandstone	Muckros Hd. Sst. Mbr	Muckros Sst. Mbr	Muckros Sst. Fm. [1]
Rinn Point Beds	Rinn Point Ls. Mbr	Rinn Point Beds	Rinn Point Ls. Fm. [2]
Upper Shalwy Beds	Shalwy Sst. Mbr	Largymore Sst. Mbr	Shalwy Formation
Lower Shalwy Beds	Croaghbeg Fm.	Shalwy Sst. Mbr	Largysillagh Sst. Fm.
Basal Conglomerates	Croaghbeg Fm.	Pollacurry Cong. Mbr	Roelough Cong. Fm.

Table 4.1 Correlation of stratigraphical names within the Shalwy Syncline - from George & Oswald (1957), Buckman (1992) and Graham (1996). The latter nomenclature is used in this study.

[1] The Muckros Sandstone Formation was not discussed by Graham (1996); however, it is added here to show its revised nomenclature in this study.

[2] This study has amended the term Rinn Point Limestone Formation from Rinn Point Formation in Graham (1996).

4.1.2 THE WESTERN PART OF THE DONEGAL BASIN

The western part of the main Donegal outcrop provides a well-exposed sequence along the coastal area of McSwyne's Bay (refer to Figure 9). The basal beds of the Oily River Conglomerate Formation crop out along the Bruckless coast and are overlain by the Largysillagh Sandstone Formation with a gradational contact. The sequence continues southeastwards with the overlying Shalwy Formation, and the Rinn Point Limestone Formation, and onto St. John's Point where the St. John's Point Sandy Limestone Formation crops out.

The Carboniferous rocks also extend northwards and inland from Bruckless and Dunkineely for 6 km, towards the faulted northern contact with Dalradian rocks. Inland exposures are observed in the Oily River and within streams and scattered crags in the Bruckless, Calhame, Gilbertstown and Garrafada areas.

The lithologies logged within the coastal sections along McSwyne's Bay do not match closely with lithologies observed inland. This is a result of lateral facies changes, which occur from south to north, and reflects the position of the shoreline during this depositional period within the Dinantian (Figure 10). Exact determination of formational boundaries inland is not often possible, due to lack of good exposure.

George & Oswald 1957 Nevin 1973	**Al Rawi 1972**	**Buckman 1992**	**Ní Bhroin - this study**
Muckros Sandstone	St. John's Pt Ls. Mbr	Muckros Sst. Mbr	St. John's Pt Sandy Ls. Fm.
Rinn Point Beds	Dunkineely Ls. Mbr	Rinn Point Beds	Rinn Point Ls. Fm.
Upper Shalwy Beds	McSwyne's Sst. Mbr	Largymore Sst. Mbr	Shalwy Formation
Lower Shalwy Beds	Bruckless Fm.	Shalwy Sst. Mbr	Largysillagh Sst. Fm.
Basal Conglomerates	Oily River Fm.	Pollacurry Cong. Mbr	Oily River Cong. Fm.

Table 4.2 The correlation of stratigraphical names within the western areas of the main Donegal outcrop - from George & Oswald (1957), Al-Rawi (1972), Buckman (1992), Graham (1996) and this study.

The following account is a synthesis of description of all the formations from the Shalwy area and the western part of the main Donegal outcrop. The data from the Shalwy Syncline is partly based on Graham's (1996) paper, on joint fieldwork with

Graham and on supplementary information added from this study. The data from the western part of the Donegal outcrop is exclusively from this study and sequences are correlated, where possible, with those formations recognised within the Shalwy Syncline.

A more detailed account of the various facies recognised within each formation has been outlined within Chapter 3.

4.2 ROELOUGH CONGLOMERATE FORMATION

4.2.1 INTRODUCTION

The Roelough Conglomerate Formation was previously named the 'Basal Conglomerates' by George and Oswald (1957) and the 'Pollacurry Conglomerate Member' by Buckman (1992). The formation was renamed the Roelough Conglomerate Formation by Graham (1996), after the exposed section at Roelough (west of Shalwy). The Roelough Conglomerate Formation comprises the oldest rocks in the Shalwy Syncline and its base forms an unconformity on the Dalradian rocks.

4.2.2 LITHOFACIES OF THE ROELOUGH CONGLOMERATE FM.

The Roelough Conglomerate Formation comprises clast-supported, moderately well-sorted, buff to brown conglomerates (Facies A), with lenses of buff, variably fine to coarse-grained sandstones (Facies B) and rare mudstones (Facies D) - (refer to Section 3.3.1.1). Graham (1996) recorded maximum particle sizes (mean of five largest clasts) for the Roelough Conglomerate Formation ranging from 10 to 48 cm (with some isolated clasts up to 80 cm in diameter). Very few schistose clasts are contained within the conglomerates, although the conglomerates rest directly on the schists as seen at Shalwy and Roelough. The clasts are generally of psammite, quartzite and some vein-quartz, the latter dominating the smaller sized grains (Plate 2). The larger clasts are subrounded to rounded.

Although Buckman (1992) stated that this unit did not contain any trace fossils, Graham (1996) observed a fluvial-indicative trace fossil called *Taenidium barreti* (after Keighley and Pickerill 1994) present within the Roelough Conglomerate Formation (refer to Plate 55). This trace fossil is approximately 5 cm in diameter and comprises an unwalled burrow. Observations of this trace fossil (formerly named *Beaconites barreti*) were previously reported from the fluvial sequences at the base of the Carboniferous sequence in Clew Bay (Graham and Pollard 1982), in the north of England (Eager *et al.* 1985) and several localities in Canada and the USA. Other depositional environments include alluvial fan, lacustrine, flood plain and crevasse splay sequences. *Taenidium barreti* has never been reported within marine sequences.

4.2.3 LOCALITY DESCRIPTIONS OF THE ROELOUGH CONGLOMERATE FM.

4.2.3.1 Roelough

On the southern side of Roelough (a small outlier between Muckros Head and Shalwy Syncline - GR16534 37419), the conglomerates display a faulted contact with the schistose rocks. This locality is accessible on the southern side of the cove. The conglomerates do not contain any schistose clasts. One quartzite clast is 80 cm in diameter. On the northern side of the cove, the unconformable contact appears to be slightly angular, where the conglomerates infill hollows in some places. However, the overall contact is planar. The maximum particle size (mean of five largest clasts) within the conglomerates is 37 cm.

A channel is observed on the northern section of Roelough. Several metres of conglomerates (with interbeds of grey siltstone containing *Taenidium barreti*) are cut by a channel-fill of coarsening-up, pebbly sandstone-conglomerate sequence. The maximum particle size (within this channel) increases up through the sequence from 10 cm at the base to between 15 cm and 20 cm at the top. Steep-dipping foresets (indicating palaeocurrent directions to the south) are observed within the basal pebbly sandstones close to the channel contact. Imbrication is present in some of the bedded conglomerates within the channel fill, and also indicates derivation from the north. A major erosion surface is observed towards the top of the channel fill.

4.2.3.2 Shalwy

The Roelough Conglomerate Formation is well-exposed to the west of a small beach at Shalwy (GR16445 37482 - refer to Figure 11), where 31 metres of section are observed (refer to Figures 12a and 12b). This locality is accessible from the beach at low tide. The base of the conglomerates displays an unconformable contact with light green coloured Dalradian schists (Plate 1). The dominant quartzite clasts are moderately well rounded and only one schist clast was observed. The basal 13 metres of the logged section contain relatively thin beds and lenses (20 to 40 cm) of sandstone and mudstone within the conglomerates. The sandstones appear to line hollows formed in probable channel bases. The amount of sandstones (interbedded with thin conglomerate lenses)

increases up-section from 19 metres to 26 metres from the base of the logged section. The top of the section (in conformable contact with the Largysillagh Sandstone Formation – Facies D siltstones) comprises a thick (approximately four metres) conglomerate bed (Plates 56 and 57). Imbrication is observed with consistent palaeocurrents to the south. Foresets also indicate palaeocurrent directions to the south. *Taenidium barreti* is exposed at the upper contact of the Roelough Conglomerate Formation with the Largysillagh Sandstone Formation. The sequence exposed west of Shalwy appears relatively sheet to sheet drape in geometry, with no evidence of channelling.

4.2.3.3 Pollacurry

The basal unconformable contact with the Dalradian rocks is accessible on the southern side of the cove at Pollacurry (GR16403 37477), where coarse conglomerates overlie the schists with a slightly irregular contact. No schist clasts are visible within the quartzite dominant conglomerates. One quartzite clast measures 80 cm in diameter, although the maximum particle size varies from 48 to 21 cm up through the sequence, indicating a general fining up sequence (refer to Figure 13). The measured section at Pollacurry is approximately 50 metres thick. However, several faults (located towards the top of the section) may have resulted in some repeated sequences. The basal twenty-five metres comprise dominantly conglomerates with irregular, discontinuous sandstone lenses. This unit displays a general reduction upwards in maximum particle size from 47.6 cm to 22.2 cm. Imbrication is seen within several of the conglomerate beds, although internal structures are not common. The sandstone lenses are generally flat laminated and often form prominent surfaces. Small-scale scour and fill structures are seen in the less coarse-grained material at twenty metres from the base. A cliff section (at 25 metres from the base) comprises complex sandstone erosion surfaces with some grey mudstone. Pebbles are common within the sandstone and inaccessible cross-strata are observed. The top part of the logged section comprises sandstones with some grey siltstone lenses (situated along the low tidal rocks) and is overlain by approximately 7.5 metres of conglomerates with irregular sandstone lenses. The lenses contain grey mudstone clasts and cross-stratification. The section west of the boat slip at Pollacurry comprises thick conglomeratic sequences, with steeply dipping (32^0) gravel foresets indicating palaeocurrent flow to the southeast. The foresets range up to 1.2 metres

thick. Schist clasts are absent from the conglomeratic sequences. Quartzite predominates in the coarser fractions, while vein-quartz is more abundant within the smaller grain sizes. Numerous erosion surfaces can be observed along the section. Small foresets and gravel imbrication are also noted within the conglomerates and indicate a northerly source. The sandstone beds contain low-angled cross-strata, but are dominantly parallel laminated and often drape the conglomerate surfaces.

4.2.3.4 Traloar

A very small section of the Roelough Conglomerate Formation is exposed along the northwestern part of the headland at Traloar Beach on Muckros Head (GR 16220 37427 - Figure 8). This clastic unit is structurally incomplete, comprising eight metres of a highly fractured sequence. Maximum particle size within the conglomerates is 31.6 cm.

4.2.4 THICKNESS OF THE ROELOUGH CONGLOMERATE FM.

George and Oswald (1957) estimated a thickness of 21 metres for the Roelough Conglomerate Formation. Graham (1996, his Fig. 6, and Figure 12a in this study) presents a thickness of approximately 31 metres for the Roelough Conglomerate Formation at Shalwy. This measurement extends from the unconformable basal contact to the upper contact with the Largysillagh Sandstone Formation on the western side of the beach.

4.2.5 PALAEOCURRENT ANALYSIS OF THE ROELOUGH CONGLOMERATE FM.

Cross-strata are observed in some sequences at Shalwy and Pollacurry. Set thickness varies up to 50 cm, although a 1.2 metre thick foreset was observed at Pollacurry. Palaeocurrents from cross-strata within the Roelough Conglomerate Formation are predominantly to the southeast (refer to Figure 14). Imbrication in the non-spherical clasts within the conglomerates consistently indicates flows to the south.

4.2.6 PROVENANCE OF THE ROELOUGH CONGLOMERATE FM.

As discussed above, southerly and southeasterly flowing palaeocurrent directions (from cross-strata and imbrication) are consistently observed within the conglomerates and interbedded sandstones. The conglomerates within the Roelough Conglomerate Formation rarely contain schist clasts, although these conglomerates unconformably overlie extensive schistose rocks at several localities in the Shalwy area (west of Shalwy beach and Pollacurry). Quartzite clasts dominate the coarser-grained lithologies, while vein-quartz is more abundant within the finer-grained fractions.

The Dalradian map by Pitcher and Berger (1972) shows extensive schistose sequences extending for at least 10 km to the north. Quartzite, psammitic and some granitic rocks outcrop north of this 10 km limit. This region would probably be the most likely source area, a conclusion also reached by Graham (1996). Nichols and Jones (1992) noted that the sandstones are petrographically immature and implied a first-cycle sedimentation from a Dalradian source. If these are first-cycle sediments, which accumulated due to aggradation and were instigated by a base level rise, then the absence of schist clasts is puzzling. Even though they would be less resistant than the quartzites, one would expect more of them to be preserved. One speculative explanation is that the land surface was already planated and that the influx of coarse detritus reflects some tectonically-induced, source uplift, upon which the base level rise may be superimposed.

4.2.7 AGE OF THE ROELOUGH CONGLOMERATE FM.

A miospore sample was obtained from east of Pollacurry, in which palynomorphs were reported. However, their preservation was too poor to yield any dates. The proposed Lower Viséan age is based on the data for the overlying Largysillagh Sandstone Formation.

4.2.8 DEPOSITIONAL ENVIRONMENT OF THE ROELOUGH CONGLOMERATE FM.

The following observations from the Roelough Conglomerate Formation must be accommodated in an environmental interpretation:

- common unidirectional palaeocurrent data from cross-strata and imbrication (indicating northerly derived sources),
- shallow erosion surfaces,
- general lack of thick cross-strata sets - most are less than 50 cm thick,
- the sandstones are thin (20 to 40 cm) and laterally discontinuous over several metres
- isolated trace fossils of *Taenidium barreti* are displayed on conglomerate bed surfaces,
- mudstones are preserved in places as lenses in channel bases but otherwise are absent. There is a general lack of intraformational mud clasts.

On the basis of the evidence discussed above and following information from Graham (1996), Schumm (1972) and Reading (1996), the Roelough Conglomerate Formation may be interpreted as the deposits of a bedload river. Gravels in the form of pebbles and cobbles and sand are the main constituents of a coarse-grained bedload river. Suspended load may also be transported, especially during floods. However, the finer-grained deposits are generally transported beyond the gravel reach. Within the Roelough Conglomerate Formation, rare mudstone infills and lenses have been preserved within the hollows of channel bases. These are interpreted to represent the final waning stages of floods. The majority of the mudload is thus, envisaged to have been flushed through the system.

The large size of some of the clasts (up to 80 cm) within the Roelough Conglomerate Formation not only reflects periods of high discharge but also implies a significant gradient. Erosion of the riverbed and its banks would have occurred, as the bed material was non-cohesive, although vertical downcutting is generally limited. Clast imbrication is common and is associated with a high discharge within single bar or channel elements (Reading 1996). The imbrication shows unimodal trends and agrees with the low variability unidirectional palaeocurrents to the south/southeast. The quartzite clasts

in the conglomerates are generally well sorted, and as noted earlier, the lack of pelite and psammite clasts suggest a transport distance of at least 10 kms.

In conclusion, the Roelough Conglomerate Formation was deposited in relatively shallow bedload rivers. The previous interpretation of beach or nearshore deposits by George and Oswald (1957) can be discounted in view of the information presented above.

4.3 OILY RIVER CONGLOMERATE FORMATION

4.3.1 INTRODUCTION

The group of dominantly reddish-brown clastic rocks exposed in the Ballyloughan area (GR17381 37596, west of Bruckless harbour) and along the Oily River (e.g. GR17467 37694, north of Bruckless) within the western limb of the main Donegal Basin are assigned to the Oily River Conglomerate Formation. Refer to Figure 9, Enclosure 4.3 and Enclosure 4.4 for locations; and Figures 15, 16 and 7 for logs. Al-Rawi (1972) termed this succession the 'Oily River Formation'.

4.3.2 LITHOFACIES OF THE OILY RIVER CONGLOMERATE FM.

The Oily River Conglomerate Formation is thought to be of similar age to the Roelough Conglomerate Formation in Shalwy, due to relatively well-matched overlying sequences. However, the following factors characteristic of the Oily River Conglomerate Formation justifies it a separate formational term from the Roelough Conglomerate Formation:

- distinctive reddish-brown oxidised colour within conglomerates, sandstones and mudstones
- the clasts include quartzite, vein-quartz, psammite and schists (the latter lithology is not observed within the Roelough Conglomerate Formation)
- internal structures include cross-stratification (tabular, wedge and trough) and rare ripples
- abundant red pebbly, coarse- to fine-grained sandstones
- common red and green variegated mudstones
- dominance of unsorted material
- subordinate graded beds

The Oily River Conglomerate Formation is characterised by reddish, unsorted conglomerates, and red, brown and green sandstones and mudstones. The conglomerates (Facies A2) vary from clast- to matrix-supported (Plate 5), even within individual beds. Clast types within the conglomerates include red-stained quartzite,

white quartzite, vein-quartz, green psammite, green mica schist and pelite. The larger clasts (commonly of quartzite) are relatively well rounded and the smaller pebbles and grains (<2 cm) are subangular. Maximum particle size (five largest clasts) varies from 25 cm to 35 cm. Rare quartzite clasts up to 70 cm have been observed within a cliff section in the Oily River at Oily Bridge. Nevin (1973) calculated the maximum clast size from Bruckless to Croagh Lough (refer to his Fig. 14 in Nevin 1973). His map shows a variable distribution of sizes, with 20 cm as the dominant clast size. He calculated a range extending from 8 cm (at Bruckless) to a maximum of 60 cm east of Croagh Lough. The conglomerates appear to be relatively immature, compared to the Roelough Conglomerate Formation. This is based on the clast composition and the degree of angularity in the smaller grain sizes.

Irregular lenses and rip-up clasts of red-green mudstones (Facies D) and subordinate sandstones (Facies B) are often observed within the unsorted, matrix-supported conglomerates (especially at Ballyloughan, west of Bruckless). The matrix within the conglomerates comprises generally coarse-grained, feldspathic sands with angular vein-quartz and feldspar grains (Plate 5). Several thick units (up to six metres thick) of thin bedded (1 cm to 10 cm), medium- to coarse-grained, feldspathic sandstones (Facies B) are also common within the Oily River Conglomerate Formation (especially at Ballyloughan and within the Oily River – refer to Enclosures 4.3 and 4.4). Internal structures within these sandstones include parallel-laminated, and low angled, tabular, wedge and possible trough cross-strata. Probable current ripples were observed on the top of cross-stratified units within the Oily River.

Variegated red and green mudstones (Facies D) commonly infill irregular surfaces of facies A2 and B conglomerates and pebbly sandstones. Palaeosol features other than the colour mottling have not been observed within these mudstones. A 1.2 metre thick mudstone bed was observed at the base of a succession at Ballyloughan (refer to Figure 15 and Plate 19).

Unidirectional palaeocurrents and imbrication are commonly preserved within the Oily River Conglomerate Formation, as are small-scale channels and erosional scours. Contacts between individual sandstone and conglomerate beds are regularly erosive,

with coarse lags often cutting down 10 to 30 cm into the sandstones and mudstones. No trace fossils have been recorded within the Oily River Conglomerate Formation.

4.3.3 PETROGRAPHICAL ANALYSIS OF THE OILY RIVER CONGLOMERTAE FM.

Three thin-sections (TCDNo.50518 L200, TCDNo.50519 L202, TCDNo.50520 L203 – refer to these locations in Appendix 1) from the sandier lithologies of the formation were analysed for point counting. Monocrystalline quartz is dominant (37.3 to 39.6 %), while polycrystalline quartz is subordinate to absent. K-feldspar, plagioclase and muscovite are present in all samples. Muscovite accounts for 15.6 % of the total in Sample L200. The iron oxides cementation, resulting in the red staining of these rocks is quite high in all three (11.6 to 17.6 %)

4.3.4 LOCALITY DESCRIPTIONS OF THE OILY RIVER CONGLOMERATE FM.

The Oily River Conglomerate Formation is best exposed along Ballyloughan Strand (on the western shores of McSwyne's Bay – refer to Figure 9). Intermittent exposures are also observed along the Oily River and as crags along the west to northwestern margin of the Donegal Basin.

4.3.4.1 Ballyloughan Strand

Conglomerates are exposed north of the small pier and on the small beach at Ballyloughan, southwest of Bruckless (GR17381 37596 - refer to Figure 9, and Enclosure 4.3 for location). To the south of the beach, pelites and semi-pelites are exposed and are cut further south by a green dolerite dyke. The metasediment-conglomerate contact is not exposed, although Al-Rawi (1972, his Fig.2/a) shows an apparent unconformable contact between the conglomerates and basement schists at this locality. This contact appears to have been concealed by modern beach clasts. The contact may be a fault, as there are several S/SE dipping normal faults exposed along the cliffs. However, an unconformable boundary may be located in close proximity, since the contact dip is fairly shallow.

The 16.3 metre thick sequence at Ballyloughan (Figure 15) comprises variable beds and lenses of clast- and matrix-supported red conglomerates (Facies A2 - Plates 5 and 6), pebbly-, coarse- and, medium-grained sandstones (Facies B), siltstones and mudstones (Facies D). Several faults cut through the section and correlation across them is not always possible.

Within a small cove, a 1.2 metre thick red mudstone unit (see basal unit of log in Figure 15) is overlain by pebbly conglomerates with a sharp erosive contact (Plate 19). Maximum particle size within the pebbly conglomerates is 3 cm. Irregular beds and lenses of clast-supported conglomerates (with maximum particle size of 4 cm), green mudstone lenses and coarse-grained, tabular cross-stratified sandstones are exposed above the conglomerates. Some fining-up sequences were observed within this unit. North of a faulted contact, approximately 3 metres of generally tabular, coarse-grained sandstones are observed. An erosional surface is observed towards the top. Above this, a metre thick conglomerate unit (with silty lenses) is overlain by c.60 cm of interbedded sandstones and siltstones, followed by another c.1 metre thick, clast-supported conglomerate unit. From 12.7 metres upwards on the logged section, thin beds of coarse-grained sandstones with variable low angle laminations, and tabular and wedge cross-stratification (Plate 58) are noted. Palaeocurrent data from the cross-strata all indicate southerly-directed flows.

At the next inlet further north, over two metres of red siltstones and mudstones are exposed beneath the topmost 1.4 metre thick sandstone unit (which is depicted at the top of Figure 15). This facies difference between the sandstone unit in the two inlets (siltstones and mudstones to the north, sandstones to the south) may be interpreted as variable channel-fills.

4.3.4.2 South of Gilbertstown

This locality (GR17500 37790 – refer to Enclosure 4.4) within the Oily River, near Gilbertstown displays a 15 metre section of red coloured conglomerates and coarse-grained sandstones (Figure 16). The base of the section commences with interbeds and lenses of conglomerates and coarse-grained feldspathic sandstones, and is overlain by a 1.2 metre thick conglomerate bed. The conglomerate is dominantly clast-supported and

grades up into coarse-grained, cross-stratified sandstones. This latter lithology continues for approximately four metres to the southeast, to a 60 cm gap. The beds dip predominantly from 22^0 to 26^0, which may indicate proximity to a fault, as these dips are much higher than the normal dip in the basin ($10\text{-}16^0$). To the southeast of the gap, approximately seven metres of inclined, wedge cross-stratified sandstone beds continue downstream. Several of the cross sets are up to a metre thick. The boundaries between individual beds are predominantly erosional (Plates 59 and 60). Plate 60 displays the contacts between bounding surfaces of individual trough cross-stratified units. The foresets are commonly concave upwards with tangential lower contacts. Small ripples are observed towards the upper surfaces of the horizontal beds. Nearly planar, parallel laminae are present within a foreset (to the left of the notebook in Plate 60). The wedge cross bedding within this section of the Oily River is most likely observed nearly parallel to the current direction, which is to the southeast. It is unclear whether these sandstones should be assigned to the Oily River Conglomerate Formation or the overlying Largysillagh Sandstone Formation. However, they show some similarities to the thin-bedded, wedge stratified sandstones (many with tangential bases) which are exposed at Ballyloughan Strand (see top succession of the log in Figure 15 and Plate 58). Thus in this study, the red cross-stratified sandstones exposed within the Oily River are assigned to the Oily River Conglomerate Formation on the basis of this similarity, proximity to the other outcrops of the same formation and the presence of several conglomeratic beds within the sequence.

The red colouration noted within the rocks in the Oily River continues east within scattered outcrops for approximately 40 metres. Beyond this area, the buff coloured sandstones (also feldspathic in composition and generally immature) become more dominant. The latter rocks are assigned to the Largysillagh Sandstone Formation.

4.3.4.3 Oily Bridge at Bruckless

A relatively thick (21 metres plus) clastic sequence is partly exposed at Oily Bridge, Bruckless (GR17467 37694 – refer also to Enclosure 4.3) at low water. Figure 17 displays the section, which commences directly underneath the bridge. A clast-supported conglomerate bed (Facies A2) is overlain by pebbly sandstones and generally tabular-bedded, coarse-grained sandstones and conglomerate beds. Ten metres of

predominantly coarse-grained, unsorted, flat bedded sandstones and a metre-thick conglomerate are observed from 4 m to 13 metres up section. The upper section is dominated by clast-supported conglomerate with two thin lenses of siltstone. At the base of a six metre high cliff, 25 to 30 cm of grey mudstones (Facies E) are exposed at very low water. A sample (L181) from the smooth textured, grey coloured mudstone was processed for palynology. However, the sample proved to be barren. The cliff section comprises clast-supported conglomerates with generally rounded clasts of quartzite and vein-quartz.

4.3.4.4 Killybegs Road Quarry

A well-exposed faulted contact between grey Dalradian pelites and red conglomerates and sandstones is observed at the north-eastern end of a working gravel quarry at GR17417 37906 (refer to Enclosure 4.4, Plate 61). The quarry is situated approximately 3 km from Bruckless on the Killybegs side of the main Killybegs to Donegal Town road. Circa fifteen metres of relatively tabular beds (up to one metre thick) of red conglomerates and unsorted, pebbly sandstones (Facies A2 and B, respectively) are exposed along the southern end of the pit. The conglomerate beds (with generally rounded quartzite clasts) vary from clast-supported to matrix-supported in composition. There are also several medium-grained sandstone beds (approximately 10 to 40 cm thick) which display flat to low angled laminations. Some planar stratification is present within the tabular beds.

4.3.4.5 Croagh Lough

Red conglomerates (predominantly clast supported) are intermittently exposed along the eastern and southeastern edges of Croagh Lough (refer to Figure 9 for location. The contact with the Dalradian schists (which crops out several metres to the northwest) is not exposed. The gap between both sets of rocks probably equates with the position of the Northern Boundary Fault. The Northern Boundary Fault terminates as a complex zone of individual splays in this northwestern part of the Donegal Basin (refer to Figure 2 and Section 9.2). At Rock House (west of Croagh Lough), Facies A conglomerates are exposed within a boggy area (GR17690 38214). This locality would appear to be situated north of the projected Northern Boundary Fault and lends support to the

hypothesis that there are several splays of the Northern Boundary Fault north of the main structure.

Pitcher and Berger (1972) presented a geological sketch-map of the area northeast of Killybegs (Figure 18). The authors depict eight predominantly NE/SW-trending faults along the western margin, which cut across the 'natural junction of basal conglomerates with older rocks'. This study has identified up to ten faults (refer to Figure 9), which affect the Carboniferous rocks of this area. These predominantly NE/SW trending faults are most likely reactivated Caledonian faults, and resulted in a fragmented western boundary of the Carboniferous main Donegal outcrop.

4.3.4.6 Ford southwest of Corker Beg

Three metres of massive, unbedded, red to purple, clast-supported Facies A conglomerates are exposed on the roadside at GR17610 38275 (Plates 7 and 8). Angular to subrounded clasts of quartzite, schist, pelite and psammite and vein-quartz are noted. Maximum particle size (mean of five largest clasts) is 25 cm.

4.3.5 STRATIGRAPHICAL CONTACTS

The western margin of the main Donegal outcrop is thought to comprise an unconformable contact between the Oily River Conglomerate Formation and the Dalradian rocks. However, no unconformable contacts are exposed and only faulted contacts with the Dalradian rocks have been noted in this study.

Al-Rawi (1972) interpreted an unconformable top contact with the 'Bruckless Formation' ..'in one locality in the Oily river'. However, this study establishes a gradational contact between the Oily River Conglomerate Formation and the Largysillagh Sandstone Formation in the Bruckless area.

4.3.6 THICKNESS OF THE OILY RIVER CONGLOMERATE FM.

The thickness of the Oily River Conglomerate Formation cannot be well constrained, as there are no complete sections of the sequence. The western margins of the

Carboniferous outcrop are frequently sliced by the northeast trending faults and may result in repeated sections. George and Oswald (1957) proposed 1300 ft (400 metres) for the 'Coarse conglomerates...followed by wedge-bedded feldspathic sandstones and siltstones with gritty and conglomeratic intercalations'. Al-Rawi (1972) estimated a thickness of between 550 to 3000 feet (corresponding to approximately 160 to 900 metres) for the 'Oily River Formation'. It would appear that these latter figures are excessive, although it is not certain how much of the Largysillagh Sandstone Formation is included within this value. Nevin (1973) refined George and Oswald's value to 125 metres for the 'Coarse red and purple conglomerate with lenses of purple arkosic grit and occasional siltstones'. This study proposes a minimum thickness of 50 metres and a maximum of 150 metres for this formation.

4.3.7 PALAEOCURRENT ANALYSIS OF THE OILY RIVER CONGLOMERATE FM.

The palaeocurrent data from the Oily River Conglomerate Formation was obtained from tabular and trough cross-strata. Unidirectional currents indicate a source primarily from the north (refer to Figure 19a).

4.3.8 PROVENANCE OF THE OILY RIVER CONGLOMERATE FM.

The Oily River Conglomerate Formation unconformably overlies Dalradian schists, psammites and pelites. Clasts of these latter rocks (in addition to the quartzite clasts) are observed within the Oily River Conglomerate Formation. This is in contrast with the Roelough Conglomerate Formation, which comprises predominantly quartzite. These lithologies comprise the basement rocks in the south Donegal area, over which the Carboniferous rocks lie. The lack of good sorting would seem to indicate that the source was relatively local and a relatively high degree of immaturity may be envisaged for the Oily River Conglomerate Formation. As shown in Figure 19, the palaeocurrent data indicates a dominant southerly-directed flow. The Pitcher and Berger (1972) map shows that chloritic schists and the Slieve Tooey Quartzite are located to the north of this area.

The variegated mudstones and siltstone clasts within the conglomerates (as observed at Ballyloughan) are inferred to be the product of reworking of previously deposited Carboniferous-age sediments. However, Nevin (1973) queried the presence of the sandstone clasts. He noted that they are less common higher up in the sequence, despite more being available for erosion and incorporation into the conglomerate sequences. He attributed this to the possibility of Carboniferous erosion of a Devonian sedimentary cover, which is now all but removed. In Section 4.2, the absence of schist clasts within the Roelough Conglomerate Formation was discussed. The numerous schist clasts observed within the Oily River Conglomerate Formation may indicate that aggradation instigated by base level rise, resulted in proximal sediments. This would imply that the outcrop area of the Oily River Conglomerate Formation represents an original topographic depression, i.e. a palaeovalley.

4.3.9 AGE OF THE OILY RIVER CONGLOMERATE FM.

As discussed above a light grey mudstone, which underlies the conglomerate section at Oily Bridge (L181 GR17467 37694) was sampled for miospores. However, the sample proved barren. It is thought that the Oily River Conglomerate Formation is of a similar age to the Roelough Conglomerate Formation, on the basis of the similarity of the overlying Largysillagh Sandstone Formation. Thus, a Lower Viséan age is assigned to the Oily River Conglomerate Formation.

4.3.10 DEPOSITIONAL ENVIRONMENT OF THE OILY RIVER CONGLOMERATE FM.

The Oily River Conglomerate Formation is predominantly a well rounded, variably matrix to clast supported, generally unsorted (within the matrix-supported units), immature conglomerate. The presence of unidirectional southerly-directed palaeocurrents (refer to Figure 19a), cross-stratification and variably unsorted to graded beds suggests deposition resulting from bedload transport within a fluvial environment.

The amount of sandstone and mudstone is much higher than in the Roelough Conglomerate Formation. The Ballyloughan exposure comprises predominantly sandy conglomerates, thought to represent the gravel bars of an alluvial channel. These

conglomerates are often overlain by low angled, cross-stratified, well sorted sandstones. Fluctuations of discharge result in alternating layers of matrix-filled and openwork gravel within the bar, and tabular sets of cross-bedded gravel and sand wedges at the downstream end of the bar. As flow over a bar reduces, the sand (previously carried in rapid saltation or suspension) becomes deposited on already static gravel. It infills pore spaces of gravel framework and accumulates on the surface. The bar flanks are depositional at high stage and become erosional at low stage, such that the internal structures reflect variable erosion and deposition (Reading 1996).

The suspended load (the finer sand grains, silts and mud constituents of Facies D and E) would have been deposited and preserved within the channels and overbank areas during periods of high flooding and flashy discharge. The reasons for the better preservation of finer grained lithologies within the Oily River Conglomerate Formation compared to the Roelough Conglomerate Formation are not clear. Factors such as a wider flood plain or greater aggradation due to greater accommodation space might be responsible. The inadequate coastal exposure of the Oily River Conglomerate Formation is such that complete cross-sections of fluvial channels are not observed. Thus, projections of river size are not possible.

George and Oswald (1957) maintained that 'between Bruckless and Largymore, the basal conglomerates and the Lower Shalwy Beds[2] were laid down on a sloping and subsiding shore, partly as beach gravels, partly as delta sands'. Nevin (1973) inferred high-energy conditions in a beach or shallow offshore environment for these conglomerates. However, it is clear from the points presented in the discussion above that a fluvial origin is more consistent with the data.

[2] These units refer to the Roelough Conglomerate Formation, the Oily River Conglomerate Formation and the Largysillagh Sandstone Formation in this study.

4.4 LARGYSILLAGH SANDSTONE FORMATION

4.4.1 INTRODUCTION

The Largysillagh Sandstone Formation within the Shalwy Syncline (refer to Figure 8 and Figure 12 for location and log, respectively) was initially referred to as the 'Lower Shalwy Beds' by George and Oswald (1957) and Nevin (1973), and the 'Shalwy Sandstone Member' by Buckman (1992). Graham (1996) renamed this suite of rocks the Largysillagh Sandstone Formation, after a well-exposed section south of the townland of Largysillagh (on the eastern limb of the Shalwy Syncline). As the sequence has a recognisable mappable basal and top contact, it is assigned Formation status (in accordance with Whittaker *et al.* 1991).

The Largysillagh Sandstone Formation is also recognised within the western limb of the main Donegal Basin at McSwyne's Bay and inland from the Bruckless-Gilbertstown area (refer to Enclosures 4.3 and 4.4). This formation, in addition to the Oily River Conglomerate Formation and part of the Shalwy Formation were originally grouped together as the 'Bruckless Grits' by George and Oswald (1957). Al Rawi (1972) designated the 'Bruckless Formation' to this unit. Nevin (1973) referred to this unit as the 'Lower Sandstone' of the 'Bruckless Grit'. The term Largysillagh Sandstone Formation (from Graham 1996) is retained in this study.

4.4.2 LITHOFACIES OF THE LARGYSILLAGH SANDSTONE FORMATION

The Largysillagh Sandstone Formation is dominated by buff, coarse- to medium-grained sandstones (Facies B - refer to Section 3.3.2). The composition is predominantly quartzitic, although some sandstones are slightly more feldspathic. The sandstones vary from poorly sorted to well sorted, with the poorly sorted sandstones often containing pebbly horizons and rounded quartzite clasts (generally less than 4 cm in size). Thin conglomerate lags (dominantly matrix-supported) are often located towards the base of the sandstone beds. The clasts comprise predominantly quartzite and vein-quartz with subordinate amounts of reworked siltstone clasts.

Numerous erosional surfaces (Plates 12 and 13) and channel complexes (Plate 62) are observed within the formation. Although bedding is predominantly irregular, tabular beds (generally 5 - 40 cm thick) are noted. These are commonly laterally persistent for distances of more than 20 metres and often coincide with better grain sorting. The bed contacts are generally sharp but not erosional. Internal structures vary from flat to low angled lamination or planar cross-strata. The irregular beds are dominantly impersistent and pinch out over several metres, being truncated by the downcutting base of overlying beds. Trough cross-stratification, planar cross-strata and subordinate flat bedding are also observed.

Several root (including *Stigmaria*), stem and coalified wood segments are observed within the sandstones throughout the formation. Trace fossils are observed on some sandstone surfaces. Buckman (1992) reviewed the stratigraphic distribution of ichnogenera within the study area and noted a very limited occurrence within the Largysillagh Sandstone Formation. His list refers to *Skolithos*, *Beaconites* (renamed as *Taenidium barreti*) and *Cochlichnus*. Buckman attributed the low diversity of ichnogenera (only domichnia and repichnia) in the Largysillagh Sandstone Formation as a reflection on its 'interpreted non-marine fluviatile nature'. However, there is ambiguity over the placement of *Taenidium barreti* as it should be placed under 'fodinichnia'. The degree of bioturbation within the Facies B sandstones is low to non-bioturbated. The massive channel sandstones of this formation are generally non-bioturbated. This reflects variable sedimentation rates, as the thicker sandstones appear to reflect higher rates of deposition.

The sequence also contains mudstones (Facies D), generally observed as tabular bedsets or lenses that locally line erosional hollows. These mudstones are red, green, grey or variegated (Plates 20, 21 and 22) and may be interbedded with thin beds or lenses (several centimetres thick) of fine-grained sandstone. Desiccation cracks and/or pedogenic carbonate nodules are commonly visible within the mudstones, indicating exposure of the sediment surface. It has been noted within the Bruckless sequences of the Largysillagh Sandstone Formation that the variegated mudstones (Facies D) are generally confined to the basal parts of the formation.

Plant fragments are observed throughout the formation, although a higher quantity is present within the Facies E grey to dark grey mudstones. This coincides with Facies E being more prominent in the upper parts of the Largysillagh Sandstone Formation (along McSwyne's Bay). The mudstones commonly show small-scale parallel lamination and some banding depicted as light and dark colours. This crude separation of plant fossil abundance between the upper and lower parts to the Largysillagh Sandstone Formation (refer also to Section 4.4.3) may be largely a function of preservation, as the grey mudstones were probably not oxidised. Several fining-up sequences (over three to five metres) have been noted within the formation. Commonly, pebbly lags are overlain by regularly bedded, cross-stratified sandstones, which are in turn overlain by siltstones and mudstones (frequently containing plant fragments.)

Figure 20 displays the facies distribution of the Largysillagh Sandstone Formation at Shalwy (refer to the logs of Figures 12a and 12b). The formation comprises Facies B (sandstones) at 68 %, with equal amounts of Facies D (variegated mudstones/siltstones) and Facies E (plant-rich mudstones) at 14 %. Facies F (HIS sandstones) comprises 4 % of the total. Along McSwyne's Bay (not shown), Facies B is also predominant, comprising 77 % of the distribution. Facies D and Facies E allow for 11 % each of the total. Facies A conglomerates are subordinate at only 1 %.

4.4.3 LOCALITY DESCRIPTIONS OF THE LARGYSILLAGH SANDSTONE FM.

4.4.3.1 Largysillagh

The Largysillagh Sandstone Formation is exposed to the west of a fault (trending 340^0) at Largysillagh in the Shalwy Syncline. The lower section comprises five metres of thin-bedded (maximum thickness of 60 cm), grey sandstones (with some quartz pebbles) covered by barnacles. Approximately 4.5 metres of weathered red siltstone, sandstones and some pebbly lenses extend as sporadic exposures to the base of the cliff. The sandstones (Facies B) contain flat to gently inclined laminae, climbing ripples and cross-strata. Red and grey mudstones (Facies D) are present as partings and lenses within the sandstone beds.

The entire section at Largysillagh is characterised by extensive lateral variability and intersecting erosional surfaces. The sandstone beds are tabular to lenticular in geometry and scattered quartz pebble horizons are observed. *Taenidium barreti* trace fossils (5 cm in diameter) and other burrows are common within the sandstones. Desiccation cracks are noted in some red mudstones and scattered nodules within other grey/red mudstones are taken to indicate pedogenic origins. Large roots (of *Stigmaria* type) and other plant debris are common. Palaeocurrent directions within the cross-stratified sandstones are consistently to the south. The upper part of the section appears more sheet-like in geometry compared to the lower sections.

4.4.3.2 Shalwy

The Largysillagh Sandstone Formation can be seen to the west of the beach at Shalwy (GR16438 37480), displaying a basal contact with the Roelough Conglomerate Formation. This contact is taken at the base of the 1.2 metre of grey mudstones and thin-bedded sandstones, which overlie the conglomerates (Figure 12a). The conglomerates become a minor constituent of the succession above this level (Graham 1996, his Fig. 6). The mudstones and fine sandstones display indistinct internal structures, which may include parallel lamination or ripples. This basal unit is progressively cut seawards by a 3.3 metre sequence of irregularly bedded sandstones. Trough cross beds are preserved predominantly within the basal section of the sandstones and parallel laminations are more common within the upper part of the sequence. Several more metres of sandstones (with internal erosion surfaces and pebbly layers) continue to the prominent bedding plane forming the western side of the next small cove. Flat to low-angled bedding are the commonest internal features, although many of the beds and lenses appear massive. Small sets of cross-strata (less than 30 cm thick) indicate a southerly-directed palaeocurrent flow. This is followed by 2.2 metres of thinly interbedded sandstones and sandy grey siltstones, which are flat laminated where visible. One of the surfaces contains a possible *Taenidium barreti* trace fossil. An extensive (circa 10 metres wide and over nine metres thick) unit of sandstones overlies the sandy siltstones and forms the first main headland. Several erosional surfaces and the occasional thin pebbly layer are present in the lower part of the sequence. Bedding planes are generally discontinuous. Flat to low angled laminations are the visible internal structures. Within a small cove, this latter unit is overlain by dark grey

mudstones, and thin sandstones containing abundant plant fragments. Several more sandstone units with erosional surfaces are observed above this. The cut bank of one channel (circa 1.8 metres thick) is well-exposed immediately west of the small gorge at the beach (Plate 11). This channel, which is also figured in Graham (1996, his Fig. 8), overlies a very prominent erosion surface.

Graham (1996) noted one clear example of Inclined Heterolithic Strata (IHS) (Facies F) within the Largysillagh Sandstone Formation (GR 16463748). This single exposure of IHS is located to the east of the beach, among rocks exposed at low tide (Plate 27). On the log in Figure 12a, it is positioned from circa 44 to 46 metres from the base of the formation. The base forms a small depression in the tidal rocks. Thin bedded sandstones and mudstones dip at varying angles. Cross-strata indicate currents strongly oblique to the dip of the IHS. This distinctive bedform is discussed in Section 3.3.6). Coarse-grained sandstones overlie the inclined sandstones with an erosive base. As the exposure on the present-day tidal area is limited, an accurate estimation of the point bar width was not achieved. However, the preserved bar thickness is 2 metres, with a width of 15 metres estimated from an oblique section. The shape and dimensions of the curved erosion surfaces confining channel fills, allow some constraints on the scale of the river channels. The sandstone-fill thicknesses vary between one and three metres (rarely four metres). Widths vary from several metres to tens of metres.

Circa six metres of thin bedded sandstones and grey mudstones (Facies D and E) overlie the prominent erosion surface which marks the last thick coarse-grained sandstone (Facies B) within the Largysillagh Sandstone Formation at Shalwy. Above this surface, the sequence is generally thinner bedded and finer-grained. Some parallel bedding planes, plant fragments, iron-rich nodules and desiccation cracks are present. A dark grey mud unit (Facies E) interbedded with parallel laminated sandstones overlies the interbedded sandstones and siltstone sequence. Plant debris is abundant and most common in the dark mudstones. There is no evidence of marine fauna or wave ripples. A metre thick lenticular sandstone unit (which is cut by a small mud-filled channel) marks the top of the Largysillagh Sandstone Formation. *Taenidium barreti* and a rootlet horizon are observed on the top of the surface, immediately beneath the basal beds of the Shalwy Formation.

4.4.3.3 Traloar

Lenticular beds of buff sandstones (Facies B) and grey mudstones (Facies E) of the Largysillagh Sandstone Formation (displaying numerous erosion surfaces) are observed at Traloar, Muckros Head (refer to Figure 8 for locality). Quartz pebbles often line the erosional surfaces. Several examples of lenticular cross-strata are visible and the trace fossil *Taenidium barreti* is present.

4.4.3.4 Muckros Head

A fault is inferred to the south of the Roelough Conglomerate Formation exposure at Muckros Head. Two faulted blocks, (comprising approximately 16 metres and 50 metres sections of the Largysillagh Sandstone Formation) are exposed south of this area. Channels and erosive surfaces, with mudstones infilling irregular hollows dominate the sandstone sequences. Some *Taenidium barreti* trace fossils are exposed on the cross-bedded and laminated sandstones. The Largysillagh Sandstone Formation exposure extends across the headland towards Trabane. The cliff along this beach comprises cross-bedded grey sandstones with erosion surfaces. Foresets are from the northwest. A NW/SE fault separates this sequence from the Rinn Point Limestone Formation to the south.

A small fault-bounded block on the western side of Muckros Head displays the contact between the Largysillagh Sandstone Formation and the Shalwy (GR622742). The lower 6.5 metres of the sequence are assigned to the upper part of the Largysillagh Sandstone Formation predominated by thin bedded, mudstones (Facies D) with pedogenic carbonate glaebules and desiccation cracks. *Taenidium barreti* is observed on a sandstone surface. The Shalwy Formation commences above this surface with interbeds of grey mudstones and micrite (Facies J) (refer to Graham 1996, his Fig. 12).

4.4.3.5 Bruckless

The Largysillagh Sandstone Formation is extensively exposed within the main Donegal outcrop along the east coast of McSwyne's Bay, from Bruckless harbour to Castle Port (refer to Figure 9, Figure 21, Enclosure 4.3 and Enclosure 4.4 for localities, and Figures 23a and 23b for logs). George and Oswald (1957) referred to the rocks exposed in the

McSwyne's Bay area as 'The Bruckless Sequence'. These authors included the calcareous fossiliferous rocks of the *'Syringopora* Bed' and the Calhame Limestone Member (terms used in this study) within the sequence (Figure 22). However, these latter two units are omitted from the Largysillagh Sandstone Formation in this study and are instead assigned to the Shalwy Formation.

The sequence along the Bruckless to Castle Port foreshore is generally comparable to the Largysillagh Sandstone Formation at Shalwy (Figures 23a and 23b). However, Facies F (Inclined Heterolithic Strata) has not been observed in the Bruckless area. The Largysillagh Sandstone Formation in the Bruckless area comprises essentially buff, coarse-grained, feldspathic sandstones (Facies B) with variable red, green and grey siltstone and mudstone (Facies D) interbeds and lenses. Laminated, grey mudstones (Facies E) with plant debris are observed within the scours and regularly drape the tops of irregular sandstone beds. Minor amounts of Facies A conglomerates are observed towards the basal sections of the formation (refer to Figure 23a).

A distinctive basal contact between the Largysillagh Sandstone Formation and the Oily River Conglomerate Formation is not apparent in the Bruckless area. However, a gradational passage from predominantly red conglomerates (with minor red sandstones and mudstones) to red sandstones with minor conglomerate and mudstone lenses is observed in the Bruckless Harbour area. The Oily River Conglomerate Formation becomes less conglomeratic and less red in colour towards the top of the formation. The base of the Largysillagh Sandstone Formation at Bruckless is taken where the conglomerates become a minor constituent, restricted to basal lag deposits. This generally coincides with the sequence appearing buffer in colour.

A lot of the Facies B sandstone units at Bruckless exhibit erosional surfaces, similar to those observed within the Largysillagh Sandstone Formation at Shalwy. Several of the sandstone beds at Bruckless are tabular with planar cross strata, while other beds comprise lenticular units, and pinch out laterally over several metres. Small channels and hollows are cut through the sandstones (generally less than 40 cm thick) and are commonly infilled with plant-bearing, interbedded grey siltstones and mudstones (Plates 25 and 26). Internal geometries within these channelled sequences include planar to trough cross-stratification, low angled cross-strata and parallel laminations

(Plates 12). Palaeocurrent directions are predominantly to the south, with minor deviations to the southwest and southeast. Other units are dominated by structureless, coarse-grained sandstones.

Refer to Enclosure 4.3 (on 6 inch to one mile map) for locality numbers referred to in text below.

Many of the pebbly lags and scours contain reworked clasts of quartzite, sandstone and siltstone, in addition to coarse-grained quartz and feldspar grains. Pebbly horizons with rounded quartz clasts (up to 10 cm thick) commonly lie along bedding planes. At Location 105 (GR17485 37646), there is evidence of minor slumping, where a pebbly lag infills an irregular channelled surface. The clasts appear to 'sink' into the underlying muddy/silty unit. It appears that a rough division can be made at Bruckless Harbour (L109 GR17502 37603), regarding pebbly units. These pebbles are less common in the upper parts of the formation further south. This alteration coincides with thicker siltstone units further up-section, to the south of Bruckless Harbour.

From L113 (GR17493 37586) southwards, plant fragments are commonly observed with grey siltstones and mudstones (Facies E). At L114 (GR17495 37576) a metre-thick unit of thin, silty, dark grey siltstone lenses with plant fragments overlies an irregular sandstone surface. At L118 (GR17532 37524), coarse-grained sandstones are interbedded with light grey and green siltstone and mudstone beds (Facies D). These beds display semi-rounded structures (approximately 4 X 7 cm in diameter) which fizz upon application of acid. These structures are probably caliche structures or diagenetic concretions. At L119 (GR17521 37528), approximately four metres thick of green, red and dark grey siltstone and mudstone (Facies D) are interbedded with thin sandstone beds. The beds are all bioturbated, with some in-situ roots (indicating subaerial exposure). A small normal fault displaces the unit by 15 cm to the north and 1.2 m basaltic dyke is in contact to the south of this unit. Within a ten metre thick exposure in this area, there are four separate fining-up sequences. The sequence comprises pebbly conglomerates fining up into sandstone, siltstone and green mudstone units. At L121 (GR17551 37428), a wave-cut platform exposes well-bedded sandstones, siltstones and subordinate mudstones. Current ripples are displayed on the surface. Some of the

lenticular sandstone bodies thin out to the north and northeast over a distance of tens of metres.

Several channel complexes have been observed, especially along the Bruckless/Killaghtee coast at L155, (refer to Plate 62 - GR17554 37507) and L157 (GR17558 37492). The channels cut into a variety of lithologies ranging from coarse-grained to fine-grained clastics. Downcutting up to a one metre thick (rarely no more than two metres) into a previously deposited channel fills and siltstone beds is common in the Darney and Killaghtee area (east and southeast of Bruckless, respectively). Nevin (1973) observed that where the channels cut into the finer grained lithologies, the channel indexes exhibit a wider range of channel index than those cut into sandstone. On the northern side of McSwyne's Castle, a ten-metre thick sandstone section is observed (Plate 12). Above the flat, thin-bedded sandstones covered with barnacles, a one-metre thick unit comprises several sets of cross-stratified, coarse-grained sandstones, with an erosional surface. An irregular channel fill of predominantly low-angled sandstones overlies this unit. This is overlain by a 40 cm to 1 metre thick, red sandstone unit with little internal structure, also displaying an erosional surface. Two beds (40 and 60 cm) of fine- to medium grained sandstone overlie this. Green siltstones and several metres of coarse-grained to pebbly sandstones underlie the ruins of the castle. To the south of the castle, several other irregular lenses of sandstones with erosional surfaces and trough cross-stratifications are observed over generally flat, thin-bedded sandstones and siltstones (Plate 13).

At L155 (GR17554 37507), a complex channel system is exposed along a cliff edge (Plate 62). Several erosional surfaces are cut into cross-stratified sandstone on the western base of the section. One channel margin is exposed towards the left of the photograph. Immediately above these sandstones are interbedded sandstones and siltstones, displaying erosional surfaces. They comprise thin beds of low-angled cross-strata. A succession of sandstone channel fills, each overlying erosional surfaces (1 to 2 metres thick and up to 15 metres wide) are noted above this. Irregular lenses of green to buff coloured, silty sandstones drape over the irregular surfaces. A pebbly lag is observed along part of the base. Above this are variable interbeds (40 to 70 cm in total) of sandstone and siltstones (with possible burrows), which are abruptly cut by a channel fill. This sandstone lens contains trough-cross stratification and some low angled cross-strata.

The Largysillagh Sandstone Formation at Bruckless may to be divided into an upper and a lower part. A Lower Sequence extends from location numbers L101 (at Bruckless Harbour - GR17501 37644) (from the the base of the formation) to L113 (GR17493 37586) and possibly including L120 (GR1751237529) – towards Killaghtee. This section comprises more extensive conglomeratic horizons towards the base (compared to the upper part of the formation). In addition, the majority of red and green mudstone lithologies (Facies D) are confined to this sequence. The Upper Sequence includes L114 (GR17495 37576) to L119 (GR17521 37528) (Killaghtee) and further south towards the boundary with the Shalwy Formation at Castle Port. This sequence comprises subordinate conglomeratic horizons. The quartz and quartzite clasts now appear to be confined to thin pebbly horizons along bedding planes. Dark grey, carbonaceous mudstones, rich in plant debris and roots (Facies E) dominate the finer-grained lithologies. The channel fills are more laterally extensive in this sequence.

Transported plant debris, casts of stems, coalified wood fragments and burrows are common throughout the Bruckless sequence of the Largysillagh Sandstone Formation. *Taenidium barreti* has been observed close to the ruins of McSwyne's Castle. Buckman (1992) observed *Skolithos* ? ichnospp. *in situ* at this location in addition to Ichnogenus *Margaritichnus* and Ichnogenus *Tomaculum* observed on loose blocks.

George and Oswald (1957) maintained that Bruckless Harbour 'is eroded in silty limestones, calcareous shales and calcareous sandstones and quartzites, estimated to be about 120 feet thick....and are richly fossiliferous with large caninioids, *Michelinia*, *Daviesiella* and *Koninckopora'*. These carbonate rocks have not been observed during this study. This author notes that where the stream meets the coast (near and beneath the bridge), the lithology comprises green feldspathic sandstones. The first exposed limestones along the coast are observed at L153 (GR17552 37513) where the '*Syringopora* Bed' crops out.

4.4.3.5.1 Inland from Bruckless

The gradual transition from the Oily River Conglomerate Formation to the Largysillagh Sandstone Formation is noted from west to east in the Gilbertstown and Oily River area (refer to Enclosure 4.4). Scattered outcrops of red feldspar-rich, pebbly sandstones and conglomerates (Oily River Conglomerate Formation) grade up into buff coloured, coarse-grained, feldspar-rich, unsorted sandstones of the Largysillagh Sandstone Formation.

Towards Gilbertstown Hill, the calcareous sandstone beds of the Calhame Limestone Member (part of the Shalwy Formation) are mapped in close proximity to the conglomerates of the Oily River Conglomerate Formation (refer to Figure 9 and Enclosure 4.4). This thinning is due to several NE/SW faults in the area, which slice up the sequence and is also a factor of lateral facies change. This occurs where carbonate lenses extending from the south, interfinger with the clastics to the north. The Largysillagh Sandstone Formation is also exposed further north towards Drumdoo, east of the Oily River (GR17500 38150). This locality comprises thin beds of coarse- to medium-grained, occasionally pebbly, buff sandstones.

4.4.4 THICKNESS OF THE LARGYSILLAGH SANDSTONE FM.

4.4.4.1 At Shalwy Syncline

George and Oswald (1957) estimated the formation at Shalwy (their 'Lower Shalwy Beds') as circa 170 feet thick (52 metres). However, a more accurate thickness of approximately 63 metres was measured along the Shalwy coastline (see Figures 12a and 12b of this study, also in Graham 1996, his Fig. 6).

4.4.4.2 At McSwyne's Bay/Bruckless

Apart from several shingle beaches, a nearly continuous outcrop of the Largysillagh Sandstone Formation is observed along the eastern coast of McSwyne's Bay (Figure 21). However, the sequence is disrupted by several faults. These faults have resulted in stratigraphic repetition and correlation of sequences across faults is not always possible,

making thickness calculation difficult. However, there is almost certainly a significant thickness difference at Bruckless when compared with the thinner sequence within the Shalwy Syncline.

One such fault is the '*Syringopora* Fault', exposed north of McSwyne's Castle at Killaghtee (L153, GR17552 37513 - refer to Figure 21). This fault (trending WNW/ESE) extending from the western part of McSwyne's Bay, trends towards the mouth of the stream at Killaghtee (where there is no exposure) and continues through the peninsula to the eastern coast of St John's Peninsula. The fault is observed as a slight bending of the downthrown rocks and displays a sinistral movement as well as northerly downthrow. The *'Syringopora* Bed' (discussed more in Section 4.5.4.2.1) and subsequent units of the Shalwy Formation crop out to the north of the fault, while older, non-calcareous sandstones (of the Largysillagh Sandstone Formation) are exposed to the south. The fault results in a repeat of stratigraphy of the Shalwy Formation, as the *'Syringopora* Bed' is entirely exposed again at the cliff section Castle Port (GR17551 37428). George and Oswald 1957 failed to observe this fault, and grouped together the Oily River Conglomerate Formation and the Largysillagh Sandstone Formation and part of the Shalwy Formation (all nomenclatures of this study) as the 'Bruckless Grits'. They cited a thickness of 2600 feet (circa 860 m) for the sequence at Bruckless. However, they included the inland exposure of the Calhame Limestone unit (this latter unit has been assigned to the Shalwy Formation) within their calculation.

Sheridan (1972) (his Fig.10) reviewed George and Oswald's thickness and stratigraphic correlation. However, he did not correct George and Oswald's observation of the Calhame Limestone unit being exposed along the coast. This observation has not been substantiated in this study. The limestone is only exposed inland at Calhame and further northwards. This study correlates the Calhame Limestone unit as the inland extension of the *'Syringopora* Bed'. Additionally, Sheridan did not recognise the faulting of the *'Syringopora* Bed' at Killaghtee. Thus, in the absence of these facts, both papers have resulted in an erroneous and considerably inflated thickness for the Largysillagh Sandstone Formation. The authors discussed above have calculated the thicknesses of three sandstones within three key marine incursions. However, the sequence should reflect only one non-marine unit (the Largysillagh Sandstone Formation), i.e. the unit

between the top of the Oily River Conglomerate Formation and the last sandstone bed beneath the *'Syringopora* Bed'.

Sheridan correlates the 'Lower Shalwy Beds' (Largysillagh Sandstone Formation - this study) and the 'Upper Shalwy Beds' (Shalwy Formation - this study) at Rinn Point with the sequence beneath the 'Bruckless - Calhame Limestones and Shales' at Bruckless. He correlates the 'Bruckless - Calhame Limestones and Shales' with the 'Rinn Point Beds'. In doing this, Sheridan then would have a problem with sequences above the 'Bruckless - Calhame Limestones and Shales'. As Figure 22 of this study displays, Sheridan could not correlate any of beds from above the 'Bruckless - Calhame Limestones and Shales' to any sequence at Rinn Point.

Buckman (1992, his Fig.2.1) correlates the Shalwy sequence to the Bruckless area. He disagrees with George and Oswald's thickness value at Bruckless (792 metres), claiming that faults perpendicular to strike have caused repetition; thus, leading to an increase in the thickness of the succession. Nevin (1973) also reached this conclusion. Buckman (1992) eliminated both the 'Bruckless-Calhame limestone' and the *'Syringopora* Bed' from the measured sequence of George and Oswald (1957) at Bruckless. This is based on these stratigraphic units being younger than the Largysillagh Sandstone Formation, and not being observed within the Largysillagh Sandstone Formation elsewhere in the Donegal Basin. This study agrees with this approach.

Nevin (1973) presented a thickness of 465 metres for the 'Coarse, often pebbly; arkosic grit and siltstone in fining-upward sequences; channel-fill and lenticular grits and sandstones common throughout: extensively developed large scale cross-stratification. Red beds in lower part' and 75 metres for the 'arkosic grit and siltstone in fining-upward sequences, channel-fill units present, but not conspicuous; extensively cross-stratified; locally developed ripple-marked surfaces'. Part of the latter value of 75 metres may be assigned to the Shalwy Formation. However, the value of 465 metres for the Largysillagh Sandstone Formation appears to be too large. Al Rawi (1972) assigned a thickness of 2,200 feet (approximately 720 metres) to the 'Bruckless Formation'. However, he includes the Calhame Limestone Member within this calculation, which is erroneous.

From field evidence in this study, there is approximately 210 m of section present from Bruckless Harbour to the *'Syringopora* Bed' at Killaghtee (the latter location marks the base of the Shalwy Formation). In addition, there is an additional 200 metre width in horizontal gaps as beaches and non-exposure (thus, possibly an extra 80 metres of section). It is possible that many of these gaps delineate zones of faulting. It is difficult to reach a conclusive thickness value for the Largysillagh Sandstone Formation at Bruckless. An estimated thickness range of 220 to 280 metres is suggested here, but with acknowledged uncertainty.

4.4.5 PALAEOCURRENT ANALYSIS OF THE LARGYSILLAGH SANDSTONE FM.

Palaeocurrent data from tabular and trough cross-strata within the Largysillagh Sandstone Formation are generally to the south/southeast (refer to Figure 24). They show more variability than the Oily River Conglomerate Formation, but still have an obvious unimodal trend.

4.4.6 PROVENANCE OF THE LARGYSILLAGH SANDSTONE FM.

The clasts within the conglomerate and pebbly sandstone lenses comprise predominantly quartzite and veined quartz. In general, the tabular beds are predominantly medium-grained and well sorted. The main constituents of the sandstones are quartz, pink and white feldspars with some minor mica grains. The sandstone grain sizes are variable, ranging from pebbly sandstones through to the medium and fine size ranges. It is thought that the Dalradian hinterland to the north of the Donegal Basin provided a lot of material for the Largysillagh Sandstone Formation as with the conglomerate units (Roelough Conglomerate Formation and the Oily River Conglomerate Formation) that underlie this formation. However, the more feldspathic sandstones are probably associated with a granitic source. The nearest exposed granite is in the Barnesmore area (some 22 kms to the east), although palaeocurrents directions do not match this source. The Ardara Pluton (approximately 10 kms to the north) may have provided some material for these sandstones.

4.4.7 AGE OF THE LARGYSILLAGH SANDSTONE FM.

During this study, five samples of siltstone and mudstone from the Largysillagh Sandstone Formation were submitted for palynology. Some disintegrated spores were recorded, although none of the samples yielded dates.

Higgs (1984, p184) recorded a Pu Biozone assemblage from the 'Bruckless Grits' (renamed the Largysillagh Sandstone Formation in this study). However, it appears to be from an unspecified horizon (Higgs 1996, pers. comm.). The Pu Biozone assignation indicates an early Viséan to Arundian age and is thus of limited precision.

The Largysillagh Sandstone Formation underlies the Calhame Limestone Member and the *'Syringopora* Bed' of the Shalwy Formation. Both of these units yielded typical Lower Viséan fauna; thus, the Largysillagh Sandstone Formation is also assigned a Lower Viséan age.

4.4.8 DEPOSITIONAL ENVIRONMENT OF THE LARGYSILLAGH SANDSTONE FM.

The Largysillagh Sandstone Formation comprises a variably sized clastic sequence ranging from conglomeratic lags, coarse- to fine-grained sandstones, siltstones, variegated sandy siltstones and grey, plant rich mudstones.

The presence of numerous channels, erosional surfaces on sandstones and the relatively poorly sorted, coarse-grained sandstones and conglomeratic horizons are all typical of limited length bedload rivers. Fining-up sequences from pebbly to coarse-grained sandstones to fine-grained sandstones and siltstones to mudstones indicate waning flow sequences within the fluvial channels.

Only unidirectional current directions have been observed within the Largysillagh Sandstone Formation. The cross-stratified sandstone units (both tabular and cross-stratified) display variable set thicknesses (commonly up to 1.4 metres thick), indicating the scale of dune and bar heights. The tabular sets are normally produced by straight-crested dunes. Trough cross-bedded sandstone records migration of sinuous-crested

dunes along the lower surfaces of point bars (Collinson and Thompson 1989). Other beds display flat to low angled lamination (inferring a higher velocity flow, possibly due to locally lower flow depths). While laminations may occur at any level in a channel sandstone, they tend to be more common towards the top. Allen (1970) observed that an increase in the overall power of the stream increases the relative abundance of large-scaled as compared with small-scale cross-stratification. He suggested that a decrease in sinuosity in the channel increases the relative abundance of plane lamination.

The isolated example of the unidirectional Inclined Heterolithic Strata (Facies F) within the Largysillagh Sandstone Formation (east of Shalwy beach) implies deposition within a migrating point bar system of a fluvial channel. A point bar is formed on the inside bends of meanders. Sediment derived from erosion and collapse of the outer banks is moved as bed load by the secondary circulation onto the inner bank of the next bend downstream, or is diffused by turbulence as suspended load into the regions of lower velocity and shallow water and deposited close to the banks. The result is the deposition of a crescent-shaped bar of sand at the inner bend of the river. The point bar has a surface that slopes into the channel at an angle of a few degrees and grows by accretion in an obliquely downstream direction (Blatt *et al.* 1972, Friend 1983). This specific IHS feature at Shalwy occurs near the top of the formation, where the stratigraphic position suggests a lower gradient coastal plain might be expected. The upper sequence of the formation at Bruckless comprises a higher percentage of grey mudstone units. This coincides with a higher preservation of plant debris and better segregation of channel and non-channel geometries, and contrasts with the multi-channel bedload rivers of the lower part of the formation.

Plant debris was washed into the fluvial system; thus, suggesting a vegetated hinterland, at least in areas adjacent to the rivers. Subaerial exposure is indicated by numerous rootlet horizons and pedogenic nodules and also by the presence of desiccation cracks. It is possible that the contrast in mudstone colours (from predominantly variegated to grey) throughout the formation is indicative of a rising of the water table towards the surface through time.

The Largysillagh Sandstone Formation contains several *Taenidium barreti* trace fossils with occasional small examples of *Skolithos*? and rare *Cochlichnus* ichnosp. As discussed previously, *Taenidium barreti* has only been reported in non-marine environments. Buckman (1992) commented on the low diversity and interpreted a *Scoyenia* ichnofacies for the formation.

The basal conglomerate lags and the-upward fining suggest deposition in mixed-load fluvial systems (LePain, Crowder and Wallace 1994). In summary, the Largysillagh Sandstone Formation is inferred as being deposited largely in bedload dominant channels of meandering streams and their associated flood plains. Meandering channels are characterised by having a coarse lag deposit overlain by progressively finer grained point bar sediments deposited by lateral accretion, commonly showing characteristics of decreasing flow regime. The flood plain sediments show evidence for exposure and soil forming processes. They are also formed in abandoned channels. The fining up sequences can be interpreted as waning flow events formed during significant floods. There is no evidence of marine influence within the formation. The trace fossil evidence is consistent with the fluvial environment deduced from the physical structures.

4.5 THE SHALWY FORMATION

4.5.1 INTRODUCTION

The Shalwy Formation was originally named the 'Upper Shalwy Beds' by George and Oswald (1957). Buckman (1992) referred to the unit as the 'Largymore Sandstone Member', while Nevin (1973) assigned it the 'Upper Sandstone' of the 'Bruckless Grits'. Graham (1996) renamed this unit the Shalwy Formation, after the well-exposed section along Shalwy Point (refer to Figures 8 and 11 for locality and Figure 12b for a log). Both the basal contact of the Shalwy Formation with the Largysillagh Sandstone Formation and the upper contact with the Rinn Point Limestone Formation are observed along this headland.

The Shalwy Formation is also recognised along McSwyne's Bay and inland (refer to Figures 9 and 21 for locality and Figure 29 for a log of this unit). In this area, the formation contains two distinctive limestone units, the '*Syringopora* Bed' (Section 4.5.4.2.1) and the Calhame Limestone Member (Section 4.5.4.2.4).

4.5.2 LITHOFACIES OF THE SHALWY FORMATION

The Shalwy Formation comprises a predominantly clastic sequence, which includes black, plant-rich mudstones, variegated to grey mudstones, siltstones, fine- to coarse-grained sandstones, calcareous sandstones, arenaceous limestones, argillaceous limestones and micrites. In its entirety, Facies B, C, D, E, F, G, H, J, and K are represented within the Shalwy Formation. The formation differs from the Largysillagh Sandstone Formation by the presence of more tabular geometries, the calcareous constituents and evidence of bipolar palaeocurrents.

The coarse-grained sandstones of Facies B are common within lower part of the Shalwy Formation, where they are cut by numerous erosional surfaces. These sandstone sequences are generally comparable in composition to those of Facies B in the Largysillagh Sandstone Formation. However, in the Shalwy Formation they typically display more tabular geometries, as downcutting and channel complexes are not so common. Several pebbly horizons are observed within the Facies B tabular sandstone

beds at Castle Port. Facies C coarse-grained sandstones display bipolar beds and locally unimodal palaeocurrent directions to the north (in contrast to the southerly-directed unimodal palaeocurrents in the underlying formations). Facies C sandstones are variably calcareous to non-calcareous. Facies D variegated mudstones and siltstones are less common compared to the Largysillagh Sandstone Formation. However, some distinctive laterally extensive 30 to 50 cms thick lenses have been noted, especially at Castle Port. One of these lenses pinch out to the south over approximately 10 metres. Bioturbation and a possible rootlet are observed towards the top of this buff siltstone lens (Plate 23). The plant-bearing grey mudstones of Facies E are relatively abundant, especially in the basal sections of the Shalwy Formation, where they commonly infill irregular hollows.

The inclined heterolithic strata (IHS), Facies F, are observed at several localities within the Shalwy Formation at Shalwy. The IHS structures at Shalwy vary from sandstone dominant to mudstone dominant (refer to Section 4.5.4.1). The latter variant locally contains abundant fusain (fossil charcoal). IHS structures were not observed in the section along Castle Port (within the main outcrop of the Donegal Basin). However, the section in the latter area is strongly two-dimensional and much more limited in extent and this absence may be a function of exposure.

Ripple-scale bedforms and flat to low-angled laminations are observed within the fine- to medium-grained sandstones (Facies G) at Shalwy and Castle Port. Some hummocky cross-strata are present within the finer-grained sandstones, especially at Rinn Point. The sandstones generally display good sorting. Angular quartz grains and pebbles are commonly present within the calcareous, coarse-grained sandstones of Facies H. The pebbles generally line on horizons parallel to bedding, although angular grains are also noted within the calcareous matrix. These calcareous sandstones and minor sandy limestones frequently display intensive bioturbation. *Syringopora* corals, crinoids, brachiopods and other broken shells are the most common fossils within these coarse-grained clastics. Facies J comprises distinctive beds of black, commonly plant-rich mudstones with associated micrite lenses and septarian nodules. Both the mudstones and the micrites commonly contain gastropods and ostracods. Several occurrences of this facies have been observed at Shalwy and south of Castle Port.

The upper part of the Shalwy Formation becomes more calcareous with tabular interbeds of the bioturbated, calcareous, coarse-grained sandstones (Facies H) and intensively bioturbated, argillaceous, fossiliferous limestone (Facies K). Towards the contact between the Shalwy Formation and the overlying Rinn Point Limestone Formation, the argillaceous limestone beds are interbedded with calcareous, fossiliferous, bioturbated silty/shaly beds. Fossils in the upper part of the Shalwy Formation include *Syringopora*, *Caninia* and horn corals, brachiopods, bivalves, and crinoidal debris. The amount of bioturbation, horizontal and vertical burrows also increase towards the top.

Buckman (1992) stated that 'The Largymore Sst. Member (Shalwy Formation in this study) is characterised by the appearance of a more diverse range of trace fossils, in particular *Rhizocorallium* and the apparent disappearance of Beaconites'. Buckman noted that this formation comprised a moderate diversity in which the most important elements are walled burrows - *Arenicolites curvatus*, *Palaeophycus* and *Scaubclindrichnus*, *Diplocraterion*, *Chondrites*, *Rhizocorallium*, and *Zoophycus*. Only *Chondrites* and *Palaeophycus herberti* were recorded from all localities. Buckman (1997) recorded an unusual new trace fossil *Intexalvichnus magnus* from the lower part of the Shalwy Formation at Castle Port (G17533746).

4.5.3 MICROFACIES AND MICROBIOTA OF THE SHALWY FORMATION

4.5.3.1 Thin-section analysis

The following thin-sections are sampled from carbonate units within the Shalwy Formation:

TCD No.50569, 95-03iii	Castle Port, McSwyne's Bay (GR17558 37439)
TCD No.50570, 95-05I	Rahan Far, McSwyne's Bay (GR17540 37413)
TCD No.50572, 95-11	Kiln Port, St John's Peninsula (GR17568 37398)

Refer to Appendices 1 and 4 for further information regarding location and grain component analysis on these and other samples within this formation.

The carbonates within the Shalwy Formation are assigned argillaceous biomicrite and poorly washed biosparite under the classification of Folk (1962) and wackestone/subordinate packstones under Dunham's classification (1962). The sections sampled include fragments of bivalves, brachiopods, bryozoa, calcispheres, gastropods, echinoderms, *Girvanella,* salebrids (these resemble bryozoans but are of uncertain affinity) and ostracods. *Earlandia* and *Endothyra* foraminifers appear to be the only foraminifers present.

4.5.4 LOCALITY DESCRIPTIONS OF THE SHALWY FORMATION

4.5.4.1 Shalwy Syncline

The 'type section' of the Shalwy Formation is exposed east of the beach at Shalwy (GR16465 37463, refer to Plate 63). The basal contact with the Largysillagh Sandstone Formation is exposed and displays a conformable, but abrupt change from the dominantly sandstone sequence beneath. The base of the Shalwy Formation is placed at the first intensely bioturbated mudstones and sandstones above a rootlet bed of the Largysillagh Sandstone Formation (refer to Figure 12b in this study - and in Graham 1996, his Fig. 6). The Facies J mudstones with associated micrites and septarian nodules contain a gastropod and ostracod fauna. These basal beds display extensive bioturbation and numerous burrows and some of the mudstones appear to be pyritous. A prominent one metre thick and approximately six metres wide channel (infilled with Facies B sandstones) cuts into other channelled sandstones which overlie Facies J micrites and carbonaceous siltstones (refer to Plate 64 and Figure 25 - green coloured channel, and Figure 12b at 101 metres). The coarser-grained sandstones of Facies B within the basal ten metres appear to be fluvial in origin (as they display southerly flowing unidirectional palaeocurrents). The sandstones are similar in geometry to the sandstones that dominate the Largysillagh Sandstone Formation.

Graham (1996) noted that some of the 'sandstones have a more tabular geometry and are extensively bioturbated. These sandstones are characterised by ripple-scale bedforms and flat lamination. Some ripples indicate oscillatory currents (using the criteria of De Raaf *et al.* (1977)'. He was referring to the Facies G in this study. Sandstones with bipolar currents

ripple lamination (Facies C) are also observed within the Shalwy Formation at Shalwy. Most of the sandstones are silty, micaceous and quite bioturbated.

The lowest occurrence of abundant marine fauna at Shalwy is associated with the first of the Inclined Heterolithic Strata (Facies F) in the Shalwy Formation. This occurs 11.5 metres from the basal contact with the Largysillagh Sandstone Formation (at 109.6 metres on the log in Figure 12b). Other IHS geometries have been noted at 33 metres, 44 metres and 48 metres from the base of the Shalwy Formation at Shalwy (Refer to Figure 12b – brown coloured units). For a discussion on IHS, refer to Section 4.5.4.1.1 below. Further up-section, Facies H is represented by the calcareous sandstones and sandy limestones, which contain variable amounts of broken shell debris.

The upper part of the Shalwy Formation within the Shalwy Syncline grades into alternating beds of bioclastic limestone and calcareous shale of the Rinn Point Limestone Formation (Facies H and K). Within the transition zone, there are fine-grained sandstone beds displaying hummocky cross stratification (Facies G). Other units are very bioturbated, with burrows displayed frequently on the bed surfaces (Facies H). Quartz granules are common in some beds. This transition is well-exposed along the eastern part of the headland at Rinn Point.

4.5.4.1.1 Inclined Heterolithic Strata at Shalwy

One important feature within the Shalwy Formation is the presence of units of Facies F 'Inclined Heterolithic Strata' (IHS) (see Plates 28, 29 and 30). The following observations have been noted in the Shalwy Formation:

- units show palaeocurrents strongly oblique to perpendicular to the dip of the IHS
- some of the strata display bipolar palaeocurrents
- surface dips are relatively low (few degrees to maximum 20 degrees)
- marine shell debris is common

Nichols and Jones (1992) postulated that the gently inclined cross-strata that form these bedsets represented the lower part of sandwave slipfaces. Graham (1996) considered the following points in rejection of the sandwave theory:

- The inclined beds vary from sand-rich to mud-rich units. This would not be consistent with an interpretation of sandwaves, as sandwave models apply only to cohesionless sediments (Allen 1980).
- The values of the dips are generally less than 10^0, reaching a maximum of 20^0. Tectonics has not affected the sediments to any great extent, so these appear to represent true dip values. These values do not agree with avalanche faces of sandwaves.
- Small-scale cross-strata (found within the inclined beds), indicate a flow direction strongly oblique to the inclination of the heterolithic bedsets.
- The units are found in close proximity to indicators of very shallow water and/or exposure (e.g. rootlets at 133.8 metres in Figure 12b).
- The bedsets conform to the description of IHS by Thomas *et al.* (1987).

Tidal channel point bar deposits are interpreted for the origin of the IHS. The gentle dips, heterolithic character and marine fauna observed at Shalwy support this interpretation.

4.5.4.1.2 Fusain Units at Shalwy

Another feature restricted to the Shalwy Formation in the Donegal Basin is the presence of fusain-rich units. The term 'fusain' is used to describe material that has a silky lustre, is black, fibrous, soft and resembles wood charcoal. Large amounts of charcoal and partially charred debris can be produced in palaeowildfires, which then become incorporated into natural drainage systems. These fossilised charcoalified plants are referred to as fusain (Nichols and Jones 1992, Jones 1994, Scott and Jones 1994). Other examples of the fusain have been recognised at Rinn Point and Muckros within the Shalwy Formation (Graham 1996). A previously undocumented thin 'Fusain unit' has also been observed in this study south of Kiln Port (L226, GR17502 37333), within the main Donegal Basin. It is located within a faulted section of the Shalwy Formation (refer to Figure 28 for location within Shalwy Formation).

Nichols and Jones (1992) examined twenty metres of section from the middle of the Shalwy Formation (refer to Figures 26 and 27 of this study). Five sandstone bodies (SB1-SB5- refer to Figure 26a) are depicted on their log and two others (SBA and SBB)

are laterally equivalent to parts of the measured section. SB1 is the most completely exposed sandstone body (Plate 28). It is 2.8 m thick in the line of Nichols and Jones's graphic log, and comprises medium-grained sandstone. Individual beds are tens of centimetres thick. Each bed is inclined to the depositional horizontal, decreasing along the length of the bed to form asymptotic cross-strata (Figure 26 b). The top of this bed is truncated by an erosion surface. This sequence is one of the examples of 'Inclined Heterolithic Strata' units described by Graham (1996) and corresponds to Facies F in this study. Each of the other sandstone bodies display similar cross bedding, superimposed on metre-scale cross-stratification. The overall geometry of the bodies is lenticular, comprising an erosive base and may have an eroded top. Cross-bedded sandstones are often separated by thin layers of clay. These layers often thicken towards the base of the cross-set and are best observed in SB5 and SBB (Nichols and Jones 1992).

Between sandstone bodies SB3 and SB4, thinly bedded, black shales and dark grey sandstones comprise a lenticular body. Rich beds of fusain fragments are observed within this body and have been referred to as the 'Fusain unit' by Nichols & Jones (1992) (refer to Figure 26c). The 'Fusain unit' ranges in thickness form 1.1 to 2.45 metres and contains up to 20 % fusain, concentrated into distinctive layers. Scott and Collinson (1978) noted that the fusain bands comprise putative gymnosperm plants and pseudoherbaceous lycopod flora. Reflectance measurements within the unit range from 1.5 to 6.5% R_{ro}. Degree of maturation explains the absence of reflectances below 1.5% $_{ro}$ (Scott and Jones 1994) (refer to Figure 26d of this study).

Jones (1994) analysed ^{13}C enriched plants within the fusain units. Isotopic analysis (from samples along Shalwy Point and Muckros Head) revealed the fossils to be isotopically anomalously heavy ($\delta^{13}C$ = -16.4 – 19.3%), when compared with other known deposits of similar age, plant assemblages and history. Jones noted that (apart from one fusain-vitrinite-fusain transition fossil) only fusinized plant remains were found within the sampled unit. This contrasts with 'modern forest floor litter at wildfire sites even in sites where intense forest-fires have burned', which display a 'significant percentage of uncharred or partially charred material'. He proposed that 'a likely 'sorting' mechanism could be the preferential removal of non-charred material by some form of biodegradation'. Biodegradation must have occurred after the material was transported,

segregated and deposited. Jones (1994) concluded that this specific fossil plant material contains 'isotopic ratios falling outside the range of modern C3 plants'. It is hypothesised that the anomalously isotopically heavy Donegal material is the end product of an, as yet, undetermined isotopic fractionation process associated with maturation or diagenesis (Jones 1994, Scott and Jones 1994).

The fusain unit at Rinn Point is located within a faulted section of the Shalwy Formation. This locality comprises an 80 cm thick bed of interbedded sandstone and mudstone, overlying an irregular topography at the top of a sandstone body. Nichols and Jones (1992) indicated that this unit comprised part of the same fusain unit at Shalwy. This assumption was based on the inferred stratigraphic position and the similarity of lithofacies. A locality (within the fault-bounded block of Shalwy Formation) at Muckros Head comprises cross-bedded lenticular sandstone bodies, interbedded with dark silty shales. Nichols and Jones (1992) stated that these beds were an equivalent stratigraphic horizon to the sandstone bodies SB1 - SB5 at Shalwy Point. Fusain is abundant in this unit and was considered by Nichols and Jones to being equivalent to the fusain unit at Shalwy. However, it was suggested that these were all separate units by Graham (1996), a view supported by the work in this thesis as discussed below.

Nichols and Jones (1992) considered the three fusain exposures discussed above (Shalwy, Rinn Point and Muckros Head) as comprising 'a single unit, which was deposited coevally at all three localities'. The authors stated that the fusain unit occurs in a stratigraphically similar position in the upper part of the cross-bedded sandstones and below the dark shales with septarian nodules unit. The unit varies from 2.45 metres thick on the northwestern exposure to 1.7 metres (in the logged section) and thins more towards the southeast, where it is 0.8 metres thick at Rinn Point. The fusain unit at Muckros is 1.1 metres thick. Nichols and Jones (1992) considered the thickness variation to be the result of deposition, over an undulating surface created by the underlying sandstone bodies (their SB2, SB3 and SBA).

Nichols and Jones (1992) estimated the size of the palaeowildfire (which produced the fusain) by considering the thickness and extent of the fusain unit, calculating the volume of fusain present, and comparing this to the volume of charcoal produced by the

burning of a modern forest fire. A value of >95, 000 km^2 was suggested and an estuarine facies association (varying from hundreds of metres to several kilometres wide) was their preferred environmental model (refer to Figure 26e). Scott and Jones (1994) maintained that this area is about three times the size of the Great Fire of Borneo (1982/1983) (after Johnson 1984) and approximately equivalent to the present size of Ireland.

However, Graham (1996) criticised Nichols and Jones's method of calculating the areal extent of the drainage basin. Evidence shows that the beds are not from the same stratigraphic level. The fusain unit (above the IHS bed) at Rinn Point contains less fusain, and comprises a slightly different sedimentological character, compared to the fusain unit at Shalwy. Nichols and Jones (1992) based their stratigraphic correlation on measuring down from the base of the Rinn Point Limestone Formation (refer to Figure 27). However, a fault is recognised at Rinn Point and a detailed correlation is not possible across it. The black mud with septarian nodules (used in correlating the unit at Shalwy with the Muckros Head unit), is not recognised above the IHS bedset (designated the Fusain Unit) at Rinn Point. Graham (1996) suggested that the two beds being correlated by Nichols and Jones (1992) (at Shalwy and Muckros Head) are in fact, 40 metres apart in a vertical section. Confirmation of the base of the Largysillagh Sandstone Formation at Muckros in this study supports this interpretation. It is suggested here that each fusain unit is lenticular and of limited extent. The units are interpreted as representing lateral accretion of tidal point bars, instead of comprising part of a sequence of sandwaves, as postulated by Nichols and Jones. Consequently, the beds containing the fusain would not represent the same stratigraphic level. The tidal point bar interpretation also leads to the calculation of a smaller drainage basin for the palaeowildfire, as each individual fusain bed must be resolved individually.

It is now clear that several wildfire events are preserved and thus, it seems likely that wildfires were a common phenomenon as might be expected (Scott and Jones 1994, Falcon-Long 1998, 1999).

4.5.4.2 McSwyne's Bay area

The base of the Shalwy Formation (comprising the '*Syringopora* Bed') is exposed south of Killaghtee (see Section 4.5.4.2.1 below), on the eastern side of McSwyne's Bay. The Shalwy Formation is well-exposed at Castle Port (refer to Figure 21 and Enclosure 4.3). A limited faulted section is exposed south of Kiln Port (refer to Figure 28 for location). Inland, the Shalwy Formation has been mapped from scattered exposures, although assigning boundaries is difficult. The Calhame Limestone Member (discussed in Section 4.5.4.2.4) crops out as a north-south lens to the north of Bruckless (refer to Enclosure 4.4).

4.5.4.2.1 THE '*SYRINGOPORA* BED'

4.5.4.2.1.1 INTRODUCTION

A quartz-rich limestone unit is exposed along the foreshore at Killaghtee (GR17552 37513 – refer to Figure 21 and Enclosure 4.3) and was named the '*Syringopora* Bed' by George and Oswald (1957). This informal name is retained in this study for descriptive purposes. The *'Syringopora* Bed' is the oldest calcareous unit along McSwyne's Bay. It is exposed north of a WNW/ESE trending fault (the *'Syringopora* Fault') (refer to Figure 21 and Plate 65). As discussed in Section 4.4.4.2, this results in a repetition of the sequence again further south at Castle Port. A formational boundary between the Largysillagh Sandstone Formation and the Shalwy Formation can be established in this latter area.

4.5.4.2.1.2 LITHOFACIES OF THE '*SYRINGOPORA* BED'

At Killaghtee coast (SE of Bruckless), the Largysillagh Sandstone Formation is overlain by a calcareous unit, rich in the coral *Syringopora* and containing quartz grains, shelly debris, and some iron enrichment. The unit is approximately 1.3 metres thick (refer to Plate 65). The base of the bed consists of an erosional surface overlain by a pebbly lag, comprising angular quartz grains and shelly debris within a calcareous matrix. This is overlain by a calcareous sandstone unit, followed by a bioturbated,

calcareous sandstone unit. The top of the bed comprises a calcareous sandstone unit comprising *Syringopora* corals, crinoidal debris, gastropods and sub-angular quartz pebbles. Bioturbation is relatively intense. The samples are relatively rich in iron oxides.

4.5.4.2.1.3 MICROFACIES OF THE '*SYRINGOPORA* BED'

4.5.4.2.1.3.1 Thin-section analysis

The following thin-sections have been sampled from the '*Syringopora* Bed':

TCD No.50504, L153 i, ii, & iii	Killaghtee, McSwyne's Bay (GR17552 37513)
TCD No.50568, 95-01i	Killaghtee, McSwyne's Bay (GR17552 37513)

The '*Syringopora* Bed' comprises sandy limestones and calcareous sandstones. The calcareous sandstones are unsorted and immature with common feldspars. The more carbonate rich samples are biopelmicrites with quartz grains. The amount of quartz is circa 25 % and the amount of ferric oxide cement is variable (c. 11%). The samples contain fragments of bivalves, brachiopods, bryozoa, moravaminid, echinoderms, gastropods, *Koninckopora* sp., and salebrids. The foraminifers *Endothyra* sp. and *Earlandia minor* are also present. Higgs and Sevastopulo (1983) reported the presence of *Earlandia minor*, *Endothyra* spp., *Girvanella staminea* and kamaenids within Sample 74/1003 of the '*Syringopora* Bed'.

4.5.4.2.1.3.2 Conodont analysis of the 'Syringopora Bed'

TCD No. 50504, L153 '*Syringopora* Bed' Killaghtee (GR17552 37513)

Conodont sampling within the '*Syringopora* Bed' was not successful during this study, as only one juvenile Pa element was extracted from Sample L153. This element may be *Clydognathus* or *Mestognathus*. *Polygnathus* sp. was extracted from this horizon by Sevastopulo in Higgs and Sevastopulo (1983). This conodont does not range higher than early Arundian. Sevastopulo assigned the '*Syringopora* Bed' a lower Viséan age. (previously termed late Chadian – refer to Chapter 8 for more discussion).

4.5.4.2.1.3.3 Point Counting analysis of the 'Syringopora Bed'

Sample L153 comprises 18.3 % monocrystalline quartz. Polycrystalline quartz is rare at 1.6 %. K-feldspar and plagioclase total 8.2 %. Calcite cement accounts for 1. 6 %, and iron oxides for 11.3 % of the total. Shelly debris constitutes 28 %, while 1.3 % of rock fragments were observed.

4.5.4.2.1.4 DISCUSSION ON THE '*SYRINGOPORA* BED'

The '*Syringopora* Bed' is the first (lowest) calcareous unit, overlying the non-marine Largysillagh Sandstone Formation. The presence of coarse-grained quartz, intensive bioturbation and iron enrichment within the '*Syringopora* Bed' may imply a lag deposit. These deposits commonly occur by slow accumulation of coarse material in a zone of winnowing (Tucker 1990).

The '*Syringopora* Bed' is thought to extend laterally to the north. Exposure is poor in this inland area, although the nineteenth century Geological Survey noted dark shaly limestone in a stream section NW of Beaugreen Glebe (GR17584 37624). This would be on strike with the '*Syringopora* Bed'. Nevin (1973) noted approximately 80 cm of limestone and shale in a small outcrop in the old railway cutting near Killaghtee Old Church. This exposure has not been observed during this study and does not appear to be extant now. The '*Syringopora* Bed' may equate with the Calhame Limestone Member (which crops out inland, north of Bruckless and is discussed in Section 4.5.4.2.4 – refer to Enclosure 4.4). Such correlation would entail questioning the thickness difference between both units. A 1.3 metre thick unit is strikingly thinner than the nearly 30 metre thick Calhame Limestone Member. The '*Syringopora* Bed' is inferred to be more proximal to the shelf and the difference in thickness could be explained by interpreting the '*Syringopora* Bed' as a condensed section.

According to Haq (1991) and Loutit *et al.* (1988), condensed sections are commonly characterised by thin zones of burrowed, and somewhat lithified beds. Slow sedimentation rates caused by sediment starvation may also concentrate authigenic minerals, pelagic fossils, organic matter and trace elements. As a transgression proceeds, the 'transgressive facies continue to be deposited progressively further updip

(landward) until the time of maximum flooding of the shelf, marked by a surface, the *maximum flooding surface*. The transgressive systems tract thins basinward and fines upwards, forming a condensed section at the maximum flooding surface owing to sediment starvation as the depocentres move landward' (Haq 1991). Thus, the '*Syringopora* Bed' unit may be interpreted as forming at a flooding surface, owing to sediment starvation as the depocentres moved landward. The iron enrichment and content of pebbles within the analysed samples could support this hypothesis. A rapid rise of base level causes rapid transgression of the shelf; hence, less time to accumulate sediment at specific sites, resulting in thinner transgressive deposits (Wood *et al.* 1993).

(Localities continued)

4.5.4.2.2 Shalwy Formation - Castle Port

The logged section at Castle Port (Figure 29) is generally similar to the 'type section' at Shalwy. However, the Inclined Heterolithic Strata (Facies F) appears to be absent from this locality, and only one fusain-rich unit has been observed in this study. This is confined to the faulted sequence south of Kiln Port. The log in Figure 29 represents only one possible profile through the Shalwy Formation. There is very considerable lateral variation over short distances, as might be expected, given the interpreted coastal depositional environment for these rocks.

The top part of the Largysillagh Sandstone Formation at Castle Port comprises a metre thick, cross-bedded, lenticular, coarse-grained sandstone with erosional surfaces. This is followed by a 60 to 80 cm bed of thin, interbeds of fine-grained sandstones and siltstones (Plate 66 - sediments underneath the red line, and in Figure 29). An underhang of well sorted, fine-grained sandstones above these latter sediments comprises 'rib and furrow', micro cross lamination of Facies G (refer to Plate 33). This bed marks the base of the Shalwy Formation.

A thin, generally tabular bed (25 cm) of sandy siltstone with vertical burrows and pebbles towards the top overlies the 'rib and furrow sandstones'. This bed is overlain by 15 cm of bioturbated siltstone, and is followed by 25 cm of fine to medium grained, parallel laminated sandstone. A 10 cm thick bioturbated siltstone follows, and is overlain by a 20 cm variable coarse to fine sandstone. This sandstone bed contains ripples, parallel laminations and low-angled cross-strata. The sequence described above varies along the contact due to lateral facies variation and are all classified as Facies G. A tabular calcareous unit is exposed towards the cliff-top (top part of Plate 66). This can be correlated with the '*Syringopora* Bed' exposed at Killaghtee (refer to Section 4.5.4.2.1). The '*Syringopora* Bed' comprises two units (approximately 100 cm in total) of sandy limestone with quartz clasts, some up to 6 cm in diameter (refer to Figure 29). *Syringopora* coral colonies are exposed and the unit is intensively bioturbated. Crinoidal debris is noted within the upper unit. Shaly partings and flasers are present throughout. The Shalwy Formation at Castle Port typically comprises planar cross-bedded and parallel laminated sandstones within channelised sequences. Erosion

surfaces are common and interbeds of fine-grained sandstone and siltstone (with rootlet horizons and plant fragments) overlie the erosional surfaces. At a cliff face at Rahan (Castle Port), a distinctive sandstone 'lens' of a channel margin is preserved between erosional surfaces and is overlain by thin lenses of sandstone and siltstone, which pinch out towards the crest of the eroded sandstone top (Plate 67). Cross-stratification (possibly bipolar) and ripples are preserved towards the top of the coarse-grained sandstone (Plate 68).

At L122 (GR17543 37404), the first of the debris rich, bioturbated carbonate sequences commences, with the gradual transition with the Rinn Point Limestone Formation occurring over several metres. *Syringopora* corals, crinoid ossicles and limestone intraclasts (generally 10 to 15 cm in diameter) are present within these tabular beds of bioturbated, argillaceous limestones with interbeds and flasers of calcareous shales.
A conspicuous one metre thick, single sandstone set, with a palaeocurrent flow indicator to the south (Plate 69) is noted towards the top contact of the Shalwy Formation. This sandstone is buff, coarse, non-calcareous and well sorted, with lensoid shaped foresets (thicknesses between 10 and 4 cm). There is typically size segregation along the foresets and a downward change from a steep angle of repose to more gently dipping bottom sets of finer grained sediments (Tucker 1991). An interpretation for this unit is discussed in Section 4.5.9. The sandstone is gradationally overlain by a bioturbated, sandy limestone, which becomes more calcareous and bioturbated towards the top of the unit. The top of this unit equates with the top of the Shalwy Formation. A thicker carbonate sequence of the Rinn Point Limestone Formation overlies it and continues southwards along the peninsula.

4.5.4.2.3 Shalwy Formation - Kiln Port to Port Ned

As discussed above, the Shalwy Formation is overlain by the biodebris-rich, bioturbated, argillaceous limestones of the Rinn Point Limestone Formation at Kiln Port (GR17544 37411 - refer to Figures 9 and 21 for locality and to the upper part of the log in Figure 29).

The Shalwy Formation is exposed again beneath the Rinn Point Limestone Formation along the wave cut platform between Kiln Port and Port Ned (GR17502 37333 - refer to

Figure 28 and Enclosure 4.3 for locality on St. John's Peninsula). However, only part of the Shalwy Formation (14.25 metres in total) is exposed here. At low tide, the base of the section is exposed and consists of coarse-grained, buff sandstones. Approximately 6 metres above this base, a 20 cm bed of calcareous buff siltstone/fine sandstone contains irregular 'nodule-like structures (comprising coarse-grained calcareous sandstone and stained black on the outside). They are possibly the infill of burrows or roots. The presence of the latter may indicate a palaeosol. A fining-up sequence within a 25 cm thick section comprises coarse-grained sandstone at the base, fining up to dark grey siltstone. Cross-stratification indicates palaeocurrent directions to the north and east. Common sandstone lenses (pinching out further south) are overlain by silty/muddy drapes, that are in turn overlain by sandstone lenses. The section comprises bioturbated siltstones and sandstones, interbedded with fissile muddy horizons. Thin beds of silty, bioturbated, fossiliferous limestones are also present. Fossils include crinoids, gastropods, ostracods and bivalves. Two thin beds of silty/sandy limestone and fine-grained, calcareous sandstone contain some fusain and coal. The Shalwy Formation is cut by a significant E/W trending fault dipping 70^0 to the south and the Rinn Point Limestone Formation exposed on the other side.

The boundary with the overlying Rinn Point Limestone Formation occurs gradually to the north towards Kiln Port, as the amount of sand decreases and the calcareous and argillaceous content increases.

4.5.4.2.4 CALHAME LIMESTONE MEMBER

4.5.4.2.4.1 INTRODUCTION

The Calhame Limestone Member is a relatively clean limestone unit within the Shalwy Formation. It crops out as a north-south band to the north of Bruckless Village (Plate 70 and Enclosures 4.3 and 4.4) and in places with no exposure, it is delineated by the more fertile fields in the area. The Calhame Limestone Member is assigned member status in this study, although its base and top are not well defined due to the poor exposure.

4.5.4.2.4.2 LITHOFACIES OF THE CALHAME LIMESTONE MBR

The Calhame Limestone Member is a predominantly micaceous, fossiliferous limestone (a variant of Facies K). An outcrop photo (Plate 71) displays some wavy texture. Crinoidal debris, ostracods and foraminifers are the most common fauna. The limestones are interbedded with sandy limestones and calcareous sandstones to the north.

4.5.4.2.4.3 MICROFACIES OF THE CALHAME LIMESTONE MBR

The thin-section TCD No.50508 from Sample L174 (at Calhame, GR17564 37753) comprises argillaceous limestone with quartz grains and calcite cement. The sample contains fragments of brachiopods, bryozoa, echinoderms and shell debris. No foraminifera were observed within this thin-section. This is most likely a function of the poor sample quality.

Sevastopulo in Higgs and Sevastopulo (1983) discussed microbiota from Samples 74-1001 and 74-1002 from the Calhame Limestone Member. This included *Diplosphaerina*, *Earlandia* sp., scarcely preserved plurilocular foraminifers, *Girvanella problematica* and *Koninckopora* with a single layered wall.

4.5.4.2.4.4 LOCALITY DESCRIPTION OF THE CALHAME LIMESTONE MBR

The Calhame Limestone Member crops out as scattered exposures in a north-extending band, inland from Bruckless (Plate 70). Its most southerly exposure is observed at a faulted contact with the Largysillagh Sandstone Formation in a stream at L182 (GR17546 37698 – refer to Enclosure 4.3). It comprises crinoidal, micaceous to silty limestone. Further north in the stream (at L174, GR17564 37753 to L176, GR17566 37747), it becomes less argillaceous and more sparry in composition. At these locations, the limestone is interbedded with sandy limestone and calcareous siltstone. The limestone unit thins out 2 km towards the north, where it becomes impossible to separate it from calcareous sandstones in the Gilbertstown area. At L177 (GR17528 37983) – (refer to asterisk locality in Figures 9 and 10, and corresponding locality in Enclosure 4.4), a distinctive exposure comprising approximately two metres calcareous sandstones overlying a clast-supported conglomerate was noted. The sandstones display bipolar cross-stratification (Plate 17). This latter location is inferred as the most northwestern extent of marine evidence at this stratigraphic level within the main Donegal outcrop.

4.5.4.2.4.5 DISCUSSION ON THE CALHAME LIMESTONE MBR

The Calhame Limestone Member is an approximately 30 metres thick carbonate unit within the Shalwy Formation, which extends as a north-south band from close to Bruckless Harbour to Gilbertstown further north. From field evidence, it appears that the bipolar sandstones at Gilbertstown are associated with these limestones at Calhame (L182 - GR17546 37698, L174 - GR17564 37753) and also further south with the '*Syringopora* Bed' at Killaghtee (L153 GR17552 37513) McSwyne's Bay. This association can be inferred as a transgressive event. It indicates the extent of the marine incursion and the lateral facies change from the limestones of the '*Syringopora* Bed' at McSwyne's Bay to the micaceous and silty limestones, calcareous sandstones and bipolar cross-bedded sandstones 5 km inland.

Localities (continued)

4.5.4.2.5 Shalwy Formation – inland from Bruckless

Another band of calcareous sandstones is mapped further east of the Calhame Limestone. This second band extends towards the Casheltown area (1.5 km NW of Dunkineely - refer to Figure 9 for location). At L190 (GR17671 37800) west of Casheltown School, several metres of east dipping, variably calcareous sandstones beneath calcareous siltstones, silty limestones and hard sparry limestone crop out along a stream section. Further north at Bloody Bridge (L191, GR17653 37854 to 17660 37861), non-calcareous quartzose sandstones are overlain by a sequence of silty limestone, calcareous siltstones and calcareous sandstones. This limestone band would appear to comprise a lens of the Rinn Point Limestone Formation extending northwards into the Shalwy Formation.

An isolated seven metre thick exposure within a dried riverbed at L193 (GR17680 38054) comprises fine-grained sandstones and siltstones interbedded with calcareous sandstones containing ostracods and gastropods. A *Syringopora* coral and some vertical burrows were also noted. At L195, East of Ballywoges Hill (GR17768 38146), calcareous sandstones are exposed beneath medium- to coarse-grained sandstones and clast supported conglomerates. Their affinity is unknown as they may be associated with the Shalwy Formation (hence the most northerly exposed of the Shalwy Formation carbonates) or may belong to the basal part of the Bundoran Shale Formation. The base of the latter formation is observed in a river section at Meenabrock (L194, GR17765 38051), where calcareous sandstones are overlain by argillaceous, fossiliferous limestones and calcareous, bioturbated siltstones (the latter lithologies signify the base of the Bundoran Shale Formation).

4.5.4.3 Shalwy Formation - Muckros Head

On the western part of Muckros Head, a NW/SE trending fault separates the Largysillagh Sandstone Formation from the Shalwy Formation further south. Bioturbated calcareous sandstones with some shelly debris, parallel laminated sandstones and ripples distinguish the Shalwy Formation from the older Largysillagh Sandstone Formation. The Rinn Point Limestone Formation is faulted (NE/SW) against the Shalwy Formation.

4.5.5 THICKNESS OF THE SHALWY FORMATION

The thickness of the Shalwy Formation at Shalwy is estimated at 63 metres – refer to Figure 12b. This section is relatively complete with little faulting; thus, this value must be close to the total thickness.

The thickness of the section at Castle Port is estimated at 35 metres (this includes the '*Syringopora* Bed'). However, the inland band of Calhame Limestone Member (at 30 metres) must also be incorporated into the overall thickness of the formation. According to field information, the Shalwy Formation is much thinner at the coast along Castle Port and increases in thickness inland. This would allow the necessary space to incorporate the Calhame Limestone Member which fingers north onto the clastics. As discussed in the '*Syringopora* Bed' section, sedimentation must have been slower at the proximal Castle Port with less material available than inland towards the Calhame area. This implies that the influx of clastics from the north was accommodated within the present inland part of the Shalwy Formation, with only a minor amount of this sediment reaching Castle Port further south. Thus, in summary, the Shalwy Formation ranges from a minimum 35 metres at the present McSwyne's Bay coastline to possibly 70–100 metres inland.

4.5.6 PALAEOCURRENT ANALYSIS OF THE SHALWY FORMATION

The Shalwy Formation is characterised by the presence of Facies C bipolar palaeocurrents (see Figure 30). The rose diagram of the Shalwy Formation at Muckros indicates two dominant northerly and southerly-directed flows. The eastern limb of the syncline comprises two dominant palaeocurrent directions towards the northeast and southwest, while the western limb displays directions to the northwest and east-southeast.

4.5.7 PROVENANCE OF THE SHALWY FORMATION

It is envisaged that the drainage systems, which supplied the clastic material for the older units (the Roelough Conglomerate Formation, the Oily River Conglomerate Formation and the Largysillagh Sandstone Formation) would also have supplied the

Shalwy Formation area. According to Graham (1996), 'the petrography of the sandstones is both compositionally (20% or more feldspar) and texturally immature as noted by Nichols and Jones (1992)'. Nichols and Jones (1992) implied that the sediments represented first-cycle detritus from a Dalradian source.

4.5.8 AGE OF THE SHALWY FORMATION

Calcareous units within the Shalwy Formation (specifically from the base of Shalwy Formation at Rinn Point, from the '*Syringopora* Bed' and the Calhame Limestone Member) all comprise diagnostic Lower Viséan fauna (refer to Chapter 8 for more detail). Sevastopulo in Higgs and Sevastopulo (1983) assigned the Calhame Limestone Member to a Chadian/Lower Viséan age. Sheridan (1972) had previously predicted an Arundian age, although there is no evidence within the microbiota to suggest this age.

4.5.9 DEPOSITIONAL ENVIRONMENT OF THE SHALWY FORMATION

The lithologies within the Shalwy Formation are relatively heterogeneous, reflecting variable depositional environments from fluvial to marginal marine. A significant discussion on the depositional environment of the Shalwy Formation is included within Nichols and Jones (1992).

Non-calcareous sandstones (Facies B) displaying evidence of channelling and erosional surfaces, imply deposition within bedload channels. These sandstones are commonly associated with siltstones and mudstones with abundant evidence (plant fragments, stem casts (Facies E), thin coal horizons, palaeosols (Facies D) and rootlet horizons) of deposition on non-marine flood plains. Some of these channel fills were deposited within the tidal reaches of the rivers. An estuarine influence is envisaged by the presence of bipolar cross-stratification (Facies C) and the mud drapes on the Inclined Heterolithic Strata of Facies F.

Inclined heterolithic stratification has been recognised in fluvial and estuarine environments, where the lithological variations are attributed to tidal influences (Thomas *et al.* 1987, Shanley *et al.* 1992). During lateral migration of the tidally influenced channels, the coarser material would have been deposited when the local

tidal flow was at its strongest. Subsequently, the finer material would then settle out when the other half of the tidal cycle followed a different path (Nichols & Jones 1992), commonly settling as mud drapes on the sand foresets. Rahmani (1988) interpreted inclined heterolithic stratification of sand-shale doublets as forming under the influence of tides in point bars of a muddy estuary. Cuevas Gozalo and de Boer (1989) maintain that, in general, the fluvial and estuarine reaches of the channel system produce coarser deposits than the transition zone, where the mixing of fresh and saline waters occur. Characteristics of the transition zone are point bars consisting of interstratified sand and mud, as noted in some of the IHS structures at Shalwy.

The variation in the current direction from place to place within the Shalwy Formation has several possible explanations. Tidal current patterns in modern seas are known to be complex, as are the shapes of estuaries (Reinson 1992, Dalrymple, Zaitlin and Boyd 1992). If tidal channels were interpreted as being normal to the shoreline, the observed patterns would indicate a curved coastline. However, there is not enough information available to make this interpretation. The association of the IHS structures with fusain units strengthens the interpretation of a near-shore marine depositional environment. The fusain is interpreted to have resulted from forest fires and the resulting charcoal typically concentrates as debris within the slack water between tidal bars in an estuary (Nichols and Jones 1992, Scott and Jones 1994). Falcon-Long (1998) discussed lithologically similar deposits within Lower Carboniferous rocks at Creevagh Head, near Ballycastle, North Mayo. He interpreted the vast quantity of charcoal present in one of the IHS units as the product of a single, catastrophic wildfire at this time.

The association of plant rich, black mudstones with the micrite beds and septarian nodules (Facies J) is indicative of lagoonal settings. The presence of ostracods and gastropods both within the mudstones and within the micrite beds would strongly suggest marine or brackish conditions.

The singular one-metre thick foreset (Facies C?) exposed towards the top of the Shalwy Formation at Castle Port marks the last clastic influx into the system before the complete marine transgression of the Rinn Point Limestone Formation commenced. These structures are commonly produced by progradation of a single delta foreset slope into a water body of limited depth. The presence of this feature may imply a water

depth similar to the delta thickness, in this case, 1-2 metres and could be interpreted as part of a 'Gilbert-type delta'.

The distinctive tabular bedded, well-sorted sandstone beds of Facies G (well displayed along the Shalwy area) are indicative of proximal shoreface to foreshore deposition by wave swash processes. These sandstones display variable flat to low angled and hummocky cross-stratification and are commonly bioturbated. Deposition of these sheeted sandstones commonly occur within relatively flat areas below the fair weather base on the shoreface.

The Shalwy Formation becomes more calcareous toward the top of the formation. The sequence contains relatively abundant evidence of both shallow marine fossils and trace fossils. These include *Syringopora* corals, horn corals and crinoidal debris. Intensive bioturbation is also noted towards the upper part of the formation. Trace fossils include *Zoophycus*, *Rhizocorallium*, *Phycodes*, *Diplocraterion*, *Chondrites* and *Margaritichnus*. These trace fossils represent a mixed *Skolithos* and *Cruziana* ichnofacies, composed predominantly of domichnia and fodinichnia with minor pascichnia, repichnia and cubichnia. This ichnofacies originates from a marginal marine environment, subject to fluviatile influence (Buckman 1992).

Angular quartz grains, very common within the carbonate sequences, indicate the constant flux of clastic material towards the shallow marine area. It is probable that during the overall base level rise indicated by the Shalwy Formation, much of the clastic sediment was accommodated either in the river systems or in the coastal zone. Tidal processes can significantly affect fluvial sedimentation well inland of any coeval shoreline. Shanley *et al.* (1992) stated that 'a rapid rise in base level will result in a significant landward translation of depositional environments.... The rapid rise in base level means that tidally influenced sediments may be deposited directly over braided river deposits and may be observed a considerable distance inland of the transgressive maxima observed in marine strata'. This maximum extension of tidal influence is observed within the Gilbertstown area (by the presence of bipolar sandstones approximately 5 kms inland from the main loci of marine deposition). Following work on the Cretaceous Kaiparowits Plateau in Utah, USA, Shanley *et al.* (1992) suggested that the maximum

landward extent of tidally influenced fluvial deposits is temporally equivalent with the maximum flooding surface in marine strata.

In summary, the Shalwy Formation represents the coastal transition between the fluvially dominated, non-marine Largysillagh Sandstone Formation and the open marine Rinn Point Limestone Formation.

4.6 RINN POINT LIMESTONE FORMATION

4.6.1 INTRODUCTION

The Rinn Point Limestone Formation was previously designated the 'Rinn Point Beds' by George and Oswald (1957), Hubbard (1966), Hubbard and Pocock (1972) and Buckman (1992). Graham (1996) applied the term 'Rinn Point Formation'. The term Rinn Point Limestone Formation is preferred in this study, as the entire formation comprises variable limestone types (albeit predominantly impure and interbedded with calcareous silty shales).

4.6.2 LITHOFACIES OF THE RINN POINT LIMESTONE FM.

The base of the Rinn Point Limestone Formation is taken where the tabular beds of limestone become dominant over the more clastic sequences of the Shalwy Formation (Figure 12b).

The Rinn Point Limestone Formation in the Donegal Basin is a predominantly impure, argillaceous limestone sequence. A typical section comprises alternating tabular beds of generally compact, bioturbated, argillaceous limestone (Facies K) and bioturbated, calcareous shale (Facies P1) (refer to Plate 39). Within several cliff sections along Rinn Point, Shalwy and St. John's Peninsula, the more compact, bioturbated limestones appear to be the dominant lithological type. Individual bed thickness varies throughout the Rinn Point Limestone Formation. Although most beds are between 30 cm to one metre thick, some of the calcareous shale beds are thicker than a metre. A nearly three-metre thick, generally fissile, calcareous shale unit (Facies P1) is noted on the eastern limb of the Shalwy syncline. Its base is depicted in Column 2, Figure 31a at 35.6 metres above the base of the Rinn Point Limestone Formation. Variable abundance of fauna are associated with the carbonate beds and are discussed in more detail in sections below.

Beds of relatively clean, sparry, commonly crinoidal limestone (a variant of Facies K) are noted in variable amounts throughout the Rinn Point Limestone Formation. This latter lithology is especially common within the basal 27 metres (Column 1, Figure

31a), and from 66 to 84 metres (Columns 3 and 4, Figure 31b) of the eastern limb of the Shalwy Syncline. On the western limb of the Shalwy syncline (refer to Figures 32 and 33 for location and log, respectively), this facies is observed on recent wave-cut platforms. The basal section to the northeast of the pier at Ballyederlan (along St. John's Peninsula) (GR17560 37285) comprises a crinoidal grainstone (Facies L) in addition to the argillaceous limestones. Facies M, comprising distinctive thin beds (10 to 25 cm) of intensively bioturbated, fossiliferous limestones and rare, sandy limestones are not common within the Rinn Point Limestone Formation. This facies is noted, however, within the St. John's Peninsula area (Portanvan and Herring Holes). Tabular beds of sandy limestones (Facies N) are restricted mostly top sections of the sequence within the Shalwy Syncline, where the Rinn Point Limestone Formation is in contact with the Muckros Sandstone Formation. Facies M and N are more prevalent within the St. John's Point Sandy Limestone Formation.

Tabular geometries characterise the Rinn Point Limestone Formation, with a few exceptions where lenses pinch out over several metres. The contacts between individual cleaner, sparrier limestone beds are often infilled with muddy, argillaceous flasers and lenses. The contacts between the compact, argillaceous, bioturbated limestones and the bioturbated, calcareous shales are nearly always gradational. This is primarily due to the bioturbation, which often obliterates bedding planes. There is a general increase in bioturbation towards the top of the calcareous shale bed, coinciding with a less fissile appearance. Additionally, the amount of mud increases towards the top of the limestone beds, to merge with the calcareous shales. Some cliff sections display the compact, argillaceous, bioturbated limestones (which are more resistant to weathering), as protruding compared to the easily eroded calcareous shales. This sometimes gives the appearance of sharper bedding contacts than are actually present.

Macrofossils are present in variable amounts throughout the Rinn Point Limestone Formation. They include brachiopods, bivalves, crinoids, caninioid corals (refer to Hubbard 1970), zaphrentoid horn corals, *Syringopora* corals, *Michelinia* corals, echinoderm plates and bryozoa. The more compact, bioturbated, argillaceous limestone units contain a greater proportion of *Syringopora* corals and brachiopod fauna. *Delepinea carinata* (Plate 72) is a conspicuously large, straight-hinged brachiopod with hinge length up to 15 cm in diameter and is commonly observed at Kiln Port and

Ballysaggart, along St. John's Peninsula. Smaller spirifers and orthids are also present in variable amounts throughout the formation. Crinoid ossicles are well represented within both the argillaceous limestones and the more fissile argillaceous limestones/calcareous shales.

It has been noted in this study that, in general, a larger proportion of caninioid corals within the Rinn Point Limestone Formation is present within the more bioturbated, shaly lithologies (Plate 45). Most of these caninioids (observed at Rinn Point and Shalwy) are displayed flattened within these beds. At Ballysaggart and Kiln Port (along St. John's Peninsula), several caninioids are exposed on the bedding planes of bioturbated, argillaceous limestone, and one example of an uncompacted specimen was observed within the limestone bed (Plate 73). The caninioid examples cited above are all preserved in a position parallel to bedding, and are believed to be dominantly death assemblages. Hubbard and Pocock (1972) referred to the coral fauna within Rinn Point Limestone Formation at the Shalwy syncline. The authors noted that the 'western limb of the syncline contains a comparatively rich coral fauna which is largely preserved in place, while the eastern limb contains a higher proportion of overturned members of this community'. An analysis of coral distributions of the Shalwy syncline, by Hubbard and Pocock (1972) is discussed in Section 4.6.4.2.1.

Burrows (both vertical and horizontal) are quite common within the Rinn Point Limestone Formation, as is more general bioturbation. In general, the compact, argillaceous limestone beds appear to have been more reworked by organisms, than the cleaner limestone units (Plate 40). *Zoophycus* burrows are commonly exposed on some of the muddier surfaces. These are distinctive spreiten structures, which radiate out from a central elevated point (Plate 74). They are commonly up to 30 in diameter. As mentioned above, within some units, bioturbation is commonly pervasive and destroys original bedding. Buckman (1992) noted a low diversity of trace fossil types within this formation, dominated by *Phycodes* and *Zoophycus*, with occasional *Teichichnus* and *Palaeophycus*. However, he did indicate that this low diversity could have been biased due to the little time spent studying the rocks of the Rinn Point Limestone Formation. A more intensive overview of the trace fossil assemblage of the Rinn Point Limestone Formation was outside the scope of this present study.

4.6.3 MICROFACIES OF THE RINN POINT LIMESTONE FM.

4.6.3.1 Thin-section analysis

The Rinn Point Limestone Formation within the Shalwy Syncline and along St. John's Peninsula has been intensively sampled in order to investigate the biostratigraphy, as discussed in Chapter 8.

- The location of samples 95-58 to 95-95 (TCD Nos.50613 to 50646) from the Shalwy Syncline are shown on Enclosure 4.2 (map), Figure 32 (map) and Figures 31 and 33 (logs).
- Samples 96-15, 16 & 17 (TCD Nos.50661, 50662 and 50663, respectively) are located within, above and beneath the Biostrome bed east of Shalwy Point, respectively (Figures 32 and 33, map and log, respectively).
- The sample numbers 95-01 to 95-56 (TCD Nos.50568 to 50611) refer to thin-sections from the correlative Rinn Point Limestone Formation along St. John's Peninsula (Enclosure 4.1 and Figure 34).

The samples chosen in Appendix 4 are located at various levels of the Rinn Point Limestone Formation and were selected to display data, which may be useful in microfacies analysis and biostratigraphy. However, it must be stressed that there is a bias in this selection. It is more difficult to make thin-sections from the shalier lithologies; thus, the thin-sections reflect sampling within the more compact, argillaceous, bioturbated limestones. According to Folk's (1962) classification, biomicrites are the dominant limestone type within the Rinn Point Limestone Formation. Other categories include biosparite and subordinate biopelsparite. In accordance with Dunham's classification (1962), the thin-sections sampled comprise predominantly packstones and wackestones, with subordinate to rare grainstones.

The following thin-sections (taken from Appendix 4) outline a brief analysis of the Rinn Point Limestone Formation:

TCD No.50574, 95-15 Between Kiln Port and Port Ned, St John's Peninsula (GR17528 37354)

TCD No.50577, 95-20ii Ballysaggart, St John's Peninsula (GR17414 37224)

TCD No.50592, 95-35I Trabane, St. John's Peninsula (GR17165 37040)

TCD No.50597, 95-41ii Ballyederlan, St John's Peninsula (GR17560 37285)

TCD No.50598, 95-43 Stranaher, St John's Peninsula (GR17494 37211)

TCD No.50602, 95-47 North of Ballyederlan, St John's Peninsula (GR17587 37307)

TCD No.50605, 95-50 Cavan Boathouse/Point, St John's Peninsula (GR17697 37386)

TCD No.50660, 96-14 Ballyederlan, St John's Peninsula (GR17563 37265)

The above localities are shown on Figure 34 and Enclosure 4.1.

TCD No.50619, 95-64 Rinn Point, Shalwy Syncline (GR16725 37558 to GR16714 37520)

TCD No.50623, 95-70 West of Rinn Point, Shalwy Syncline (GR16712 37552)

TCD No.50626, 95-73 West of Rinn Point, Shalwy Syncline (GR16702 37553)

TCD No.50629, 95-76 West of Rinn Point, Shalwy Syncline (GR16694 37545)

TCD No.50631, 95-78 West of Rinn Point, Shalwy Syncline (GR16681 37537)

TCD No.50633, 95-80 West of Rinn Point, Shalwy Syncline (GR16669 37535)

TCD No.50635, 95-82 West of Rinn Point, Shalwy Syncline (GR16657 37533)

The above localities are shown on Figure 34 and Enclosure 4.2.

The debris of all the major skeletal components is represented in these thin-sectioned samples, including brachiopods, bivalves, echinoderms, gastropods, ostracods, calcispheres and bryozoa. Variable amounts of *Koninckopora and Girvanella* algae are found throughout. The samples outlined above contain *Earlandia minor*, *E. Elegans*, *Endothyra*, *Eostaffella*, *Eoparastaffella*, *Brunsia*, *Forschia*, *Pseudoglomospira, Omphalotis, Tetrataxis Pseudotaxis, Tournayella, Valvulinella* and possibly *Septabrunsia, Dainella*, *Pseudoglomospira*, *Eblania, Urbanella, Palaeosplectammina* and *Mediocris*. It was noted that the foraminiferal assemblages in thin-sections from lower down in the Rinn Point Limestone Formation are less abundant, compared to those higher up in the sequence. The dominant foraminifers are *Earlandia* and *Endothyra*, which are invariably observed throughout the sequence. Subordinate amounts of *Forschia*, *Tetrataxis*, *Valvulinella* and *Septabrunsia* are represented in the samples located lower within the formation. Other foraminifers (*Brunsia*, possibly *Dainella*, *Eostaffella*, *Eoparastaffella, Septabrunsia (?)*, and *Tournayella*) are observed towards the upper parts of the formation, i.e. from Location 95-78 upwards within the Shalwy Syncline.

Refer to Appendices 1 and 4 for further information regarding location and grain component analysis on these and other samples within this formation.

4.6.3.2 Conodont analysis

TCD No. 50660, Location 96-14 Ballyederlan, St. John's Peninsula (GR17563 37265)
Fifty conodonts were yielded from sample 96-14 at Ballyederlan on the southeastern coast of St. John's Peninsula). These include well preserved specimens of *Polygnathus bischoffi* (Pa element) and *Mestognathus beckmanni*, in addition to numerous fragments. The presence of the conodont *Polygnathus bischoffi* within the Ballyederlan section gives an upper limit on the age of the Rinn Point Limestone Formation. This would indicate that the formation would not be younger than earliest Arundian (George Sevastopulo 1997, pers. comm.).

TCD No.50661, 96-15 Biostrome locality, Shalwy Syncline (GR16531 37469)
The biostrome locality at Shalwy was sampled for conodont extraction. However, only a single indeterminate ramiform element was yielded.

Sample 96-51 (at Cavan Port – GR17720 37407) did not yield any conodonts.

4.6.4 LOCALITY DESCRIPTIONS OF THE RINN POINT LIMESTONE FM.

The Rinn Point Limestone Formation is exposed on both limbs of the Shalwy syncline, where it conformably overlies the Shalwy Formation (see Figure 8). The contacts are at Shalwy Point (western limb of the syncline) and at the eastern edge of the Rinn Point peninsula (on the eastern limb of the syncline). These localities will be described in more detail below. A smaller exposure of the Rinn Point Limestone Formation is seen at Muckros Head. Here, the Rinn Point Limestone Formation displays faulted contacts with the Muckros Sandstone Formation, the Largysillagh Sandstone Formation and the Shalwy Formation (Figure 8). Within the main Donegal outcrop, the Rinn Point Limestone Formation is exposed extensively along St. John's Peninsula from Kiln Port to St. John's Point area (Figure 34).

4.6.4.1 Rinn Point and eastern limb of Shalwy Syncline

A nearly complete log of the Rinn Point Limestone Formation was obtained from the eastern limb of the Shalwy syncline (Figures 31a and 31b). This log commences at the basal contact with the Shalwy Formation at Rinn Point and continues westwards, towards the centre of the Shalwy syncline, where the Muckros Sandstone Formation overlies the Rinn Point Limestone Formation. The logged section is approximately 96.9 metres thick. However, several gaps occur in sandy beaches and pebbly areas. A fault is seen at 39 m (from base). Estimating the amount of displacement across faults is difficult, due to the lack of marker horizons.

The boundary between the Shalwy Formation and the Rinn Point Limestone Formation is generally gradational over approximately ten metres (Figures 31a and 31b). The Shalwy Formation becomes more calcareous, argillaceous and fossiliferous towards the top, where the calcareous sandstones are replaced by sandy limestones. A sandy limestone bed represents the top of the Shalwy Formation. The base of the Rinn Point Limestone Formation is taken at a bioturbated, argillaceous limestone bed, which marks the start of a continuous sequence of interbedded argillaceous, bioturbated limestones and bioturbated, calcareous shales. The sequence is intensively bioturbated with both horizontal and vertical burrows. This pattern of bioturbated, slightly fissile, calcareous shale (with caninioid corals) interbedded with compact, bioturbated, argillaceous limestone (containing *Syringopora* corals, caninioid corals and brachiopods), continues up throughout the Rinn Point Limestone Formation. Occasionally, 30-50 cm thick interbeds of hard sparry limestone are observed. These latter limestones contain very little argillaceous material apart from some flasers and thin horizons between the bedding planes.

Approximately 25m from the base, the sequence appears thinner bedded and the compact, argillaceous limestone beds become more sparry, though not sandy. Caninioid corals are quite abundant, especially in the more fissile beds and generally lie flat along bedding. From 34 to 40 metres from the base of section on the eastern limb of the syncline, the caninioid-bearing calcareous shales are dominant. Although the entire sequence is bioturbated, the argillaceous, compact limestones are (in general) more bioturbated than the calcareous shales. *Zoophycus* burrows are observed on several surfaces at several horizons. The section (Figure 31b) continues westwards to the

contact with the Muckros Sandstone Formation, where the upper boundary is the first tabular calcareous sandstone unit with possible bipolar cross-strata. The total thickness of the Rinn Point Limestone Formation on the eastern limb of the syncline is 96.9 metres.

4.6.4.2 Shalwy Point and western limb of Shalwy Syncline

The basal contact with the Shalwy Formation is observed at Shalwy Point (on the western limb of the syncline - see Figures 32 and 33). A portion of the western limb of the Shalwy Syncline is inaccessible, therefore, a complete log of the western limb was not feasible. Figure 33 commences at the contact of the Rinn Point Limestone Formation. The underlying Shalwy Formation is not displayed. Bioturbated units of sandy limestones and calcareous sandstones (containing *Syringopora*, crinoids and comminuted shell debris) of the Shalwy Formation grade into argillaceous limestones and calcareous shales of the Rinn Point Limestone Formation. Figure 33 illustrates a 48 metre logged section of the western limb of the Rinn Point Limestone Formation. (An inaccessible cove above the 48 metres prevents further logging). In contrast to the rocks of the eastern limb of the syncline, the western limb appears to be shalier. There is additional rock (probably up to 50 metres) beyond the inaccessible section, along the cliffs towards the core of the syncline. This has not been logged in this study.

4.6.4.2.1 'Biostrome' locality – Shalwy Syncline

The 'bioherm', as noted by Hubbard and Pocock (1972) was relocated within the Rinn Point Limestone Formation (east of Shalwy – GR16531 37469) during fieldwork for this study. The term 'bioherm' is used to describe small lensoid, biogenic buildups (Cummings 1932), while the term 'biostrome' relates to more tabular and bedded biogenic deposits. Tucker (1991) states that these terms have been misused in the literature and proposed to use the term 'bank' to describe any topographic feature on the seafloor. Per definition, the rather limited coral assemblage in the Shalwy Syncline shows more affinity with the description of a biostrome; thus, this latter terminology is preferred.

The biostrome is situated (Figure 32) beyond two coves, which are accessible from the western limb of the syncline along Shalwy Point. The first cove may be difficult to get to; however, at low tide it is possible. The second cove is more difficult to reach, even at low tide. The beds in this locality dip shallowly to the NE. The biostrome is located approximately 36 metres (disregarding the effects of faulting) from the basal contact with the Shalwy Formation (refer to Figure 33). It is approximately 60 cm thick and 6 metres in width (Plate 75 – note the mark where the sample was removed). The corals are located within bioturbated, argillaceous limestone. They comprise *Solenodendron* cf. *hibernicum* (Clarke 1966) (refer to Plate 76), *Syringopora, Michelinia* and caninioid corals. Table 4.6.1 (below) displays the number of coral genera visible within the biostrome. It is quite difficult to ascertain all the exposed individual species, as several of their walls tend to link together within the colony.

CORAL	***In situ***	***Inverted***
Solenodendron	10	12
Syringopora	5	4
Michelinia	4	0
Caninioid	1	0

Table 4.3 The types and approximate numbers of corals observed (in this study) within the biostrome located east of Shalwy Point (GR16531 37469) on the western limb of the Shalwy Syncline.

The colonies of *Solenodendron cf. hibernicum* were previously described as *Lithostrotion* by Hubbard and Pocock (1972). Hubbard and Pocock cited three localities from northwest Ireland: Rinn Point in Co. Donegal and Streedagh Point and Serpent Rock in Co. Sligo. The authors implied a correlation of the three and suggested that the latter two localities were 'some 32 km down the original sedimentary dip from the former outcrop of the Rinn Point Beds'.

According to the Hubbard and Pocock (1972), the general fauna within the Rinn Point Limestone Formation at Shalwy represented a 'proximal' sequence, comprising a coral fauna of 'ubiquitous thin skeletoned, solitary, cylindrical caninioids, conical zaphrentoides, and fasciculate syringoporids which are characteristic of the muddy limestones; and cerioid

micheliniids in the more limey intervals. These are all characteristically dominated by conspicuous tabular elements, and the micheliniids have mural pores'. Hubbard and Pocock (1972) believed that this 'proximal' fauna contrasted with the 'distal' coral fauna of Sligo (as observed at Streedagh Point and Serpent Rock). The authors also postulated, that the biostrome located within the generally proximal sequence at Shalwy represented a more distal coral association. This biostrome would thus equate with the distal facies of the Sligo fauna. 'Caninioids persist (within the biostrome of this study) but are more substantial in every dimension. A low ''creeping'' auloporid largely replaces the structurally analogous bushy syringoporid colonies; but this is invariably a less conspicuous faunal element. Instead three types of lithostrotionid colony are found' (refer to Table 4.6.2 below).

TYPE	CALICE DIAMETER	FORM	LOCALITY
Lithostrotionid 1 *	2 mm	Fine fasiculate	Shalwy, Serpent Rock, Streedagh Pt.
Lithostrotionid 2 *	3-5 mm	Coarse fasiculate	Serpent Rock, Streedagh Pt.
Lithostrotionid 3 *	None given	Cerioid	Serpent Rock, Streedagh Pt.

Table 4.4 The types of lithostrotionid colony located within the 'distal' sequences of the 'Rinn Point Beds' of Donegal and Sligo, as described by Hubbard and Pocock (1972).
* This study discounts the presence of Lithostrotion corals in the Shalwy Syncline.

A log (Hubbard & Pocock 1972, their Fig. 9, and Figure 35 in this study) displays the biostrome (they used the term 'bioherm') with 28 lithostrotionids noted. The biostrome is located at 30.3 metres from the base of their log. Eighteen of these lithostrotionids were observed *in situ* and ten were inverted. According to Hubbard and Pocock, the biostrome comprised Lithostrotionid$_1$, (plus 14 'syringoporids' *in situ*, 5 inverted 'syringoporids', two 'caniniids' and one 'michiliniid'). The Sligo sequences at Serpent Rock and Streedagh Point contained all three types of Lithostrotionid ($_1$ to $_3$). The Sligo sequences are confirmed as Arundian in age. The Rinn Point Limestone Formation was also considered to have been Arundian in age. However, this study discounts an Arundian age and instead assigns a Lower Viséan age to the sequence. This topic is discussed further in Chapter 8.

During fieldwork for this study, a sample of a coral colony (30 cm by 30 cm in size) was collected from the biostrome locality in the Shalwy Syncline. The coral is believed to have equated with a portion of Hubbard and Pocock's (1972) Lithostrotionid colony. Five thin-sections were made of a slab from the sample, which was cut perpendicular to the axis of the coral columns (TCD No. 49158). It has been confirmed by Dr. John Nudds (University of Manchester, 1997, pers. comm.), that this specific coral (TCD No. 49158) is *Solenodendron* cf. *hibernicum* (Clarke, 1966) (Nudds and Ní Bhroin, in prep). Nudds discounts the coral being *Lithostrotion martini*, as the sample has far too few septa and none of the corallites appear to have a columella. He inspected another sample of *Solenodendron hibernicum* from the Burren, Co. Clare. This latter coral was collected from just below the peloidal limestone, which is used in the Burren to mark the base of the Arundian (Sevastopulo 1981a, Nudds 1997, pers. comm.). The sample is from the Tubber Formation, Ballyaneen Member (unpublished names) from Gortaun Townland (GR14180 19550) in the Burren. The coral has a well-developed aulos and the right number of septa (22-25) to be placed within the range of *Solenodendron hibernicum*. Consequently, the sample from the Burren would appear to lower the range of *S. hibernicum* to just below the base of the Arundian.

The Rinn Point Limestone Formation biostrome coral in the Shalwy Syncline obtained in this study and discussed above (refer to Plates 75, 76 and 77) would also seem to belong to *Solenodendron*. However, it differs slightly from *S. hibernicum* in having a lower septal number. Although the average septal number is often less than 20, a few of the corallites show 21 to 22 septa, which would extend the colony into the range of *Solenodendron hibernicum.* This species normally has 22 to 25 septa. Nudds also noted that a coral with 20 septa displays an aulo, indicating that this example is probably a fully mature corallite. Many of the corallites in TCD No. 49158c have developed aulos. The thin-sections TCD No. 49158b and TCD No. 49158e both show that the colony comprises axial budding. Nudds (1997, pers. comm.) feels confident that these observations would further support *Solenodendron*, and states that this definitely rules out *Siphonodendron*.

Following this study, the *Solenodendron* range of variability is to be redefined to include this biostrome specimen (TCD No.49158) from the Rinn Point Limestone Formation. Additionally, the *Solenodendron* range can now be extended down into the

Lower Viséan (previously termed late Chadian age). This is preferable to assigning the biostrome specimen (TCD No.49158) to a new species or subspecies (J. Nudds 1997, pers. comm.). Therefore, the assertion by Hubbard and Pocock (1972) regarding the presence of Lithostrotionid corals within the Rinn Point Limestone Formation, appears to be erroneous. The presence of *Lithostrotion* corals in the Rinn Point Limestone Formation at Shalwy would have implications for the Carboniferous biostratigraphy in the British Isles. In other areas within the Northwest Basin of Ireland, *Lithostrotion* corals only occur in rocks of Arundian age and younger.

4.6.4.3 St. John's Peninsula

The Rinn Point Limestone Formation is well-exposed along the St John's Peninsula, from Kiln Port, southwards towards the St John's Point area (refer to Figure 34 and Enclosure 4.3). However, difficulty arises in correlating precisely between the northwestern and southeastern coastal sections, as there is virtually no inland outcrop. Also, due to its limestone/shale cyclicity, there is a lack of marker horizons within the formation. A gradational basal boundary with the underlying Shalwy Formation is seen at Castle Port. The stratigraphical top of the Rinn Point Limestone Formation is in faulted contact with the St. John's Point Limestone Formation at Portanvan and Trabane. Another faulted contact (against a dominant tabular, calcareous sandstone lithology) is observed at Cavan Point (GR17718 37402). In general, the Rinn Point Limestone Formation at St. John's Peninsula is similar in lithology to its correlative at Shalwy within the Shalwy Syncline. However, an exception is observed at Ballyederlan (eastern part of St. John's Peninsula – refer to Figure 40 for these localities), where extensive crinoid ossicles packstones/grainstones are overlain by a dominantly non-bioturbated, calcareous shale (refer to Figures 36a and 36b, and Section 4.6.4.3.13).

The general dip of the limestones within the Rinn Point Limestone Formation along St. John's Peninsula (excluding faulted areas) varies from 8 to 16^0 towards the southeast with the strike roughly parallel to the length of the peninsula. Bed thickness varies from several centimetres to more than one metre.

Below is a description of various localities (west and east of St. John's Peninsula) which demonstrates the range of lithological variation and similarities within the area (refer to Figure 34).

4.6.4.3.1 Kiln Port

As noted in Section 4.5, the top of the Shalwy Formation at Kiln Port becomes more fossiliferous, calcareous and bioturbated. The base of the Rinn Point Limestone Formation is taken at the first major calcareous and fossiliferous unit (see Figures 29 and 37) at Kiln Port. The base comprises argillaceous, bioturbated limestone with crinoidal debris, bryozoa, *Syringopora* corals and small brachiopods. This limestone is overlain by bioturbated, fossiliferous, calcareous shales with thin limestone layers and horizontal burrows. Seven metres above the base, large straight-hinged brachiopods *Delepinea carinata* are exposed along bedding planes. These predominantly appear in a convex-up position. Portions of the preserved shells commonly display a distinctive pinky-red colour. Echinoid fragments are also observed within these beds. Some limestone beds display distinctive dome-shaped surfaces, approximately 30 cm in height and 60 cm in diameter. Several of them contain uncompacted, *Delepinea carinata*. These dome-structures may reflect diagenetically early, calcareous concretions. These hummocky surfaces are confined to the present-day, wave-cut platform along St. John's Peninsula. Interbedded with the limestones are fissile shaly layers, containing abundant biodebris horizons. These horizons appear to represent death assemblages, due to the abundance of broken and varied shell debris.

This basal contact is repeated along the southern end of Kiln Port by an east-west trending fault. The Shalwy Formation is also exposed approximately 700m further south, along the platform (refer to Figure 28). South of this exposure of faulted Shalwy Formation, the present-day wave-cut platform comprises bioturbated, argillaceous limestone (with *Delepinea carinata*, caninioid corals, bryozoa and crinoid ossicles) of the Rinn Point Limestone Formation. Bedding remains constant, dipping shallowly to the southeast.

4.6.4.3.2 Port Ned

The present-day wave-cut platform at Port Ned comprises continuous beds of bioturbated, argillaceous limestone and minor calcareous, bioturbated shales striking parallel with the coastline. Crinoidal debris and caninioid corals are the main fossils exposed in the Port Ned area. A fault trending east/west is exposed at Port Ned and thin-bedded, argillaceous limestones display irregular and disturbed surfaces. On the southern side of Port Ned, veined calcite is observed within a small fault zone.

4.6.4.3.3 West Ballysaggart

To the west of Ballysaggart, ten to twenty cm thick beds of weathered brown coloured, bioturbated, calcareous shales (of the Rinn Point Limestone Formation) are interbedded with 20-40 cm thick units of argillaceous, bioturbated, fossiliferous limestone. Fossils include caninioid corals, *Delepinea* brachiopods and crinoidal debris.

From Port Ned, the view to the south of the peninsula shows the irregular bedding nature of the limestones in the Ballycroy area (inland). From a distance, these rocks appear to be tightly folded into anticlines, each tip of 'anticline' representing a small hill in the topography. However, these topographical highs resulted from NE/SW trending, normal, high-angled ($60\text{-}70^0$) faults in the area. This NE/SW trend continues west along the peninsula towards Ranny's/Pound Point.

4.6.4.3.4 Ballycroy

Approximately 400m south of Ballysaggart School, the rocks comprise clean, sparry to slightly sandy limestone with crinoid ossicles and large brachiopods. The argillaceous content is quite low and the sequence displays an overall rubbly, irregular texture. This feature is also indicative of the overlying Rabley Limestone Member (of the St. John's Point Sandy Limestone Formation), although these latter rocks are also relatively sandy (discussed in Section 4.7). The rubbly section at Ballycroy appears to represent an isolated outlier of the Rabley Limestone Member, which is faulted against the Rinn Point Limestone Formation. The outcrop from here south to Kathleen's Rock and Horse Sound (refer to Figure 34) is not safely accessible. Therefore, it is not known whether

the contact between the younger Rabley Limestone Member (St. John's Point Sandy Limestone Formation) and the older Rinn Point Limestone Formation is displayed. At L209 (GR17359 37186) crystalline, sparry (slightly sandy) crinoidal limestone of the Rabley Limestone Member is exposed on a small ridge inland. The fault south of Ballysaggart School may extend southwards across the peninsula to Ballyederlan. The topographical contours inland indicate the fault's traverse, with a significant ridge east of Ballycroy hill.

4.6.4.3.5 Pound Point/Ranny's

At the northwestern edge of Ranny's, the sequence youngs from north to south. The rocks in proximity of the quay and boat-slip are disturbed and faulted, displaying an overall younging direction to the north. The northern end of Ranny's was logged in this study (refer to Figures 38 and 39). A 23.15m thick log extends from Ranny's to Pound Point to Long Snout. Logging was confined to the northwest and west of the boat-slip and faulting.

The base of the logged sequence consists of thin-bedded, bioturbated, richly fossiliferous, argillaceous limestone with crinoids and brachiopods. This area is covered at high tide with limpets, mussels, seaweed etc. Overlying this sequence are tabular beds of compact, argillaceous limestone (with caninioid corals) displaying a hummocky surface, similar to those described from the Kiln Port area. The succession then continues with alternating tabular beds of bioturbated, often fossiliferous, calcareous shales and beds of compact, bioturbated, fossiliferous, argillaceous limestone. A north-east/south-west trending fault separates this section from a 20.25m thick section along Lackadawson. The sequence here again comprises alternating tabular beds of bioturbated, calcareous shales and compact, bioturbated limestone beds. Fossils include solitary horn corals, brachiopods, caninioid corals, *and Syringopora* corals. Abundant bioturbation and burrows including *Zoophycus* are observed. A rare vein-quartz pebble was observed *in situ* within the argillaceous limestone at Lackadawson.

It is difficult to estimate the thickness of the succession along the western coast of St. John's Peninsula. It is not known how the sequences at Kiln Port (31 metres thick) and Ranny's/Pound Point (43.5 metres thick) correlate with each other. Several faults have been mapped between both sections.

4.6.4.3.6 Portanvan

There are approximately ten metres of rock between Lackadawson and Portanvan (Figure 38). Lithologies include thin-bedded (2-25 cm), bioturbated, argillaceous limestone; minor beds of bioturbated, fissile, fossiliferous calcareous shales, and some sandy, bioturbated limestone beds. This is the first appearance of a sandy facies within the Rinn Point Limestone Formation, and it corresponds with an overall decrease in the argillaceous component. This appears to be a lateral and upward variation into the sandier lithologies of the St. John's Point Limestone Formation. Although there is a lot of faulting in the area, this section would seem to be close to the top of the Rinn Point Limestone Formation.

A fault at Portanvan (exposed several metres north of the shingle beach) may continue across the peninsula to Cassan Sound (refer to Figure 40). South of the fault are thin bedded, rubbly, bioturbated interbeds of sandy and argillaceous limestone with *Zoophycus* traces. This is the Rabley Limestone Member (the basal member within the St. John's Point Limestone Formation). This unit continues south from the 40 metre horizontal gap at the shingle beach. The Rinn Point Limestone Formation to the north of the fault comprises argillaceous, bioturbated limestone with interbedded calcareous shales units. Caninioid corals and brachiopods dominate the fauna.

4.6.4.3.7 Trabane

The St. John's Point area is traversed by numerous faults. It is now clear that the St. John's Point Sandy Limestone Formation is a separate faulted unit from the Rinn Point Limestone Formation. The St. John's Point Sandy Limestone Formation is described more in detail in Section 4.7. Due to at least two ENE/WSW faults (exposed north and south of Trabane beach – refer to Figure 40), the Rinn Point Limestone Formation (the older block faulted against the St. John's Point Sandy Limestone Formation) is exposed along the northern part of the beach at low tide. The lithology of the latter comprises thin bedded, quite micaceous, bioturbated (non-rubbly) argillaceous limestone with crinoidal debris. It is difficult to establish the oldest part of the Rinn Point Limestone Formation on the eastern coast, or how it relates to the exposure on the western coast. The sections are not continuous and are separated by faults, pier constructions and shingle beaches.

The following localities are located on the eastern side of St. John's Peninsula (refer to Figures 34 and 40):

4.6.4.3.8 Cassan Sound to Herring Holes

North of Cassan Sound, the argillaceous limestone and minor calcareous shales dip (approximately 8^0) to the south along a wave-cut platform. The sequence is well-bedded with very little fossiliferous content. This latter feature is unusual for the Rinn Point Limestone Formation. There is also a smaller amount of argillaceous material, in contrast with the rocks at Ballysaggart. The surfaces exhibit the distinctive hummocky surfaces, previously described at Kiln Port. *Zoophycus* trace fossils are exposed on the surface.

4.6.4.3.9 Herring Holes area

The coastal rocks to the south of Ballycroy Hill comprise argillaceous, bioturbated limestones with the comminuted fossiliferous debris, confined to thin centimetre thick horizons. The macrofossils include solitary horn corals, caninioid, *Syringopora*, crinoids, brachiopods and bivalves. A fault (dipping 50^0 to the west) is exposed further east. The rocks in proximity to the fault display a rubbly appearance. However, the rubbliness does not extend much beyond the fault-zone and is thought to be due to localised faulting. Calcite veins and joints are parallel to the fault. The fault trend curves from a NE/SW to a more N/S trend towards the sea. Although the trend is parallel with the fault exposed north of Ballycroy, the dips oppose, with the Ballycroy fault dipping to the east. Therefore, the two faults do not appear to link up. To the east of the fault, *Syringopora*, caninioid and large brachiopods are observed within the bioturbated, argillaceous limestone. The sequence at Herring Holes conforms to the Rinn Port Limestone Formation, in that the beds appear generally tabular and comprise alternating compact, argillaceous limestone and bioturbated, often fossiliferous, calcareous shales.

4.6.4.3.10 Ackle Back

Ackle Back represents a complex area of faulting within the Rinn Point Limestone Formation. The lithologies are dominated by tabular beds of clean and argillaceous limestone, with minor calcareous shales. A prominent east-west fault cuts the rocks to the west of Ackle Back. This results in the rocks to the north of the fault dipping quite steeply at 36^0, whilst the rocks to the south dip at 8^0 to the south. A small, open anticline is also seen at the southern section. Crinoidal debris is abundant within the limestones of the southern section.

4.6.4.3.11 East Ballysaggart

The coastal rocks of the southeastern part of Ballysaggart display a bedding style similar to the Rinn Point Limestone Formation. However, the former suite of rocks differs in their low fossil content and their beds appear to be much shalier. South of the disused graveyard, the lithology is rubbly and less argillaceous with abundant fossils (including crinoids, echinoids, and small brachiopods). The rubbly aspect continues north to Ballysaggart pier. *Zoophycus* is present on the surface. Faulting is not visible, although an erosion surface is noted. The feature may be due to lateral facies variation. To the north of the pier, 20-30 cm thick, regular beds of fossiliferous, argillaceous limestone resume. The rocks differ south across the pier. Immediately south of the pier, irregular bedding surfaces are exposed. Bedding is thicker, with abundant bioturbation and evidence of horizontal burrows and *Zoophycus* traces. This may be due to a fault trending beneath the pier.

4.6.4.3.12 Stranaher

The rocks along the wave cut platform from Ballysaggart to Stranaher are similar to the argillaceous, often bioturbated limestones described at Kiln Port. Large *Delepinea carinata* brachiopods and caninioid corals dominate the fauna. The rocks dip approximately 12^0 to the southeast. A very rich bioclastic debris horizon is exposed along the cliff face at Stranaher. A gentle open anticline is seen to the north of this locality.

4.6.4.3.13 Ballyederlan

Coastal exposure is complete from Stranaher to Ballyederlan (refer to Figure 28), comprising generally tabular interbeds of compact, argillaceous limestone and bioturbated, calcareous shales. Rich biodebris horizons are exposed throughout the sequence. Some beds contain cephalopods, large brachiopods, solitary horn corals, bryozoa and crinoidal debris. Bedding dip is approximately 10^0 to the E/SE. Several faults cut the sequence. However, due to the lack of marker horizons, it is difficult to estimate displacement. Bian Rock comprises approximately 7.5 m of compact, argillaceous limestone and calcareous shale beds. Younging direction is to the east.

To the north of the quay, a NW/SE trending fault is exposed along the foreshore. This fault may link up with the fault along the wave-cut platform from Kiln Port to Port Ned that cuts out the Shalwy Formation. To the north of this fault at Ballyederlan, extremely rich crinoidal debris beds are exposed. Some of the beds are grainstones containing almost wholly crinoid ossicles (assigned to Facies L). No complete crinoid was found, although, abundant crinoid stems are noted. Large *Syringopora* coral colonies are observed in the beds located towards the boulder clay cliffs. Overall younging direction at Ballyederlan is to the northeast, towards Menamny.

Eighty metres of section were logged at Ballyederlan during this study (refer to Figures 36a and 36b), which extends from the crinoidal beds north of the fault at Ballyederlan Quay to Menamny. The basal section is very fossiliferous with crinoids, fish fragments and *Syringopora* corals dominating the fauna. It is also very bioturbated, with abundant 2 cm diameter horizontal burrows. The crinoid ossicles are generally contained within a grainstone/calcarenite with minor muddy matrix and lenses present (Plates 41 and 42). The crinoidal diameters and preserved lengths vary. The longest preserved stems extend up to 30 cm. Six metres from the basal section, other fossils such as brachiopods, bryozoa, caninioid corals are also displayed. Some of the beds are irregular and lensoid in geometry. The crinoidal debris horizons become less common 50m from the base of the sequence, and a more tabular geometry becomes apparent further upsection (refer to Figures 36a and 36b). Another notable change from mid-section upwards, is the dominance of finer-grained, shaly sequences, compared to other Rinn Point Limestone Formation sequences. Sixty centimetres to one metre thick beds of fissile, calcareous

shales dominate the succession in this part of the sequence and are assigned to Facies P2. Several thin (8-10 cm) tabular interbeds of very fine-grained, calcareous sandstone and siltstone are present at 58.5 metres and 66 metres in Column 3, Figure 36b. These rocks (Facies Q), along with the fissile, unbioturbated calcareous shales (P2) might imply an association with the Bundoran Shale Formation or be assigned to a separate member of the Rinn Point Limestone Formation. The Ballyederlan section has been sampled for archaediscid foraminifera, which would have allowed a biostratigraphical link with the Bundoran Shale Formation. However, none of these specific foraminifers were observed at this locality during this study.

It is not easy to correlate the logged section at Ballyederlan (Figures 36a, 36b) with other sections within the Rinn Point Limestone Formation. The section is, however, included within the Rinn Point Limestone Formation in this study, as it appears to contain a pre-Arundian fauna, and is conformably overlain (at Menamny - see below) by a sequence indicative of the Rinn Point Limestone Formation. The Ballyederlan section is most likely to reflect a lateral facies change within the Rinn Point Limestone Formation. The sequence could be due to a relatively small rise in sea level; thus, resulting in the argillaceous sediments being deposited within a more distal to basinal setting. Later, a small sea-level drop would have resumed normal offshore shelf deposition (as observed at Menamny - see below).

4.6.4.3.14 Menamny Port

The exposure is almost continuous from Ballyederlan to Menamny. At Menamny Port the overlying rocks are similar to the other outcrops of the Rinn Point Limestone Formation. It comprises interbeds of compact, bioturbated, argillaceous limestone and bioturbated, calcareous shales. Hummocky style bedding is apparent, as are bioturbation and burrows.

The area north of Menamny is intensively faulted, similar to that at Ackle Back. Three south-dipping (50^0 to 60^0) faults are exposed. Two faults display reverse movement to the north and one is normal. North of this area, a possible wrench fault dips 38^0 to the north. Bedding is disrupted and dips 50^0 to the south. Further faulting is observed at the boathouse with two N/S trending faults and an E/W fault cutting argillaceous limestone

with very fossiliferous crinoidal debris horizons. The similarities of the disrupted rocks make displacement difficult to calculate.

4.6.4.3.15 Cavan Point

A major north dipping fault (58^0) is exposed at Cavan Point (Locality 95-51, GR17718 37402 - refer to Figure 9). This fault places the Rinn Point Limestone Formation Limestone to the south of the fault in contact with tabular sandstone, argillaceous limestone and laminated, calcareous siltstone and fine-grained sandstones to the north of the fault. These latter sandy sequences are assigned to the Cavan Sandstone Member (of the St. John's Point Sandy Limestone Formation - refer to Section 4.7.4). The Cavan Point Fault would appear to link up with the '*Syringopora* Fault' at Kiln Port.

4.6.5 THICKNESS OF THE RINN POINT LIMESTONE FM.

Section thicknesses have been discussed above within the individual localities at Shalwy and St. John's Peninsula. The formation is close to 95 metres thick within the Shalwy Syncline (refer to Figure 31).

The thickness along St. John's Peninsula is more difficult to establish, due to numerous faults within specific sections. It is noted that top contact with the St. John's Point Sandy Limestone Formation at St. John's Point and Cavan Point is always faulted; thus, significant section may be absent from these areas. It is also unclear whether the Ballyederlan section (along east of St. John's Peninsula) correlates with any section within the Shalwy Syncline.

From the evidence presented in this study, the Rinn Point Limestone Formation along St. John's Peninsula is significantly thicker than the Shalwy exposure, probably ranging from 130 to 180 metres. This thicker sequence may be due to increased subsidence during deposition within the main part of the Donegal Basin, although this cannot be determined.

4.6.6 AGE OF THE RINN POINT LIMESTONE FM.

The foraminiferal assemblage (as shown in Section 4.6.3 and Appendix 4) indicates a Lower Viséan age. The sample at Ballyederlan (96-14) may contain *Viseidiscus*. This foraminiferan is normally found within the basal metres of the Arundian (Sevastopulo 1999, pers. comm.). However, there are no other indications of an Arundian fauna within these samples and in view of the sampling density, it must be concluded that the Rinn Point Limestone Formation is pre-Arundian – thus, Lower Viséan in age.

4.6.7 DEPOSITIONAL ENVIRONMENT OF THE RINN POINT LIMESTONE FM.

As presented within the lithofacies and microfacies section (4.6.2 and 4.6.3, respectively), the Rinn Point Limestone Formation comprises predominantly cyclical interbeds of argillaceous limestones and bioturbated, calcareous shales. The compact, argillaceous limestones are otherwise classified as biomicrites under Folk's scheme and wackestones/packstones under Dunham's scheme. Minor interbeds of clean sparry limestones (biosparite - packstone/grainstones) are also observed.

Limestones formed *in situ* lack the structures commonly associated with more clastic influenced sediments. These limestones tend to be generally fine-grained, reflecting their accumulation in a nearly currentless environment. They seldom contain oolites or intraclasts, and fossils or skeletal material are generally abundant. Such a rock has a bimodal size distribution – of larger skeletal fragments embedded in lime mud. Pellets may also be present within the fine-grained matrix. Such carbonates are the 'wackestones' of Dunham (1962), in contrast to the grain-supported, mud-free 'grainstones' of hydrodynamic rather than *in situ* origin (Pettijohn 1975). The grain constituents within the carbonates include brachiopods, bivalves, echinoderms, foraminifers, ostracods, gastropods, corals, bryozoans, algae and subordinate cephalopods. Non-skeletal grains include peloids and subordinate intraclasts. The skeletal material contributing to the carbonate sequence would have been derived predominantly from the echinoderms, brachiopods and bivalves and benthic foraminifers.

The assemblage comprising the majority of the above fossils in modern day, open shelf seas is termed chlorozoan (Lees and Buller 1972), and is typical of warm tropical shallow waters. Non-skeletal grains such as peloids are also restricted to relatively warm seas.

The Rinn Point Limestone Formation was deposited within a relatively shallow-water, low energy, offshore shelf environment. A carbonate shelf is a shallow-water, land-attached platform with a pronounced break in slope into deeper water. Scoffin (1987) postulated depths of between 10 to 200 metres for these open platforms, so much of the depositional area might have been below fair-weather wave base.

The presence of a high argillaceous content within the sequences at both Shalwy Syncline and St. John's Peninsula might imply that the Rinn Point Limestone Formation was deposited primarily within the proximal areas of the shelf. This is in contrast to the relatively cleaner carbonates of the younger Ballyshannon Limestone Formation sequence at Serpent rock and Streedagh Point (further south in the Sligo Syncline – outside the area of this study), which were deposited within more distal areas of the shelf during the Dinantian. However, the mud content in the limestone successions is more likely to be related to supply. Fewtrell (1979) in her discussion on Carboniferous reef and basinal limestones in Yorkshire, England referred to argillaceous limestones. She suggested that 'the presence of argillaceous limestones (and calcareous shales which are interbedded with them) is due only to the free availability of terrigenous material rather to any fundamental difference in depositional environment'. Fewtrell sites the Inner Shelf area of the Great Barrier Reef of Australia as 'characterised by a high percentage (commonly 20–60 %) of terrigenous mud and silt even in water of only a few fathoms depth, and (at greater depths) at distances well in excess of 100 km offshore'.

The presence of light-dependent algae (*Koninckopora* and *Girvanella*) within the Rinn Point Limestone Formation would suggest deposition within the shallow water photic zone. The formation does not exhibit any evidence of tidal channels, oolites or peritidal micrites to suggest near shore, tidal settings. Nor does it contain evidence of turbidites. The photic zone ranges down to at least 60 metres depth, near the effective storm wave base.

Intensive bioturbation structures within the formation comprise horizontal, vertical and branched burrows and surface crawling traces such as *Zoophycus*. These structures are all are commonly associated within mid-shelf seabed. The ichnofaunal assemblage (presented in Section 4.6.2) represents an open-marine environment dominated by fodinichnial burrows (Buckman 1992).

4.7 ST JOHN'S POINT SANDY LIMESTONE FORMATION

4.7.1 INTRODUCTION

The St. John's Point Sandy Limestone Formation is a new name proposed for the group of rocks (predominantly calcareous sandstones, sandy limestones and oolitic limestones), which overlie the Rinn Point Limestone Formation in the western part of the main outcrop of the Donegal Basin. George and Oswald (1957) referred to these rocks at St. John's Point as the 'Muckros Head Sandstones'.

In this study, the St. John's Point Sandy Limestone Formation comprises three newly named members:

- the Rabley Limestone Member displays a gradational, but faulted contact with the Rinn Point Limestone Formation at Portanvan, St. John's Point.
- the Gullhuch Sandy Limestone Member is faulted against the Rabley Limestone Member, although it is thought that it would conformably overlie this member.
- the Cavan Point Sandstone Member is exposed in faulted contact with the Rinn Point Limestone Formation to the east of Dunkineely Village.

Each of these members will be discussed separately later in this chapter.

The St. John's Point Sandy Limestone Formation is well-exposed along the southern end of St. John's Peninsula. Smaller inland exposures of the St. John's Point Sandy Limestone Formation include a small outlier at Ballycroy (L209, GR17359 37186), inland from Cavan Point (Locality 95-40, GR17687 37441) and inland, east and southeast of Dunkineely Village (Locality 95-39, GR17717 37554). The contacts observed between both members and also with the underlying Rinn Point Limestone Formation always appear to be faulted. The St. John's Point area is intensively faulted (Figure 40), a factor also noted by Millar (1990).

The St. John's Point Sandy Limestone Formation may be correlated with the Muckros Sandstone Formation (within the Shalwy syncline), as both these formations overlie the Rinn Point Limestone Formation (albeit the former is always in faulted contact).

However, the Muckros Sandstone Formation comprises a much higher percentage of arenaceous material.

Buckman (1992) noted the following trace fossils within the St. John's Point Sandy Limestone Formation: *Skolithos*, *Saportia*, *Monocraterion*, *Phycodes* and *Teichichnus rectus*. Buckman also noted the absence of *Diplocraterion*. Since he did not separate this formation into the two carbonate members recognised in this thesis, it is unknown whether any of these fossils are restricted to each member erected in this study.

4.7.2 RABLEY LIMESTONE MEMBER

4.7.2.1 INTRODUCTION

The Rabley Limestone Member is named after Rabley Hill, a drumlin situated on the northwestern part St. John's Point (refer to Figure 40). From mapping information, it would appear that the Rabley Limestone Member is older than the Gullhuch Sandy Limestone Member.

4.7.2.2 LITHOFACIES OF THE RABLEY LIMESTONE MBR

The Rabley Limestone Member comprises thin wavy beds (generally 5 - 20 cm) of dominantly argillaceous limestone to sandy limestone (Facies M), which are separated by thin units of argillaceous limestones and calcareous shales. Several thicker (up to one metre) bioturbated, calcareous shale beds (Facies P1) (with lenses of sandy limestone and argillaceous limestones have also been noted (Figure 41). The argillaceous units within the Rabley Limestone Member are generally more bioturbated than the sandier lithologies. *Zoophycus* and horizontal burrows have been observed on argillaceous surfaces. Fossiliferous material, mainly brachiopods, *Syringopora* corals and crinoid ossicles is present in variable amounts. The Rabley Limestone Member differs to the Gullhuch Sandy Limestone Member, in the former's distinctive overall, rubbly, irregularly thin-bedded appearance (Plate 43).

4.7.2.3 MICROFACIES OF THE RABLEY LIMESTONE MBR

4.7.2.3.1 Thin-section analysis

The Rabley Limestone Member comprises predominantly biosparites; some are poorly washed and biomicrites are also noted. Under Dunham's 1962 classification, the member falls within the packstone/wackestone category.

The following thin-sections (refer to Appendix 4) outline a brief analysis of the Rabley Limestone Member:

TCD No.50582, 95-25ii	North of Dough Cove, St. John's Point (GR17128 37039)
TCD No.50585, 95-28ii	North of Dough Cove, St. John's Point (GR17055 36957)
TCD No.50531, L229ii	South of pier at Cassan Sound, St. John's Point (GR1722737088)

The foraminifers are abundant and include *Earlandia*, *Endothyra*, *Eostaffella*, *Eoparastaffella*, *Forschia*, *Dainella, Brunsia, Omphalotis, Valvulinella*, *Tetrataxis*; and possibly *Palaeospiroplectammina*, *Glomospiranella* and *Pseudoammodiscus Omphalotis*. Biodebris comprise bivalves, brachiopods, crinoids, echinoderms, calcispheres, *Girvanella*, *Koninckopora*, moravamminids, *Mendipsia,* ostracods and salebrid. Quartz grains are also observed in some samples.

Refer to Appendix 1 and Figure 34 for further information regarding location, and to Appendix 4 for a grain component analysis on these and other samples within this member.

4.7.2.3.2 Conodont analysis

TCD No.50532, Location 230 (south of fault at Cassan Sound, St. John's Point - GR17230 37087) yielded an indeterminate conodont fragment.

4.7.2.4 LOCALITY DESCRIPTIONS OF THE RABLEY LIMESTONE MBR

4.7.2.4.1 Western Part of St. John's Point

As discussed in section 4.6.4.3.6, a gradational boundary between the Rinn Point Limestone Formation and the Rabley Limestone Member occurs north of Portanvan (southwestern side of St John's Peninsula – refer to Figure 40). However, a steep, south-dipping fault does fully separate the two units further south. The beds to the north of the fault are all assigned to the Rinn Point Limestone Formation. To the south of this fault, the Rabley Limestone Member comprises thin bedded, rubbly, wavy, bioturbated limestone. However, George and Oswald (1957) assigned these beds to the top of the Rinn Point Limestone Formation. The rubbly nature within the Rabley Limestone Formation is most likely a function of the increased bioturbation. Interbedded calcareous shales are also present, as are *Zoophycus* trace fossils, small brachiopods, echinoid and crinoid fragments.

Across the shingle beach at Rabley, St. John's Point (refer to Figure 40), the sequence is quite similar to that south of the fault at Portanvan. It comprises thin-bedded, rubbly-textured, interbeds of sandy to argillaceous limestone with variable amounts of calcareous shales. The sequence is quite bioturbated and fossiliferous material is generally absent from this section. George and Oswald (1957) described the beds at Rabley as 'dark nodular limestones with insignificant shale partings. They contain thin sandy layers..'. Two (NE/SW trending) faults are exposed. These faults appear to be cut by a later NE/SW trending wrench fault (with sinistral) movement. The wrench fault extends from north of Blast Holes and links up with the fault north of Trabane. The Blast Holes area comprises a series of (generally E/W trending) faulted units. Correlation is difficult due to lack of marker horizons, as the sequence is almost uniform in lithology. The rocks comprise variably bedded, rubbly-textured, sandy to crinoid-rich limestone and fossiliferous, bioturbated argillaceous limestone beds. Fossils include *Syringopora*, echinoids and crinoids. The sequence appears to become sandier to the south at Lackaphuill (circa GR17068 36987).

The rocks north of Dough Cove (circa GR17055 36957) comprise thin bedded (5-20 cm) units of argillaceous, rubbly, bioturbated limestone with some visible biodebris. Muddy horizons are subordinate. A two metre wide (NNE/SSW trending) zone of intense brecciation separates the Rabley Limestone Member (west) from the Gullhuch Sandy Limestone Member (to the east of the fault - refer to Figure 40 and Plate 80). This zone has been named the 'Dough Cove Fault'. Angular clasts of the Rabley Limestone Member are incorporated into this fault zone. The fault dips 44^0 to the east and the beds of the Gullhuch Sandy Limestone Member are warped against the contact.

4.7.2.4.2 Eastern Part of St. John's Point

Approximately sixty metres of the Rabley Limestone Member was logged in the Cassan Sound area (refer to Figure 40 for location, and Figure 41 for log), near a small beach on the northeastern side of St John's Point. The log commences at the northwestern faulted end at Cassan and continues south towards Trabane. Younging direction is to the south. The Rinn Point Limestone Formation is exposed to the north of Cassan Sound.

The basal 1.5 metres of the section (Figure 41) comprise argillaceous limestone with crinoids and *Zoophycus* and some bioturbation. Thin, irregular beds of argillaceous limestone displaying a 'wavy' texture overlie this unit and are commonly separated by horizons or lenses of fissile shale. Above the argillaceous limestones, tabular beds of sandy limestones are overlain by variable beds of rubbly, generally sandy limestone. The sequence continues with interbeds of irregularly bedded, argillaceous limestone, calcareous shales and tabular, sandy limestone. The majority of these units are bioturbated. Fossils include brachiopods and crinoids. A *Syringopora* colony is exposed (see 18 metres from the base of Figure 41) six metres above and south of the pier. At least eight colonies (dominantly in life position) have been noted. The sequence continues upwards with sandy limestones as the prevalent lithology, interbedded with calcareous shales and argillaceous limestones. Towards the top of the section, 1.3 metres of coarse-grained, calcareous, quartzose sandstone is exposed towards the sea at low tide. This is the only coarse-grained, quartzose bed noted in the Rabley Limestone Member. The top bed of compact, sandy, bioturbated limestone overlies this unit. These top beds may belong to the overlying Gullhuch Sandy Limestone Member, although this cannot be confirmed.

George and Oswald (1957) did not identify the two distinct members within the St. John's Point Limestone Formation at St. John's Point. Instead they postulated that the 'Rinn Point Beds' (Rinn Point Limestone Formation of this study) extended further south to a faulted contact at Lackaphuill and south of Trabane (George and Oswald, 1957, their Fig. 4 – Figure 42 in this thesis). Therefore, the majority of the Rabley Limestone Member recognised in this study is actually assigned to the 'Rinn Point Beds' on George and Oswald's map.

4.7.2.5 THICKNESS OF THE RABLEY LIMESTONE MBR

No faults are visible within the Cassan Sound to Trabane section (as shown in Figure 41), although the sequence at the pier is slightly disturbed. If there is no displacement at this locality, the Rabley Limestone Member is at least 60 metres thick.

4.7.2.6 AGE OF THE RABLEY LIMESTONE MBR

No foraminifers diagnostic of Arundian Stage have been observed during examination of thin-sections from limestones in this unit during this study. Thus, the Rabley Limestone Member is assigned a Lower Viséan age.

4.7.2.7 DEPOSITIONAL ENVIRONMENT OF THE RABLEY LIMESTONE MBR

The Rabley Limestone Member comprises thin bedded, argillaceous and sandy limestones, with minor interbeds of calcareous shale. The entire sequence displays a high degree of bioturbation. The overall texture is predominantly packstone although some wackestones are also noted. The majority of samples shows a high percentage of calcite spar, and are classified as biosparites. Micrite is observed generally as coating some of the grains.

Whole fossils are not common within the Rabley Limestone Member (some crinoids and *Syringopora* corals), although the debris comprises fauna (brachiopods, crinoids and bivalves) largely associated with normal marine conditions. The faunal assemblage is similar to that of the older Rinn Point Limestone Formation (brachiopods, bivalves,

echinoderms, calcispheres and bryozoans). Algae, namely *Girvanella* and *Koninckopora* would attest to deposition within the photic zone. There is no obvious evidence of peritidal micrites or oolites; thus, shallow depths or high-energy conditions cannot be well constrained.

A shelf environment is proposed for the Rabley Limestone Member. This is inferred by the distinctive wavy bedding within the limestones, which is common in these settings. Burrows and bioturbation are the most common sedimentary structures observed in shelf limestones. The normal shelf wackestone has a thoroughly bioturbated structure (Wilson and Jordan 1983). The Rabley Limestone Member displays a general upward increase in sandiness from the more argillaceous limestones. This would imply a period of renewed clastic input or a shoaling effect towards the top of the member.

4.7.3 GULLHUCH SANDY LIMESTONE MEMBER

4.7.3.1 INTRODUCTION

The Gullhuch Sandy Limestone Member is named after the well-exposed cliff-section at Gullhuch (GR17047 36927), northwest of the lighthouse at St. John's Point (refer to Figure 40). This place-name probably originated from the sound of the sea gulls, which nest among the cliffs in summer. The base of the Gullhuch Sandy Limestone Member is not seen, as it is always in faulted contact with the underlying Rabley Limestone Member.

4.7.3.2 LITHOFACIES OF THE GULLHUCH SANDY LIMESTONE MBR

The Gullhuch Sandy Limestone Member comprises tabular, variably bedded (5 to 50 cm thick), sandy limestones, oolitic limestones, clean limestones and calcareous sandstones (Facies N). Some limestone horizons are altered to dolomite. This member differs from the underlying Rabley Limestone Member, in that it is significantly less argillaceous; thus, cleaner and much richer in sandstone units. The contacts between individual sandy limestone and calcareous sandstone beds are generally sharp. However, to the west of the lighthouse, some limestone beds are separated by calcareous siltstone and shales horizons. Crinoids, brachiopods and *Syringopora* corals are quite common within the limestone lithologies (Plate 78). Subordinate *Michelinia* corals have also been observed. The sequence is not as bioturbated as the underlying Rabley Limestone Member, although several intensively burrowed horizons and horizontal burrows have been noted (Plate 79).

4.7.3.3 MICROFACIES OF THE GULLHUCH SANDY LIMESTONE MBR

4.7.3.3.1 Thin-section analysis

The Gullhuch Sandy Limestone Member comprises variants of biosparites and biomicrites depending on the presence peloids, intraclasts and ooids. The texture is

predominantly packstone, although grainstones and some wackestones have also been observed.

The following thin-sections (refer to Appendix 4) outline a brief analysis of the Gullhuch Sandy Limestone Member:

TCD No.50590, 95-33 North of Heelin Port, St. John's Point (GR17184 36988)

TCD No.50591, 95-34ii South of Trabane, St. John's Point (GR17162 37000)

TCD No.50587, 95-30 Inland St. John's Point (GR17062 36916)

TCD No.50593, 95-36 North of Dunkineely (GR17722 37708)

TCD No.50594, 95-38 North of Dunkineely (GR17710 37681)

TCD No.50595, 95-39i Dunkineely 'Station' (GR1771737554)

TCD No.50647, 96-01 Boatslip area, St. John's Point (GR17028 36895 to GR17304 36890)

TCD No.50654, 96-08 Boatslip area, St. John's Point (GR17028 36895 to GR17304 36890)

TCD No.50657, 96-11 Boatslip area, St. John's Point (GR17029 36895 to GR17304 36890)

The thin-sections contain a relatively rich biodebris (brachiopods, bivalves, bryozoans, calcispheres, salebrid, echinoderms, gastropods, ostracods, *Koninckopora*, moravamminids, ostracods, *Girvanella* and *Mendipsia leesi*. Variable amounts of peloids, ooids and intraclasts are present. Foraminiferal content varies in different samples. However, in general the following assemblage has been observed: *Endothyra*, *Earlandia*, *Eostaffella*, *Eoparastaffella, Omphalotis*, *Forschia, Brunsia, Tetrataxis*, *Dainella*, *Palaeospiroplectammina*, *Mediocris, Pseudotaxis* and possibly *Urbanella*, *Glomospiranella, Pseudotaxis* and *Dainella*.

Refer to Appendix 1 and Figure 34 for further information regarding location, and to Appendix 4 for a grain component analysis on these and other samples within this member.

4.7.3.3.2 Conodont analysis

TCD No. 50523, Location 209, Ballycroy, St. John's Peninsula (GR17359 37186)
This sample yielded *Mestognathus beckmanni* and *Apatognathus*. These conodonts are not very significant in biostratigraphical assessment, except that they are commonly noted in Lower Viséan assemblages.

4.7.3.4 LOCALITY DESCRIPTIONS OF THE GULLHUCH SANDY LIMESTONE MBR

4.7.3.4.1 Southeastern part of St. John's Point

From mapping and logging information, it is thought that this suite of rocks at Gullhuch cliff is the oldest part of the member. The cliff at Gullhuch is inaccessible, therefore only an estimated thickness of 19.2 metres of section could be drawn up (refer to the log in Figure 43). The basal section of the cliff comprises approximately three metres of 20-40 cm tabular beds of bioturbated, argillaceous limestone with thin calcareous shale interbeds. The middle nine-metre section of the cliff contains generally tabular interbeds of argillaceous limestone and sandy limestone. The top five metres are sandier with some oolitic, crinoidal limestone present. Subordinate amounts of argillaceous material are confined to thin interbeds, lenses and flasers. The rocks within the top 90 cms of the cliff are quite rubbly and fractured.

The large fault zone exposed at Dough Cove (Plate 80) trends south towards Gullhuch (Figure 40). However, this fault does not appear to displace the rocks above the basal unit. The suite of rocks at the Gullhuch cliff section (Figure 43) extends south beneath the lighthouse and forms the southern headland of St. John's Point. The 3.4 metre thick sequence at the top of the Gullhuch cliff may also extend southwards towards the boat-slip, unless faulting has affected the sequence. Several faults cut the rocks south of the lighthouse; however, it is not possible to observe displacement of marker horizons.

Approximately twelve metres of section were logged at Fox's Hole, south of St. John's Point to the boat-slip (refer to Figure 40 for location and Column 1 in the log of Figure 44). The base of the unit comprises thick beds of calcareous sandstone. Irregular

hummocks on the surfaces (comprising sand-rich material) are observed on the wave-cut platform. *Syringopora* corals, crinoids, indeterminate shell debris and bioturbation are noted. The basal six metres are very rich in sandy material. The sequence is cut by a fault with unknown displacement. This basal unit is in faulted contact with fossiliferous, bioturbated, sandy limestone with subordinate calcareous sandstone beds and argillaceous horizons. Stylolites are observed within the fossiliferous, clean limestone immediately beneath the fault at the boatslip. Fossils within these beds include brachiopods, crinoids, and *Syringopora* (Plate 78).

The eastern coastal area from the boat-slip to Heelin Port (to the northeast of the Point) contains several faults (refer to Figure 40). It is difficult to observe whether stratigraphy has been repeated within the area, as the dominant lithology is of sandy limestone, and marker horizons are absent.

The 36.3 metres thick logged section from the base of the boat-slip to Portanagh is displayed in the 2nd and 3rd columns in Figure 44 (refer to Figure 40 for location). The basal six metres comprises a cliff section of tabular beds of sandy limestone; thin-bedded sandy limestone with argillaceous flasers; and sandy limestone with possible pseudo-bedding and stylolites. Beds are generally 20 cm thick. Some of the more argillaceous beds are hummocky and irregular. Twelve metres from the base of the log, there is a zone of intensive horizontal burrows (Plate 79). The burrows are 1.5 cm in diameter, with maximum length of 40 cm (in a curved position) and are embedded within muddy flasers. The 1.6 metre sandy limestone unit above this contains stylolites. Oolitic sandstone is observed above twenty-one metres from the base. The section then continues to a fault at Portanagh. It comprises predominantly tabular interbeds of crinoidal, sandy and oolitic limestone. Several argillaceous limestone and shale beds and horizons are also present.

A two metre thick zone of disturbed rocks disrupts the section (top of the log in Figure 44) at Portanagh. It is estimated that there is approximately 36 m of generally sandy to crinoidal limestone between the fault at Portanagh and the fault northwest of Stag Leap (Figure 40). Bedding is quite steep in the Portanagh area. Stag Leap comprises inaccessible cliffs (of dominantly sandy limestone), dipping (16^0-20^0) towards the sea. Approximately ten metres of section separate the faults between Stag Leap and

Knockintraw. The sequence comprises variable sandy limestone with crinoid ossicles and burrows, and interbeds of fissile, argillaceous limestone. Another 12 metres of section (generally sandy to clean crinoidal limestone) are observed between the fault at Knockintraw, and the southeastern end of Knockintraw.

Knockintraw Hole appears to contain the youngest rocks within this faulted block. The younging direction is to the southeast. Excluding the effects of faulting south of Heelin Port, there are thirty-two metres of sandy limestone in the section. Abundant in-situ *Syringopora* corals are located north of the fault at Knockintraw.

Rinnanane is the headland south of Trabane beach (Figure 40). The north-facing cliff exposes a series of anticlines and synclines. The beds within the cliff face are generally between ten and forty centimetres thick, with variable amounts of quartzose sands within the sandy limestone. Crinoidal debris horizons are common. An east/west trending fault (dipping south at 60^0) cuts through the cliff. The rocks to the north and beneath the fault comprise sparry, clean limestone with crinoidal debris. The rocks above the fault (and to the south), are light brown in colour and sandier in composition.

Sparry limestones are seen at the southern tidal rocks at Lobster Rock on Trabane Beach. The rocks appear disturbed and are possibly close to a fault zone. This fault may be the contact between the Rinn Point Limestone Formation to the north (at Bracklagh) and the Gullhuch Sandy Limestone Member to the south. This unexposed fault would be quite significant, as it would cut out the Rabley Limestone Member from the sequence (Figure 40). Oolitic limestone and crinoidal sparry limestone are exposed in a small hollowed area (Locality 95-34, GR17162 37000), inland from the faulted cliff at Rinnanane (where the roadway bends uphill). Bipolar palaeocurrents are preserved within the oolitic limestone, with approximate directions to the north and east. 3-D surfaces are not available for accurate measurements. These rocks are part of the Gullhuch Sandy Limestone Member.

4.7.3.4.2 Inland exposures of St. John's Point

Inland exposures at St John's Point are not continuous. Therefore, the eastern and western coastal sections (across the headland) cannot be correlated with great confidence. Sandy and oolitic limestones are exposed as ridges between Rinnanane (east) and Dough Cove. These rocks trend northeast/southwest and display a series of (generally south plunging) folds.

A small outlier of the Gullhuch Sandy Limestone Member is exposed northeast of Ballycroy Hill and is in faulted contact with the Rinn Point Limestone Formation.

A disused quarry near 'Dunkineely station' (GR17717 37554) exposes several metres of bioturbated and burrowed crinoidal and oolitic limestones. Sample 95-39 was taken from this locality. Similar lithologies are exposed on the ridge (further west) containing a limekiln. Calcareous sandstones and argillaceous limestone beds underlie the clean, crinoidal limestones. It is thought that this sequence is part of the St. John's Point Limestone Formation, which has been displaced by several east-west faults within the peninsula. George and Oswald (1957) also noted this faulted sequence and equated them with the 'St. John's Point sandy limestones'.

Cashelfean north of Dunkineely village (GR17710 37681) comprises interbedded calcareous sandstone and sparry, clean fossiliferous limestones with intraclasts (thin-sections: TCD No.50510 - L184, TCD No.50511 - L185, TCD No.50593 95-36 and TCD No.50594 95-38). The sequence may represent a lens of St. John's Point Sandy Limestone Formation.

4.7.3.5 THICKNESS OF THE GULLHUCH SANDY LIMESTONE MBR

Since the Gullhuch Sandy Limestone Member is intensively faulted along St. John's Point, no complete section has been observed. From mapping and logging information, the thickest unfaulted sequence is 36.5 metres, from the Boatslip to Portanagh Rock (refer to Figure 44). It is likely that the true thickness of this member is closer to 50 metres.

4.7.3.6 AGE OF THE GULLHUCH SANDY LIMESTONE MBR

As discussed above and from field information, the Gullhuch Sandy Member would appear to be younger than the Rabley Limestone Member. Hence, the former is assigned to the upper part of the Lower Viséan, if not in the lowest Arundian (archaediscid foraminifers were not observed in thin-sections within this member). It is suggested from lithological information that this member is overlain by the Bundoran Shale Formation, although this contact has not been observed.

4.7.3.7 DEPOSITIONAL ENVIRONMENT OF THE GULLHUCH SANDY LS. MBR

The Gullhuch Sandy Limestone Member comprises tabular beds of predominantly sandy limestones in addition to calcareous sandstones and oolitic limestones. The well-washed nature of these lithologies and the presence of intraclasts and ooids would imply deposition within shallow water, high-energy environments.

Intraclasts are lithoclasts derived from within the basin of deposition, and contain grains that are contemporary with those of the host rock. They are common where forces of erosion are prevalent, e.g. reef front, tidal channel or beach. The sites of active ooid formation are shallow agitated waters, commonly of slightly higher temperature and salinity than normal open marine water. The common characteristics of the environments of ooid formation are as follows: warm shallow water, normally 0 to 4 metres deep, commonly close to a supply of deep cold water rich in dissolved $CaCo_3$ and agitation of grains by tidal currents, wind-driven currents and waves. This turbulence removes fines, and rolls sand grains to and fro, sweeping the bottom clean (Scoffin 1987). At St. John's Point, bipolar cross-strata in the oolitic limestones also signifies shallow depths, although there is no evidence of channels. Carboniferous oolite shoals are regarded to have formed as offshore tidal bars or along beach fronted sandplains (Burchette *et al.* 1990, Keith and Zuppann 1993). The presence of marine algae (*Koninckopora*) implies water depths within the photic zone, extending down to maybe 100 metres. Filamentous blue-green and dasycladacean algae are present in normal marine environments but are more tolerant of salinity variations and are

commonly found in water of less than 5 metres (Wilson and Jordan 1983). Salebrids are bryozoan-like organisms of uncertain affinities.

It may be inferred that the Gullhuch Sandy Limestone Member was deposited within high-energy, shallow water during a shoaling upward succession from the more argillaceous, slightly deeper part of the shelf, which deposited the Rabley Limestone Member.

4.7.4 CAVAN SANDSTONE MEMBER

4.7.4.1 INTRODUCTION

The Cavan Sandstone Member (a newly erected member within this study) crops out on the northeastern coastal area of St. John's Peninsula. This arenaceous member maps out as isolated units with irregular geometries. Figure 45 shows the area from Cavan Point to east of Dunkineely village. The logs in Figure 46 (Columns A and B) depict the sections seen at Cavan Point (Figure 45, Insert B) and east of Dunkineely (Figure 45, Insert D), respectively.

In this study, the Cavan Sandstone Member is assigned a member status within the St. John's Point Sandy Limestone Formation. However, the author acknowledges reservations about the placement of this member within the St. John's Point Sandy Limestone Formation, as it may likewise be assigned as a basal member within the Bundoran Shale Formation. As the member's basal or upper contact with either of these formations is not observed, a decision was made to assign it to the older St. John's Point Sandy Limestone Formation.

4.7.4.2 LITHOFACIES OF THE CAVAN SANDSTONE MBR

The Cavan Sandstone Member is a relatively heterogeneous unit, comprising coarse- to fine-grained, calcareous and non-calcareous sandstones, bioturbated argillaceous limestones, calcareous micaceous siltstones and calcareous shales. The member becomes more argillaceous and calcareous towards the top. Facies G forms relatively tabular beds of well sorted, variably bioturbated, fine- to medium-grained sandstones. Parallel lamination and some ripples have been observed within these sandstones. The coarse-grained, calcareous sandstones and sandy limestones with abundant small pebbles represent Facies H. There are variable amounts of bioclastic debris and bioturbation (some horizontal burrows) and preservation of some cross-beds. The clastics in this region are interbedded with bioturbated calcareous siltstones, shales and argillaceous limestones, many containing fossils (Facies Q, P and K, respectively).

4.7.4.3 MICROFACIES OF THE CAVAN SANDSTONE MBR

4.7.4.3.1 Thin-section analysis

As discussed above, the Cavan Sandstone Member is a heterogeneous sequence. Samples vary from biomicrite with some spar to samples that are calcareous siltstones and mudstones with very low fossil content.

A brief description of the following thin-sections within the Cavan Sandstone Member is taken from Appendix 4:

TCD No.50609, 95-54 The Scar, St. John's Peninsula (GR17749 37486)

TCD No.50610, 95-55 Ballybodonnell east, St. John's Peninsula (GR17773 37534)

These samples comprise a foraminiferal assemblage, which include *Earlandia*, *Endothyra*, *Eostaffella*, *Tetrataxis*, *Brunsia, Forschia*, *Tournayella* and possibly *Valvulinella* and *Uralodiscus*. Biodebris includes bivalves, brachiopods, bryozoa, salebrid, echinoderms, *Girvanella* and *Koninckopora*.

Refer to Appendix 1 and Figure 34 for further information regarding location, and to Appendix 4 for a grain component analysis on these and other samples within this member.

4.7.4.4 LOCALITY DESCRIPTIONS OF THE CAVAN SANDSTONE MBR

4.7.4.4.1 Cavan Point

The Cavan Sandstone Member is well-exposed to the north of a normal, north-throwing fault (Plate 81) at Cavan Point (Figure 45, Insert A). To the north of the fault, a six metre thick clastic sequence is observed (refer to Column A in Figure 46, Plate 82). This sequence comprises generally tabular beds of coarse-grained, bioturbated sandstones (Facies H), fine-grained, calcareous, variably bioturbated sandstones and siltstones (Facies G) with interbeds of calcareous shales and siltstones (Facies P and Q,

respectively). Parallel laminations, bioturbation and wave ripples and hummocky cross-stratification are observed in the lowermost sandstone beds (Facies H - Plate 83). Although apparently tabular in geometry in isolated sections, the thick sandstone beds appear to gradually thin laterally over five metres. These sandstones are similar to sandstones of Facies G and H exposed at Shalwy and at Castle Port (within the Shalwy Formation).

Brachiopods, crinoids and some shell debris are present in small amounts within the minor interbeds of calcareous siltstone. Zoophycus burrows are observed on some surfaces. The dominantly arenaceous rocks are eventually overlain to the north by interbeds of medium-grained sandstone, micaceous calcareous siltstones and calcareous shales, which are disturbed by several faults. Figure 45 (Insert C) shows the location of younger micaceous, calcareous siltstones and shales and the argillaceous limestones, which overlie the clastics at The Scar.

4.7.4.4.2 South of the Scar

To the south of The Scar (Figure 45, Insert B), a sandstone sequence is exposed along the foreshore (seen towards the top of the diagram). The coarse-grained to pebbly sandstone (Facies H) unit is approximately 1.5 metres thick. Bedding is very irregular and bioturbation is intense. At one section, lensoid beds (2 cm to 10 cm thick) are displayed (Plate 84). These appear to be trough cross-stratified units separated by erosional surfaces. Towards the top of this sandstone unit, a possible spreite-filled burrow (approximately three cm in diameter, comprising fine millimetre-scale curved lamellae, which probably belongs to *Rhizocorallium*) was observed (Plate 85). Buckman (1992) stated that this trace represented a 'sediment-feeding mode of life in a normally quiet water environment'. They are known in both marine and non-marine deposits, although 'the Irish *Rhizocorallium* is most probably marine in origin, given their association with other typical marine trace fossils'. Gastropods have also been observed within the sandstones. The sandstone is overlain by bioturbated, calcareous shales.

4.7.4.4.3 Coastal area east from Dunkineely Village

The coastal locality to the east of Dunkineely Village (Figure 45, Insert D) comprises a faulted block of calcareous sandstones (Facies G), interbedded with argillaceous limestones and micaceous calcareous siltstones and shales (refer to Column B in Figure 46). An erosional contact between the coarse-grained, calcareous sandstones (Facies H) and the underlying calcareous shales is exposed. The sandstones are overlain by interbedded micaceous, calcareous siltstones and shales (Facies Q and P, respectively). The calcareous, micaceous siltstones contain some plant debris and possibly lingulid brachiopods. The upper shales are overlain by argillaceous, crinoidal limestones (Facies K).

4.7.4.5 THICKNESS OF THE CAVAN SANDSTONE MBR

The exposure from Cavan Point to the small beach east of Dunkineely is not continuous and the beds dip relatively gently. Eighteen metres of section of the Cavan Sandstone Member are observed from the faulted basal contact with the Rinn Point Limestone Formation at Cavan Point (refer to Figure 46) to the next fault further north. Another 7.5 metres of section were logged towards the beach east of Dunkineely. In the absence of continuous section, an estimated thickness of 40 metres is presented for the Cavan Sandstone Member in this study.

4.7.4.6 AGE OF THE CAVAN SANDSTONE MBR

The Cavan Sandstone Member contains diagnostically Lower Viséan fauna. There is no biostratigraphical evidence to suggest an Arundian age for this sequence. A 200-metre horizontal gap separates the highest exposed bed of this member from the Bundoran Shale Formation to the northeast, the latter is confirmed Arundian in age at Dunkineely.

However, the possibility could exist that the sequence could belong to the basal part of the Bundoran Shale Formation – even if diagnostic foraminifers were not observed.

4.7.4.7 DEPOSITIONAL ENVIRONMENT OF THE CAVAN SANDSTONE MBR

The Cavan Sandstone Member comprises Facies G, H, K, P and Q. The basal part of the Cavan Sandstone Member (as noted in the sediments exposed immediately north of the fault at Cavan Point) comprises tabular beds of fine- to coarse-grained, calcareous to non-calcareous quartz-rich sandstones, commonly interbedded with calcareous shales, siltstones and fossiliferous limestones. The bioturbated, low-angled to parallel lamination, trough cross-stratification, wave ripples, hummocky cross-stratification (of Facies G) are typical of coastal marine sands (McCubbin 1982), dominated by wave action. The coarse-grained, calcareous sandstones and sandy limestones (representing Facies H) are interpreted as the deposits of the surf zone. Their unsorted, coarse-grained nature with shelly debris would imply deposition during periods of local coastal retreat. The irregular sandstone sequence noted to the SE of Dunkineely (Section 4.7.4.4.2 - Plate 84) may be comparable to incised scour surfaces (with up to 1 metre of relief) within episodic high-energy flows in Silurian shelf sandstones, inferred as being produced by rapid bedform migration (Driese *et al.* 1991).

The clastics in this region are interbedded with bioturbated, calcareous shales, siltstones and argillaceous limestones containing fossils (Facies K). Deposition of this finer sediment would have occurred during fair-weather periods.

Walker (1984) stated that only storm-dominated processes transport sand below fair-weather wave base. The first clue to the storm origin of some beds is; therefore, the occurrence of sandstones (and/or conglomerates) interbedded with bioturbated mudstones of the *Cruziana* or *Zoophycus* ichnofacies. Such sandstones commonly have sharp and/or erosive bases, and average 5 to 100 cm in thickness. Thus, the Cavan Sandstone Member would appear to have been deposited predominantly in the shoreface zone, often beneath the storm wave base. It is also possible that hyperpycnal flows resulted in the transport of sands below fair weather wave base. Hyperpycnal flows (under flow) occur during floods and pass beneath the basin waters as density currents cause sediment to bypass the shoreline and are deposited on a lower delta front or prodelta (Reading 1996).

Wave swash is the dominant process in the beach environment, producing planar, low angled cross-stratification. On the seaward slope of offshore bars, small-scale cross-stratification and planar stratification (due to the predominantly landward migration of ripples) are common. Farther offshore, (towards the base of the shoreface and onto the shelf), grain size generally decreases and the interbedded calcareous siltstones, mudstones and argillaceous limestones (Facies P, Q and K, respectively) become more abundant (as noted in the south to north traverse from Cavan Point to east of Dunkineely).

Howard and Reineck (1981) interpreted the deposition of comparable beds in California as the result of a two-part process: sediment would have initially been brought to nearshore areas by river floods and then redistributed offshore by storm-induced waves. Bioturbation of interbedded muds and along the surfaces of the sand layers suggests slow sedimentation between episodes of sand deposition (McCubbin 1982).

The Cavan Sandstone Member does not appear to fit the general shelf environment already argued for the Rabley Limestone Member and the Gullhuch Sandy Limestone Member. The Cavan Sandstone Member represents a more shoreward sequence, where storm processes were significantly influential. This unit is also much more heterogeneous than the other two members of the St. John's Point Sandy Limestone Formation (the Rabley Limestone Member and the Gullhuch Sandy Limestone Member). The Cavan Sandstone Member incorporated periods of carbonate deposition (albeit rather argillaceous), in addition to the clastic deposition on the marine sandflats and surf zone areas.

However, a pattern may be suggested for the St. John's Point Sandy Limestone Formation, whereby the open marine shelf-deposited Rabley Limestone Member is followed by the Gullhuch Sandy Limestone Member, which is a product of shoaling upwards. The uppermost member (the Cavan Sandstone Member) would attest to an even shallower setting, influenced by renewed clastic input.

4.8 MUCKROS SANDSTONE FORMATION

4.8.1 INTRODUCTION

The Muckros Sandstone Formation forms the youngest rocks of the Carboniferous succession within the western part of the Donegal. The formation was formerly named the 'Muckros Head Sandstone' by George and Oswald (1957) and the 'Muckros Sandstone Member' by Buckman (1992). The best localities are observed along the southern part of the headland at Muckros Head Syncline and within the core of Shalwy Syncline at Largymore (refer to Figure 8 for localities). It is most likely that this formation is a proximal equivalent to the St. John's Point Sandy Limestone Formation (exposed along St. John's Peninsula), as they both overlie the Rinn Point Limestone Formation. However, these formations are sufficiently different in lithofacies as to merit separate formation status.

4.8.2 LITHOFACIES OF THE MUCKROS SANDSTONE FM.

The Muckros Sandstone Formation comprises a predominantly tabular bedded, feldspathic sandstone succession, with variable amounts of carbonate material. Coarse-grained to pebbly, calcareous to non-calcareous, cross-bedded sandstones form the basal succession (Facies C/Facies H). This gradually fines upwards to interbeds of sandstones, silty sandstone and calcareous sandstones (Facies G). Erosive surfaces and shallow scours (generally less than 60 cm thick) are common throughout the formation (Plate 86). Several mudstone lenses drape over irregular surfaces. Apart from the lowermost pebbly sequences, the sandstones are generally well sorted. Tabular and trough cross-stratification (Plate 87) are present within the sandstones. Bipolar cross-stratification with northerly and southerly palaeocurrents has also been noted. The more calcareous parts of the sequence comprise tabular beds (commonly up to a metre thick) of oolitic limestone and thin beds (approximately 30 cm) of micrite (Facies N). The oolitic limestones commonly contain shelly debris. Buckman (1992) noted the rare presence of radial tree-root systems.

Bioturbation and burrowing are present throughout the succession. Buckman (1992) noted the presence of the following trace fossils within the Muckros Sandstone

Formation: *Arenicolites*, *Skolithos*, *Chondrites*, *Phycodes*, *Rhizocorallium jenense*, *Taenidium*, *Chomatichnus* and several unnamed vertical burrows.

Distinctive honeycomb textures are observed on some cliff faces due to the effect of weathering.

4.8.3 MICROFACIES ANALYSIS OF THE MUCKROS SANDSTONE FM.

4.8.3.1 Thin-section analysis

TCD No.50636, 95-83 Core of Shalwy Syncline (GR16663 37533)

This sample comprises fossiliferous, muddy limestone classified as an argillaceous wackestone under Dunham's classification. The sample comprises bivalves, brachiopods, bryozoans, echinoderms, *Koninckopora*, *Mendipsia leesi*, ostracods and possibly salebrids. Foraminifers include *Earlandia*, *Endothyra*, *Pseudotaxis* and possibly *Dainella*.

4.8.4 LOCALITY DESCRIPTIONS OF THE MUCKROS SANDSTONE FM.

As discussed above, the Muckros Sandstone Formation is exposed along the headland of Muckros Head and forms the top part of the syncline at Largymore within the Shalwy Syncline.

4.8.4.1 Muckros Headland

The basal contact of the Muckros Sandstone Formation with the Rinn Point Limestone Formation is not observed at Muckros Head. A twelve-metre cliff section is present at the fault against the Rinn Point Limestone Formation on the southeastern side of Muckros headland (Figure 8). Coarse-grained, pebbly non-calcareous sandstones form the lowest metre of section. This is overlain by grey mudstones and thin interbeds of sandstones, burrowed silty sandstones and variably calcareous sandstones (Plate 86). A twenty cm thick, pale grey micrite overlies the sandstones. The upper part is burrowed and is overlain by calcareous and oolitic sandstones containing shell fragments. The

upper seven metres of the cliff are sandier in nature, with foresets in the cross-stratified units indicating a southwesterly flow. Vertical burrows and carbonate concretions are noted. Buckman (1992) noted the occurrence of coiled chambered cephalopods and orthocones within oolitic beds along Muckros Head.

4.8.4.2 Northwestern side of Muckros Head

On the northwestern side of Muckros Head, approximately 25 metres of section are exposed (Figure 8). Non-calcareous sandstones, sandy oolitic limestones and sandy limestones dominate the sequence. The basal sequences comprise barnacle-covered, calcareous sandstones and trough cross-stratified, non-calcareous sandstones. Foresets dip towards the east. Sandy oolitic limestones with shell fragments, a colonial coral and some quartz pebbles, overlie this. The top forms an extensive bedding plane. A 3.7 metre thick unit above this bedding plane comprises trough cross-stratified, non-calcareous sandstones. Trough axes are exposed on the foreshore (Plate 87). Foresets indicate currents flowing from the southwest to northeast. The stratified sandstone unit is overlain by granule-rich, calcareous sandstones and very coarse-grained sandstones with abundant quartz pebbles. The lower bed comprises mainly flat laminae with southerly-directed foresets exposed towards the top. A fining-up sequence is observed in the upper unit. The base of this latter unit forms an extensive bedding plane beneath the first overhang. The cliff section comprises several metres of calcareous sandstones with numerous cut-and-fill structures, mud drapes and bioturbation. Palaeocurrent data in the cross-stratified sandstones indicate current flow to the west. Tabular calcareous sandstones follow this, with foresets indicating an easterly current-to direction. The calcareous sandstone beds above this are more laminated in nature. A 30 cms thick micrite unit is noted and is overlain by several beds of calcareous sandstone and quartzose sandstone with carbonate concretions. The top of the cliff comprises sandy limestone with barite rosettes in the upper part of the bed. This unit can be traced along the cliff top.

4.8.4.3 Core of Shalwy Syncline at Largymore

Within the core of the Shalwy Syncline, argillaceous to slightly sandy limestones of the Rinn Point Limestone Formation are overlain by approximately twelve metres of

calcareous sandstones of the Muckros Sandstone Formation. The dark grey, argillaceous limestones and shales of the Rinn Point Limestone Formation become more arenaceous, browner, tabular and thinner bedded towards the top of the formation (lower half of the sequence in Plate 88). The base of the Muckros Sandstone Formation is taken at the lowest calcareous sandstone bed (the notebook and compass overlie this latter unit).

Three metres of intensively bioturbated sandy limestones with some silty lenses form the upper beds of the Rinn Point Limestone Formation. These beds are thin, ranging from 8 to 12 cm each. Horizontal and vertical burrows are visible. Above this, two beds (80 cm each) of coarse-grained to pebbly, tabular cross-bedded, calcareous sandstones form the basal beds of the Muckros Sandstone Formation. Interbeds of variable thickness, comprising very bioturbated, burrowed arenaceous limestone and calcareous sandstones overlie this. Some thin lenses of calcareous grey siltstone are present. Further up-section, a 50 cm thick, thin-bedded, medium-grained sandstone displays a hummocky surface. The sandstones are brown in colour and appear to be dolomitised. Cross-strata are more pronounced further up-section, indicating bipolar palaeocurrents towards the north and the southwest. Some asymmetric ripples are visible in the sandstones. The top of the syncline comprises three tabular, metre-thick beds of low angled, cross-stratified, coarse-grained sandstones with angular quartz grains, displaying palaeocurrents towards the southeast.

4.8.5 THICKNESS OF THE MUCKROS SANDSTONE FM.

Buckman (1992) reported an approximate thickness of 22 metres at the type section along Muckros Head. This is at variance with the thickness of 40-43 metres reported by George and Oswald (1957). The thickest section noted within this study is the 25 metres thick unit on the northern side of Muckros Head. Only 12.2 metres are exposed in the Largymore Syncline. Thus, all that can be stated is that the formation exceeds 25 metres but it cannot be stated by how much.

4.8.6 PALAEOCURRENT ANALYSIS OF THE MUCKROS SANDSTONE FM.

As noted above, both unidirectional and bipolar sets are noted within the Muckros Sandstone Formation. Foresets within the tabular and trough cross-strata are quite varied. At any one locality or level the palaeocurrents are typically bipolar.

4.8.7 PROVENANCE OF THE MUCKROS SANDSTONE FM.

Mature quartzose grains dominate the more clastic parts of the Muckros Sandstone Formation. There is no reason to suggest that there is any major change in provenance from lower in the succession within the Donegal Basin. However, there is the possibility of influence from some uplift and rejuvenation. This would have provided adequate material to cause such a rapid shallowing of the water depth from the marine shelf conditions of the Rinn Point Limestone Formation to the higher-energy, nearshore Muckros Sandstone Formation.

4.8.8 AGE OF THE MUCKROS SANDSTONE FM.

The underlying Rinn Point Limestone Formation is dated as Lower Viséan in age. No archaediscid fauna (indicating an Arundian age) has been found in the arenaceous limestones towards the top of this formation at Largymore. However, Sevastopulo (in George *et al.* 1976) did note the presence of *Permodiscus* (an Arundian foraminiferan – now termed *Uralodiscus* - Sevastopulo 1999, pers. comm.) within this sequence at Muckros Head. However, this report needs to be confirmed.

Thus, it not clear whether this latter formation is of late Lower Viséan or earliest Arundian age. In the absence of any definitive faunas, a Lower Viséan age is tentatively suggested; thus, correlating stratigraphically with the St. John's Point Sandy Limestone Formation at St. John's Peninsula.

4.8.9 DEPOSITIONAL ENVIRONMENT OF THE MUCKROS SANDSTONE FM.

The high percentage of clastic material within the Muckros Sandstone Formation compares with the Cavan Sandstone Member (within the St. John's Point Sandy Limestone Formation). The presence of wave ripples, low angled and parallel laminated, trough-cross-stratified, calcareous sandstones might infer a proximal, nearshore/shallow water regime. This setting contrasts with the distal shelf position of the Rabley Limestone Member and the Gullhuch Sandy Limestone Member within the St. John's Point Sandy Limestone Formation.

The bipolar palaeocurrents within the calcareous sandstones suggests some tidal influence. A high-energy environment with reworking within shallow water is inferred from the presence of the well-washed, generally well sorted sandstones and the oolitic limestones. It is possible that a sea-level fall could have occurred towards the end of Rinn Point Limestone times. This would have resulted in an increase in the amount of clastic material (from the Muckros Sandstone Formation) being deposited within the shallow water/nearshore zone. These sands were probably then reworked by high-energy tidal conditions and re-deposited. However, periods of more normal marine conditions (albeit at relatively shallow depths) are thought to have occurred with the deposition of oolitic limestones containing nautiloids.

4.9 SLIEVE LEAGUE OUTLIER

4.9.1 INTRODUCTION

Slieve League comprises a predominantly Dalradian mountainous ridge (schist and quartzite) overlain by two small outliers of Carboniferous clastic rocks at 595 metres. The southern boundary of the ridge comprises a sea cliff, thought to be one of the highest in Europe. During this study, the unconformable contact between the Dalradian and the Carboniferous rocks was mapped (Figure 47). The boundary is generally irregular with the clastic rocks infilling the topographical lows. The age of the structure which has caused a circa 500 metres elevation of the Carboniferous rocks relative to the rest of the Donegal outcrop, is not certain.

4.9.2 LITHOFACIES OF THE SLIEVE LEAGUE SUCCESSION

The One Man's Pass area comprises Dalradian quartzites unconformably overlain by three to four metres of nearly horizontal, generally clast-supported, immature conglomerates and four to six metres of pebbly sandstones. The clastics are grey to light brown in colour. These conglomerates, pebbly sandstones and coarse sandstones are located along the summit of the One Man's Pass area (at 595 metres elevation) and extend eastwards towards the ruins of the Church (at 480 m). Clasts comprise quartzite, vein-quartz and psammite and are predominantly subangular, displaying a high degree of immaturity and poor sorting (Plate 89).

There is a small gap in exposure along the One Man's Pass. Pebbly sandstones overlie mica schists towards the ruins of the Church, whilst quartzites underlie the clastics further south towards the ridge. The sandstones contain tabular cross-stratification with sets varying from 10 to 50 cm thick. Data at Keeringear includes westerly, northerly and easterly directed palaeocurrents. Many of the larger blocks are loose; thus, the majority of the measured data are not reliable. It would appear however, that the predominant direction is towards the east. Several *Stigmaria* roots have been observed on surfaces at this locality (Plate 90). Some of the loose blocks comprise thinly bedded to laminated sandstones. Buckman (1992) noted the occurrence of *Taenidium barreti* (formerly *Beaconites)* within the Slieve League succession.

4.9.3 THICKNESS OF THE SLIEVE LEAGUE SUCCESSION

Approximately 10 metres of *in situ* material were noted during this study, although the area is covered with an abundance of loose eroded material. It is probable that the succession would have been at least 30 metres thick.

4.9.4 AGE OF THE SLIEVE LEAGUE SUCCESSION

The exact age of these beds is difficult to constrain, as siltstone/mudstone material is not available for palynological dating. Buckman (1992) suggested a Devonian to Carboniferous age for these beds, due to the occurrence of *Taenidium barreti* (formerly *Beaconites)*. The nineteenth century GSI mapping placed this group within the 'Lower Carboniferous Sandstone division'. In terms of composition, colour and sedimentary structures, these Carboniferous rocks on Slieve League resemble the clastic succession of the Banagher Sandstone Formation which caps Banagher Hill towards the eastern part of the study area (refer to Section 5.4). However, it cannot be inferred that they are of similar ages on this basis. The age of the Banagher sequence is well constrained by the underlying Clady Limestone Member (Lower Viséan) and the overlying Bundoran Shale Formation (Arundian). The clastics at Slieve League represent a completely isolated sequence and are more likely analogous to the other basal successions in the Donegal Basin.

In the absence of definitive data, this study proposes a Lower Viséan age for these rocks, although these beds are not incorporated with the stratigraphical succession within the Donegal area. The possibility of being assigned an older, Tournaisian age cannot be discounted.

4.9.5 DEPOSITIONAL ENVIRONMENT OF THE SLIEVE LEAGUE SUCCESSION

The Carboniferous succession on Slieve League rests unconformably on the Dalradian rocks. The presence of the trace fossil *Taenidium barreti* (*Beaconites)* and *Stigmaria* roots suggest a fluvial environment, where the predominantly conglomeratic to coarse-

sandstone beds were deposited as bedload material. Buckman (1992) maintained that a *Scoyenia* ichnofacies was applicable for this sequence.

CHAPTER 5 LITHOSTRATIGRAPHY OF THE EASTERN AREA OF THE MAIN DONEGAL OUTCROP

The eastern part of the main Donegal outcrop (refer to Figures 2 and 48) extends from the Edergole Formation (the oldest part of the succession) in the northeastern area (north of Lough Eske), and southwards towards the Donegal Town area, where the Donegal Limestone Member of the Ballyshannon Limestone Formation is exposed in rivers and along the coast. In this eastern area, there is extensive drumlin cover and forested landscape, resulting in a lack of good quality exposure. Nevertheless, there is sufficient information to demonstrate differences from the western succession.

5.1 EDERGOLE FORMATION

5.1.1 INTRODUCTION

The term Edergole Formation was formally proposed by Graham and Clayton (1994) after Edergole stream, where the sequence is best exposed. This unit was originally referred to as 'Edergole grits, conglomerates and quartzites' by George and Oswald (1957) They considered this succession to be the lowest unit in a conformable Lower Carboniferous succession, whereas Sheridan (1972) interpreted the sequence as an isolated fault-bounded sequence of 'Upper Old Red Sandstone'.

This section on the Edergole Formation is in part extracted from the work published by Graham and Clayton (1994), with additional field information collected during this study added where necessary.

5.1.2 LITHOFACIES OF THE EDERGOLE FORMATION

The Edergole Formation comprises conglomerates, sandstones and subordinate siltstones. The sequence is generally reddish in colour, although purple and green mottled units are also present. The conglomerates are clast supported and poorly sorted, with clasts predominantly of psammitic schist, schist, psammite and subordinate vein-quartz. The degree of clast roundness ranges from subangular to angular. As noted by Graham and Clayton (1994), the exposures are too small in size to infer bed geometries.

Where best exposed, most of the beds are generally less than a metre thick. Graham and Clayton also recorded a maximum clast size (mean of five largest clasts in any one bed) of 25 cm in the upper part of the coarsening-upward sequence near Edergole Bridge and in the lower parts of the unit at Corabber Bridge. Individual clast sizes up to 45 cm have been observed within the sequence. Although many of the beds appear to be devoid of internal structure, some traces of horizontal stratification and clast imbrication are present. The sandstone and siltstone lithologies (Figure 50) display current ripples, wave ripples and interference ripples on some bedding surfaces. The finer-grained, mica rich, muddy units contain many fragmented plant stems.

5.1.3 LOCALITY DESCRIPTIONS OF THE EDERGOLE FORMATION

Exposure of the Edergole Formation is limited to the Edergole and Greenan streams and to a small part of Corabber river, near Corabber Bridge (refer to Figure 49).

5.1.3.1 Corabber Bridge

Red coloured conglomerates and coarse-grained to pebbly sandstone beds are located beneath Corabber Bridge (GR19748 38614). These rocks extend northwards along the stream for approximately twenty metres and represent the structurally lowest part of the outcrop. Maximum particle size for clasts within individual conglomerate beds range from 5 cm to 15 cm. Individual schist and quartzite clasts extend up to 35 cm. The strata dip quite steeply (from 36^0 to 46^0) to the north and northwest. The high dip values may indicate the proximity to a fault-bounded margin. There are no other Carboniferous exposures to the east of this section. A marked feature trends from just beneath the schist exposure at Ballynavvel (GR19790 38651) towards the lakeshore at Lough Eske. To the east of this area, the drift constitutes metamorphic clasts and may equate with the easternmost extent of the formation. Owing to the near parallelism of this boundary with the strike in the Edergole Formation, a faulted contact or an unconformable contact are possibilities.

5.1.3.2 Edergole Stream

Several exposed sections are seen in Edergole Stream. The section to the southeast of Edergole Bridge (GR19704 38672 to GR19731 38656 - refer to Plate 91) comprises thin bedded, pebbly sandstones and conglomerates, dipping to the northeast. Maximum particle size for individual conglomerate beds range from 10 to 20 cm. A waterfall east of Edergole Bridge consists mainly of conglomerates. The section immediately west of Edergole Bridge displays more westerly dips (varying between 6^0 and 14^0 – Figure 49). Graham and Clayton (1994) noted that 'exposures in the Edergole and Greenan streams display a coarsening upwards sequence, which can be correlated between the two streams'. This feature is observed in a five metres thick section, which is exposed from the base at Edergole Bridge to a small waterfall further west. The sequence comprises pebbly red sandstones, overlain by poorly sorted conglomerates with maximum particle size of 20 cm. The clasts constitute psammite, schist and vein-quartz. Red sandstones are then overlain by approximately two beds (circa one metre thick each) of poorly sorted conglomerates. Possible imbrication may be detected, indicating flow from the north/north-east. Sandstone is exposed in the plunge pool within the stream. Access up through the waterfall is quite difficult. There is approximately 200 metres of a horizontal gap to where the next units crop out further upstream.

Approximately seventeen metres of section of near continuous exposure through Edergole Gorge (GR19658 38700 to GR19645 38702) was logged by Graham and Clayton (1994) (see Figure 50). The basal section of Edergole Gorge comprises two beds (circa 60 cm thick each) of coarse-grained sandstone (Facies B), which are separated by a 20 cm siltstone unit. The siltstone unit marks a prominent surface on the stream floor. The sandstone is overlain by thin interbeds of purple to green coloured, fine-grained sandstone and siltstone (Facies D). Miospores were recovered from one of these siltstone beds. Graham and Clayton (1994) assigned a CM Biozone (latest Tournaisian) to this sequence at Edergole. This topic is discussed further under Section 5.1.7.

Approximately two metres of thin bedded sandstones and siltstones continue towards a gap in exposure. Wave rippled surfaces and plant debris have been observed within this part of the succession. The section above the gap reveals poorly sorted, micaceous

sandstone overlain by pebbly, micaceous sandstones and thin red siltstone horizons. Poorly sorted, coarse-grained, micaceous, red sandstones dominate the upper sequence of the log from 11.2 metres to 16.8 metres. These sandstones contain isolated schist and vein-quartz pebbles. Flat beds are more common in the upper sandstones. A forty centimetre conglomerate bed at 13 metres comprises angular schist and vein-quartz clasts.

At the gorge locality, the sequence strikes in an east-south-east/west-north-west direction with northerly dips. A synclinal axis is inferred west of the miospore locality (refer to Figure 49). Thus, the sandstones at the gorge (dipping $7\text{-}10^0$ to the east) represent the western limb of the syncline. The rocks further northwest in the Edergole stream dip more to the east and southeast. Graham and Clayton (1994) interpreted the change in dip and strike as being 'disposed about a north-east-plunging open syncline'. The above authors noted that a critical 'exposure occurs in Edergole Stream at the upstream limit of Carboniferous exposure and adjacent to a dolerite dyke'. The 1.8 metre thick, north-west/south-east trending dolerite dyke with chilled margins is exposed to the west of the gorge. Further west, a coarse-grained, generally well sorted conglomerate is exposed (GR19623 38719). Dip and strike measurements are not possible. This conglomerate contains a higher proportion of vein-quartz and very few schist clasts. Maximum particle size is about 20 cm. The clasts within the conglomerate are better rounded and better sorted than those of the Edergole Formation. Graham and Clayton (1994) noted a few pink granite clasts, which have not been noted in the Edergole Formation. Thus, petrographically and texturally, this westerly sequence is different from the suite of rocks belonging to the Edergole Formation.

This latter conglomerate forms the basal unit of the Lough Eske Sandstone Formation, previously referred to as the 'Basal Clastics' by George and Oswald (1957) and Graham and Clayton (1994). Graham and Clayton interpreted the contact between the 'Basal Clastics' with the Edergole Formation as an unconformable boundary (Figure 42). The eastern limit of these authors 'Basal Clastics' is defined by large accumulations of loose blocks and thus cannot be precisely located. The inferred boundary follows the line expected from the strike of the Lough Eske Sandstone Formation, which is exposed further south, even though outcrop measurements are not possible.

Sheridan (1972) did not recognise a difference in the rock types within Edergole stream. However, he did observe a change in lithology from the rocks of the Edergole section to those in the Eglish River and the area northwest of Ardnamona. He inferred a structural relationship between the two types of rocks, rather than lateral variation as proposed by George and Oswald (1957, p145-146). However, as Graham and Clayton illustrated, the postulated fault as shown in Sheridan (1972, his Fig. 5) is not necessary.

5.1.3.3 Greenan Stream

Greenan stream is rather difficult to access and the individual lithologies are not easily deciphered. The sequence (GR19718 38636 to 19688 38637) is dominated by grey-green coloured, coarse-grained sandstones. Sandstone partings tend to weather out prominently. There is good correlation across strike between these rocks and the succession within Edergole stream as they both display northwest dipping rocks. The most easterly exposed section at Greenan comprises pebbly sandstone and is overlain by conglomerate (see Figure 49).

5.1.4 THICKNESS OF THE EDERGOLE FORMATION

It is difficult to resolve an exact thickness for the Edergole Formation. The exposure is not continuous and small faults may be present in unexposed areas. Sheridan (1972) estimated 183-305 metres, citing 396 metres as a maximum figure. Graham and Clayton (1994) stated that an 'estimated thickness of the Edergole Formation preserved in this area is 400 metres'. This latter figure is maintained in this study.

5.1.5 PALAEOCURRENT ANALYSIS OF THE EDERGOLE FORMATION

Many of the beds appear structureless, although some traces of horizontal stratification and possible clast imbrication were noted. However, insufficient exposure deterred accurate measurement readings.

5.1.6 PROVENANCE OF THE EDERGOLE FORMATION

As discussed above, the Edergole Formation is dominated by angular to subangular clasts of psammitic schist, schist, psammite. Vein-quartz is generally subordinate. These factors contribute to the theory of relative proximity to the source area. The hinterlands of the Edergole area (north of the Northern Boundary Fault), comprise the predominantly psammitic Dalradian Argyll Group (Hutton and Alsop 1996). During Caledonian times, these metasediments were intruded by the Barnesmore Granite (Pitcher and Berger 1972). The granitic pluton is exposed to the north of the Northern Boundary Fault. However, no granitic fragments are recorded with the Edergole Formation, implying that the granite roof was not exposed during the deposition of the Edergole Formation. As the Argyll group suite matches the clast composition within the Edergole Formation, and it is in near proximity, it may be inferred as the most likely source for the clasts.

5.1.7 AGE OF THE EDERGOLE FORMATION

George and Oswald (1957, p.144) assigned a Viséan age to their 'Edergole grits, conglomerates and quartzites'. Sheridan (1972) maintained that the Edergole succession was 'of Upper Old Red Sandstone aspect'. Sheridan discussed the problem of interpreting 'the diachronism of 'Upper Old Red Sandstone' facies across a Caledonian hinterland. If simple diachronism of this nature is correct, a time span from the Famennian of southern Ireland to the Viséan of Co. Donegal is indicated'. He then questioned where the fluvial rocks of the Edergole succession, if Viséan, would have entered into a marine-deltaic environment. Sheridan (1972) also maintained that George and Oswald (1957) did 'not formally recognise Upper Old Red Sandstone facies within the (Donegal) syncline'. However, Sheridan stated that 'the basal part of their Bruckless sequence .. and the lower part of their Edergole succession .. are of Upper Old Red Sandstone facies'. This statement by Sheridan refers to lithological characters only and did not imply a specific age.

Graham and Clayton (1994) recovered miospores from one carbonaceous siltstone within the Edergole Formation (refer to Figures 49 and 50 in this study): 'Preservation was poor to moderate, and the organic residue was dominated by large particles of vitrinite and inertinite, no marine indicators were recorded, though exines of some miospores were

pyritised'. Most of the miospore taxa recorded by the authors have relatively long stratigraphic ranges. However, the absence of *Lycospora pusilla* (Ibrahim) Somers and the presence of *Schopfites claviger*, *Anaplanisporites atheticus* and *A. baccatus* permit the assemblage to be assigned to the *Schopfites claviger-Aurospora macra* (CM) Biozone. The authors also proposed the possibility of a position towards the base of the zone, due to the relative rarity of *Schopfites claviger* and *Anaplanisporites baccatus*. The CM Biozone, is latest Courceyan (latest Tournaisian) in age (Higgs *et al.* 1988).

5.1.8 DEPOSITIONAL ENVIRONMENT OF THE EDERGOLE FORMATION

The Edergole Formation is the oldest (CM Biozone) succession within the Carboniferous Donegal Basin, as no other Tournaisian sequences have been recognised within the basin. The formation's contacts with the Dalradian metamorphics are not visible within the Edergole area, although the Northern Boundary Fault (between the Carboniferous rocks and the Dalradian and granitic rocks of the Blue Stack Mountains) can be detected as a break in landscape (Plate 93).

The conglomerates of the Edergole Formation are thought to represent proximal, first-cycle detritus, deposited 'in an area adjacent to a contemporaneous basin margin fault zone' (Graham and Clayton 1994). A depositional environment of a stream flow dominated alluvial fan, '.. with no clear evidence for debris flow ..' was suggested by the authors. They state that the palynofacies evidence is consistent with this model. The following factors support this theory:

- Locally derived material (angular to sub-angular clasts) with poor sorting.
- Vein-quartz (even in the finer grained sizes) is rare, while micas are extremely common in all sandy lithologies. These factors would probably indicate first-cycle metamorphic detritus, with limited transport by stream flow.
- A projected thickness of up to 400 metres for the Edergole Formation is relatively thicker than most basal conglomerates, which represent infilling of topography during periods of renewed sedimentation.
- Fault-bounded fan sequences commonly display coarsening-upward sequences.

- Several re-activated basement faults of the Northwest Carboniferous Basin of Ireland were active during the Dinantian. Lateral facies and thickness changes are synonymous with these north-east/south-west faults.
- The strikes in the Edergole Formation are parallel to the trend of these northeast faults.

Graham and Clayton (1994) inferred a correlative for the Edergole Formation in the Ballyness Formation within the Fintona Block in Co. Tyrone. This follows work by Mitchell and Owens (1990) who demonstrated that syn-sedimentary faulting was active in this area during the early Carboniferous. They state that 'Northward migration of the early Carboniferous marine transgressions in the northern part of Ireland coincided with the sequential propagation of back-stepping faults and resulted in the development of diachronous facies belts between late Courceyan and Arundian times'.

The Ballyness Formation (one of the basal clastic sequences within the Fintona Block) resulted from activity on one of these faults. It is estimated as 300 metres thick and comprises a series of red beds with pebbles of vein-quartz and variable metamorphic rocks. Although some disparities exist between the Ballyness Formation and the Edergole Formation (the Ballyness Formation differs in its vein-quartz composition, inferring a longer transport history, and displays a conformable boundary with the overlying Clogher Valley Limestone Formation), there are also some comparisons. The Ballyness Formation overlies the basement rocks in the Clogher Valley/Slieve Beagh area and Devonian rocks in the Fintona Block, representing extensional basins with syn-sedimentary faulting.

In comparison, the Edergole Formation represents Tournaisian sedimentation, most likely due to locally enhanced subsidence adjacent to syn-sedimentary faults in south Donegal. Graham and Clayton (1994) postulated that tectono-sedimentary settings similar to the Edergole Formation and the Ballyness Formation might exist within other areas of the Carboniferous. However, they were likely to have been overstepped and covered by younger sequences as the basins expanded.

5.2 LOUGH ESKE SANDSTONE FORMATION

5.2.1 INTRODUCTION

The Lough Eske Sandstone Formation is a new name proposed for the 'Basal Clastics' previously used by George & Oswald (1957) and Graham and Clayton (1994). Sheridan (1972) referred to the sequence as the 'Basal Sandstones, Limestones and Shales'. The Lough Eske Sandstone Formation unconformably overlies the Edergole Formation (refer to Figures 2, 48 and 49). The Lough Eske Sandstone Formation is exposed to the east of Lough Eske in the Greenan area (refer to Figure 2) and displays a gradational upper contact with the Clady Limestone Member and the Donegal Limestone Member (both of the Ballyshannon Limestone Formation) (refer to Enclosure 5.3 for location). This study places the Lough Eske Sandstone Formation as the eastern correlative of the Oily River Conglomerate Formation, the Largysillagh Sandstone Formation and the Shalwy Formation (exposed in the western part of the main outcrop of the Donegal Basin). However, insufficient exposure renders it impossible to delineate any subdivision of the unit in this area. Moreover, there does appear to be genuine differences between the Lough Eske area and that seen in the western part of the Donegal Basin.

5.2.2 LITHOFACIES OF THE LOUGH ESKE SANDSTONE FORMATION

Below is a descriptive account of the individual facies within the Lough Eske Sandstone Formation. However, it must be emphasised that while these lithologies are assigned facies letters similar to those observed in the western area of the Donegal Basin, there are several differences in the eastern area. These variations will be discussed where appropriate.

The Lough Eske Sandstone Formation comprises generally two facies assemblages, which display an overall fining-upwards and an increase in the calcareous content from the base to the top of the formation:

- conglomerates and coarse-grained sandstones with subordinate siltstone and shale intervals (Facies A2, B and D),

- buff coloured, non-calcareous and calcareous sandstones (Facies C and possibly Facies G and H ?)

The lower assemblage (Facies A2/B/D) is observed in the lower part of the Lough Eske Sandstone Formation (where they unconformably overlie the Edergole Formation – refer to Figure 49). The conglomerates of the Lough Eske Sandstone Formation (variably purple red and grey in colour) are dominant over the sandstones in the northern area. Clasts within the conglomerates include quartzite, pink and white vein-quartz, psammite and grey pelite. Maximum clast sizes range from 10 to 15 cm. Pink granite clasts are a notable constituent, although they are never common. The green/grey coloured, coarse-grained to pebbly sandstones (Facies B) are unsorted and relatively micaceous. Both tabular and wedge-bedded geometries are observed within the sandstones, with bed thickness generally varying from 20 to 60 cm. Cross-strata were noted; however, palaeocurrent data collection was not feasible due to unsuitable exposure. The sandstones display thin interbeds of micaceous siltstone and silty shale (Facies D). No evidence of marine conditions has been noted within this facies assemblage. As the sequence is similar to the facies assemblage exposed in Bruckless and McSwyne's Bay area, it is considered to represent the eastern equivalents of the non-marine Oily River Conglomerate Formation and the Largysillagh Sandstone Formation.

The upper assemblage comprises variably grain-sized (fine to pebbly), non-calcareous and calcareous, buff coloured sandstones of Facies C. Within the Greenan/Lough Eske area, this assemblage is placed stratigraphically above the conglomerates and sandstones of Facies assemblage A2/B/D. The medium-grained calcareous sandstones are the most commonly exposed and are generally well sorted and well washed. Bed geometries within the sandstones are generally tabular, and commonly between 10 to 40 cm thick. Cross-strata (both unidirectional and bi-polar) have been observed. Pebbly horizons (comprising quartz and quartzite clasts) are commonly arranged along bedding planes and cross-stratal surfaces. Many of the sandstone surfaces display a calcareous pocked or honeycomb weathering.

Facies G (tabular beds of parallel-laminated sandstones) and Facies H (coarse-grained calcareous sandstones and sandy limestones with biodebris) may be included within this formation. However, poor exposure renders it difficult to clearly recognise them.

5.2.3 LOCALITY DESCRIPTIONS OF THE LOUGH ESKE SANDSTONE FM.

5.2.3.1 Area west of Edergole Stream

The conglomerates and coarse-grained to pebbly sandstones facies are observed within scattered outcrops and subcrops in the boggy area along the Northern Boundary Fault, extending from the Edergole stream westwards towards the Eglish River. At GR19567 38728, green to grey coloured quartzose, generally flat bedded, coarse-grained sandstones with pebbly conglomeratic horizons are exposed near the end of the first dirt track, which terminates south of Lough Nacollum. The pebbles include granite and some grey pelitic rocks. At GR19543 38687, conglomerates are overlain by grey, micaceous, silty sandstone. The bedding is horizontal and the largest clast is 12 cm in size. At GR19546 38724, some bedding appears to be present and the clastics are moderately sorted. At GR19535 38725, maximum clast size within the conglomerates is 25 cm. A prominent orange-pink granite clast was noted at this location. The granite clast (20 cm in length) is similar in appearance to smaller clasts in the orange-pink granitic sandstones observed at Sallows (GR18824 38668 - 6 km to the west – refer to Figure 2). This latter granitic source may be the Barnesmore Pluton, which is exposed immediately north of the Northern Boundary Fault (NBF).

The exposure in the Eglish River towards the NBF (GR19445 38730, refer to Figure 2 for location) comprises vein-quartz and quartzite conglomerate (Facies A), interbedded with lensoid sandstones (Facies B). The sandstones are relatively well sorted with loose blocks displaying cross bedding. There is a gap in exposure to the north of the river, which contains only poorly sorted, red coloured loose blocks. The next outcrop to the north displays greenish micaceous sandstones and coarse conglomerates. Granite clasts are also noted here and may also be sourced from the Barnesmore Pluton.

5.2.3.2 Greenan area

The eastern basal slopes of Banagher Hill exposes many crags of Facies C herringbone cross-stratified sandstones (refer to Enclosure 5.1). At GR19585 38585, approximately eighteen metres of northwest dipping, parallel interbeds of pebbly sandstones, calcareous sandstones and sandy limestone are exposed (Plate 18). Some of the beds display bipolar cross-strata, with currents indicating current to the east and west. These beds continue further north, striking north-east/south-west and eventually pass up conformably into the purer calcareous beds of the Clady Limestone Member of the Ballyshannon Limestone Formation.

Several loose blocks of pebbly sandstones (some calcareous) are located in the area from GR19604 38608 to Caldragh (GR19641 38577). To the northwest of Caldragh (GR19615 38592), several metres of coarse to fine-grained calcareous, cross-stratified sandstone are exposed. These beds strike northwest to southeast. This deviation of strike may be influenced by the Caldragh Fault, which displays a similar trend. Cross-strata indicate palaeocurrents to the northwest, although these are probably not true readings as the 'exposures' appear to consist of slightly moved blocks. At GR19598 38598, steep south-south-east dipping (46^0), calcareous sandstones are likely to be in the line of the Caldragh Fault. Across the road from the lodge at Caldragh (GR19627 38585), *in situ* well washed, calcareous, pebbly sandstones crop out.

The road from Caldragh to the Clady River contains numerous examples of the Facies C calcareous sandstone. The majority of the rocks in this vicinity are *in situ*, although some of the exposures are loose blocks. A west-dipping, discontinuous cliff (extending across several fields) displays a well-exposed section of this facies assemblage to the east of the main road (GR19600 38513). Approximately three metres of medium to coarse-grained, calcareous sandstone are separated from the overlying exposure by a gap several metres thick. Above this gap, a five-metre cliff of thin (circa 5 cm) interbeds of calcareous sandstone and pebbly sandstones are observed. Three metres of sandy limestone and three metres of calcareous sandstone overlie this. Hard sparry limestone has also been noted further east (beneath the base of the cliff section). This carbonate sequence is most likely part of the better-washed sections of the Donegal Limestone Member.

5.2.3.3 Clady River

The most easterly exposure of the Lough Eske Sandstone Formation is at the tip of the wooded area near the shore of Lough Eske (L292, GR19694 38428 – refer to Enclosure 5.1) within the Clady River. A two metre thick exposure comprises medium-grained, calcareous sandstones, silty limestone and pure sparry limestone overlain by medium to coarse-grained, calcareous sandstone. Three *Syringopora* corals and crinoidal debris have been observed. After a gap further west, northwest-dipping, fissile, silty limestones are eventually overlain by well sorted, medium-grained, calcareous sandstones and fossiliferous sandy limestones. The section of the river from this locality to the Lodge, contains loose boulders only. At the Lodge (north of the river), Facies C and G medium-grained, well sorted, calcareous and some non-calcareous sandstones are exposed in the riverbanks. The rocks have opposing dips on either side of the river. To the south of the river, the sandstones dip to the west. To the north of the river, the sandstones dip to the east. Due to poor exposure, it is not known if this structure is a fold or a fault. Some bipolar cross-strata are visible, showing palaeocurrent flow directions to the northwest and southwest. An igneous dyke is exposed within the river, which may trend parallel with a fault. Further west towards Clady Bridge, exposures within the river display micaceous, fossiliferous limestone and sandy limestone. The interbedded limestones (predominantly micaceous and quartz rich) are interpreted as thin interbeds of the Donegal Limestone Member within the Lough Eske Sandstone Formation.

5.2.3.4 Southeast of Ardnamona estate

Loose boulders and cobbles of grey to red coloured, pebbly sandstones and conglomerates are observed along the northwest part of the lake edge (GR19695 38520 – refer to Enclosure 5.1), approximately 200 metres from Ardnamona House. Although loose, it is most likely that these blocks have not travelled far and probably belong to the Lough Eske Sandstone Formation. This would indicate that the lower facies assemblage (A2/B/D) is probably present in this area.

5.2.3.5 Lateral facies change at Lough Eske

The Burns Mountain Fault cuts through the Friary area and may result in a thinning of the Lough Eske Sandstone Formation (refer to Enclosure 5.2). This fault can be traced northeastwards across Lough Eske into the Dalradian and Barnesmore Granite hinterland (refer to Figure 51). The exposure at Locality 291 (northwest of Pigeons Island - GR19677 38322) comprises medium-grained, calcareous sandstone with joints and small faults. The shore of Lough Eske in the Grania's Island vicinity exposes extensive (approximately 60 m thick) argillaceous, fissile, fossiliferous limestone. This latter suite of rocks is placed within the Donegal Limestone Member. This facies relationship can be mapped as a series of inter-fingering calcareous sandstones facies of the Lough Eske Sandstone Formation terminating southwards, whilst the argillaceous limestones units of the Donegal Limestone Member terminate northwards. This lateral facies change is displayed in Figure 52.

5.2.3.6 DN-69-17 Borehole

An unpublished report by Philcox (1983) discusses Penarroya's hole DN-69-17. This borehole was drilled vertically to a depth of 151.8 metres, near the southeast corner of Lough Eske (GR19797 38206). According to Philcox (refer to Table 5.1 below), the hole penetrated a succession of shales and sandstones with minor argillaceous limestones and evaporites and 'in contrast to those holes to the south that reached "basement" (Moinian schists, etc.), DN-69-17 penetrated some 12 m of red beds below the Basal Sandy Beds, the contacts appearing conformable'.

Penarroya DN-69-17 Borehole			
	DEPTH	**TRUE THICKNESS**	**UNIT**
Top	15.6 to 72.3 m	50 m	Lower Shale *
	72.3 to 130.2 m	54.5 m	Basal Sandy Beds *
	130.2 to 142.7 m	11.75 m	Red Beds *
Base		circa 9 m	Basement schists

Table 5.1 An outline of the depths and thickness recorded by Philcox (1983) from the DN-69-17 borehole, south of Lough Eske (GR19797 38206). * These unit names are only used in the discussion of Borehole DN-69-17 and are not otherwise applied in this study.

In contrast to the borehole DN-69-17, unconformable contacts with the schists are not seen above surface in the Lough Eske area. Philcox (1983) described the 'Red Beds' within the core as mainly fine-grained, red sandstones; in addition to grey calcareous sandstones; bird's-eye micrite, skeletal calcarenites and possible replaced evaporites. The lithologies within the top three metres (the carbonate sediments outlined above) suggest deposition within a marine influenced environment. It is not known if there are other correlatives of this unit within the Donegal Basin, as neither evaporites nor any structures indicating their former presence have been observed during this study. Biostratigraphical dates are not available from this borehole, although this section is assigned a Pu Biozone (refer to Section 5.2.7). Philcox (1983) maintained that the 'Red Beds' unit was distinct from the 'Basal Sandy Beds', on the basis of the latter's position stratigraphically beneath typical 'Basal Sandy Beds' conglomerates. However, it is highly unlikely that the 'Red Beds' can be correlated to the Edergole Formation, due to the presence of marine influence within the 'Red Beds'. Philcox (1983) did not suggest the presence of calcareous sequences within the 'Basal Sandy Beds', nor is it discussed whether bi-polar sandstones are present within the core (as it is unlikely to see bipolar cross-stratification in this core). He noted an overall upward change from coarse-grained sandstones and conglomerates, to laminated silty sandstones and shales. This unit would thus appear to correlate with this study's Facies A non-calcareous, coarse-grained sandstones and conglomerates of the basal part of the Lough Eske Sandstone and may also include rocks further up in the formation. However, there is uncertainty in this correlation as the 'Red Beds' may also be correlated to the lower part of the Lough Eske Sandstone Formation.

The 'Lower Shale' is thought to correlate with the fossiliferous calcareous shales and silty limestones (of the Donegal Limestone Member in this study) exposed along the southwestern shores of Lough Eske. From field mapping, these fissile argillaceous limestones and calcareous shales at the lake appear to extend and crop out further southeastwards. Philcox (1983) observed some variations within the 'Lower Shale' unit in DN-69-17. He noted a 40 cm thick massive sandstone, which seemed atypical of the 'Lower Shale'. Thin sandstone units have been noted to the south of Lough Eske in this study and are thought to be the distal equivalents of the younger Banagher Sandstone Formation. Serpulids, which were observed in the core have not been noted in the field during this study, although this may be a factor of exposure and preservation. The well

washed calcareous sandstones and pure crinoidal limestone facies within the upper units of the Clady Limestone Member are not represented in DN-69-17. Alternatively, the 'Lower Shale' may be a lateral facies change of the Clady Limestone Member, reflecting a more basinal, shalier marine environment further south from Lough Eske. Either of these scenarios would result in the 'Lower Shale' being stratigraphically younger than the Lough Eske Sandstone Formation.

5.2.3.7 Owenboy

Variable beds of sandstone are exposed within the Sruell River at Owenboy (GR19082 38656 to GR19081 38643 – refer to Figure 2 and Enclosure 5.3 for location). In the northern part of the river section, a shallow waterfall exposes approximately five metres of pebbly to coarse-grained, unsorted sandstones (most likely to equate with Facies B). They are relatively irregularly bedded (due to erosional surfaces), but are predominantly south dipping. Further downstream and upsection, the bed geometry becomes more regular and tabular. Two 50 cm thick tabular beds of medium to fine-grained sandstones overlie the coarser beds described above, and display a gradual fining-upwards sequence with the overlying shales. The calcareous shales are approximately three metres thick and are very fissile; thus, thin-section sampling was not possible. Approximately five metres of cross-stratified, predominantly medium-grained sandstones overlie the shales with an abrupt contact (Plate 94). The cross-stratified unit is approximately one metre thick. Palaeocurrent directions within the cross-stratified beds are towards the north and northeast. A channel cut is also observed just above the cross-stratified beds on this cliff section. Bed thickness in the more tabular overlying beds varies from 15 to 40 cm. This exposed section at Owenboy is rather isolated. The nearest rocks crop out as follows:

- at Meenawilderg (700 metres to the south at the confluence of the Sruell and Eglish Rivers – refer to Enclosure 5.3), micaceous and calcareous sandstones are overlain by fossiliferous siltstone and argillaceous limestone;
- calcareous sandstones and shales are exposed in a stream section 600 m to the east of Owenboy, and
- immature granitic sandstones crop out at Sallows (3 km to the west)

From field evidence it would appear that the Owenboy sequence (unless disrupted by faulting) is older than the Meenawilderg sequence (the latter is confirmed as Arundian in age). However, as Owenboy sequence has not been constrained biostratigraphically, difficulties arise in placing it within a logical lithostratigraphic framework beneath the Bundoran Shale Formation. It is possible that the Owenboy sequence equates with a more marine-influenced upper part of the Lough Eske Sandstone or possibly a clastic dominated section of the Clady Limestone Member (and the topmost sandstones equates with the Banagher Sandstone Formation). This would imply a thinning of the Banagher Sandstone Formation due to the Belshade Fault south of Owenboy, which is eventually overlain by the Bundoran Shale Formation at Meenawilderg. Alternatively, it may be assigned to the younger Killin Sandstone Member (part of the Bundoran Shale Formation).

In the absence of affirmative data to suggest otherwise, the Owenboy sequence is assigned to the Lough Eske Sandstone Formation, with an associated marine incursion during early Ballyshannon Limestone Formation times (formerly known as late Chadian, this term is now revised to Lower Viséan).

5.2.4 THICKNESS OF THE LOUGH ESKE SANDSTONE FM.

Due to the absence of logged sections and incomplete exposure, an accurate figure of the thickness of the Lough Eske Sandstone Formation is not possible. However, based on the field mapping information assembled in this study and from the topography in the Lough Eske area, the thickness range of the formation is estimated between 100 and 120 metres.

5.2.5 PALAEOCURRENT ANALYSIS OF THE LOUGH ESKE SANDSTONE FM.

The Lough Eske Sandstone Formation is subdivided into two parts. The lower non-marine unit comprises conglomerates and coarse-grained sandstones. Palaeocurrent data could not be extracted from this unit due to insufficient exposure. The upper part of the formation comprises Facies C bipolar cross-stratified sandstones, which display variably directed palaeocurrent directions. Exposures of this sandstone are spatially

separate (Greenan area and the Clady River area) and the scattered data within each area shows great variability to the north and southwest.

5.2.6 PROVENANCE OF THE LOUGH ESKE SANDSTONE FM.

The clasts within the lower beds of the Lough Eske Sandstone Formation comprise quartzite, pink and white vein-quartz, psammite, grey schists and subordinate granite clasts. The conglomerates are interbedded with micaceous siltstones and silty shales. The Lough Eske Sandstone Formation unconformably overlies the Edergole Formation. As discussed in Section 5.1.8, a short transport history is inferred for the Edergole Formation, due to the relative immaturity of the clasts and the low occurrence of vein-quartz. In contrast, the conglomerates within the Lough Eske Sandstone Formation are well rounded and contain abundant vein-quartz and granite clasts. This would imply that the rivers eroding the Dalradian hinterlands to the north and northeast (which transported this material during the Lower Viséan) would have undergone a significantly different and longer transport history than the Edergole Formation. This history may have included some recycling. The presence of pink granite clasts within Lough Eske Sandstone Formation may infer that at least one river had drained through the Barnesmore Pluton (refer to Figure 51). This would suggest that the roof of the pluton had been exposed during the early Viséan.

5.2.7 AGE OF THE LOUGH ESKE SANDSTONE FM.

Higgs (1984) obtained spores from Sample 81-4224 (depth 122 metres) within the 'Basal Sandy Beds' in DN 69-17. The assemblage includes *Schopfites claviger* Sullivan, *Crassispora trychera* Neves and Ioannides, and numerous species of *Convolutispora*, notably *C. circumvallata* Clayton. Also present are rare specimens of Lycospora pusilla (Ibrahim) Somers. The assemblage is assigned to the Pu Biozone and the rare occurrences of the index species indicate a position low in the biozone. Based on field relationships with the underlying Edergole Formation and on biostratigraphical analysis within the interfingering lime-rich beds, the Lough Eske Sandstone Formation is Lower Viséan (formerly late Chadian) in age.

5.2.8 DEPOSITIONAL ENVIRONMENT OF THE LOUGH ESKE SANDSTONE FM.

A similar depositional history is envisaged for the Lough Eske Sandstone Formation as that described within the basal units of the western part of the Donegal Basin. The units from this latter area (the Oily River Conglomerate Formation, the Largysillagh Sandstone Formation and the Shalwy Formation) are discussed in Chapter 4.

Within the Lough Eske area, a large amount of clastic material was still being introduced into the system by bedload as they continued their path southwards towards the coast. The source area for this clastic influx is believed to be from the Dalradian hinterlands to the north.

The Facies C bipolar sandstones (calcareous and non-calcareous) noted along the eastern basal slopes of Banagher Hill are characteristic of tidally influenced channels, thus tidal conditions had reached as far north as the Banagher Hill area during the deposition of the Lough Eske Sandstone Formation. Lateral facies changes are evident with interfingering of the clastic-dominant sequence in the north with the argillaceous, fossiliferous limestones of the Donegal Limestone Member to the south. Some of the well sorted, quartzose sandstones (possibly Facies G) exposed within the Clady River may be inferred as shallow marine. It is likely that the sandstones in the upper part of the formation were reworked by marine processes (most likely tidal to shoreface area), due to their well-sorted nature.

George and Oswald (1957) stated that the 'rapid changes in lithology and thickness are an indication of the close proximity of the contemporary land-mass from which the arenaceous detritus was derived. Fast-flowing streams tumbled off a hinterland of high-relief, depositing deltaic sands and gravels near the present boundary fault: they soon lost speed on entering the sea, as is shown by the general reduction in grain-size'.

The whole setting within the Lough Eske area appears to be rather coarser-grained than in the western part of the Donegal Basin. Thus, there exists the possibility of steeper gradients towards the palaeocoastal area. Within a fining-upwards of the succession, the marine influence became more influential towards the upper part of the formation.

Carbonate material (including gastropods, corals and crinoid debris) was introduced into the system from the south, with several lenses extending northwards onto the fluvial dominated area. To the northwest of Lough Eske, this transgressive pulse culminates in the well washed, sandy limestones of the overlying Clady Limestone Member (inner shelf setting). Further south (to the south and west of Lough Eske), the clastics of the Lough Eske Sandstone Formation are interbedded with limestones of the younger Donegal Limestone Member (the latter contains a higher argillaceous content than the Clady Limestone Member, and is indicative of open marine deposition).

5.3 THE DONEGAL LIMESTONE MEMBER

5.3.1 INTRODUCTION

The Donegal Limestone Member is proposed for the sequence of carbonate rocks found in the area south of Lough Eske and towards Donegal Town (refer to Figure 2 for location). These rocks may be correlated with the 'sub-Ballyshannon Limestone', to differentiate from the 'mostly-shale free Ballyshannon Limestone' (MacDermot *et al.* 1983). The Donegal Limestone Member is, in essence, part of the Ballyshannon Limestone Formation, originally named the 'Ballyshannon Limestone' by George and Oswald (1957) and the 'Ballyshannon type' by Sheridan (1972). However, in this study it is considered that lithological differences in Lough Eske-Donegal Town area are sufficient to differentiate it from the main Ballyshannon Limestone Formation. George and Oswald (1957) have also observed this, where they stated that north of Ballintra, 'the relatively massive character of much of the Ballyshannon Limestone breaks down. Partings of shale become increasingly prominent in both number and thickness'.

The Donegal Limestone Member and the Clady Limestone Member are allocated a member status within the Ballyshannon Limestone Formation. The eastern basal contact of the Donegal Limestone Member is not seen in the study area, as it is obscured by Lough Eske. Elsewhere, the member displays an inter-fingering contact with the Lough Eske Sandstone Formation. Further south, it displays an irregular upper contact with the Banagher Sandstone Formation.

5.3.2 LITHOFACIES OF THE DONEGAL LIMESTONE MBR

The Donegal Limestone Member comprises predominantly thin beds of argillaceous, bioturbated, fossiliferous limestone (Facies K), calcareous sandstones and sandy limestone (Facies H) and calcareous silty shales (Facies Q). This facies assemblage is commonly observed as interbedded with the Facies C sandstones from Lough Eske Sandstone Formation due to a lateral facies change. *Syringopora* corals and crinoid ossicles are the dominant fossils (within Facies K), with subordinate amounts of gastropods in the upper units. Bioturbation is variable within the member, although the argillaceous limestones display a greater amount.

Variable amounts of mica are present, especially within the more arenaceous units. These arenaceous units are generally well washed and well sorted, with very little argillaceous content. The argillaceous particles are generally confined to thin lenses and flasers of calcareous siltstone and shales, which separate the sandy limestone beds.

Subordinate beds of clean, sparry limestone with crinoid ossicles have been observed. As these latter beds comprise limited exposures, they cannot be easily mapped. Thus, it is not clear whether they should be assigned to the surrounding Donegal Limestone Member or as thin lenses of the Clady Limestone Member.

5.3.3 MICROFACIES OF THE DONEGAL LIMESTONE MBR

5.3.3.1 Thin-section analysis

The following thin-sections (refer to Appendix 4) outline a brief analysis of the Donegal Limestone Member:

TCD No.50552, L265b	Bridge at Lough Eske (GR19686 38204)
TCD No.50555, L268	South-west of Lough Eske (GR19543 38164)
TCD No.50564, L300	Ross dhu, Lough Eske (GR19639 38221)
TCD No.50699, 96-67	Clarlougheask (GR19648 38127)

A microfacies analysis of this member shows that the majority of samples are wackestones. The argillaceous content is relatively high; thus, they are assigned biomicrites to calcareous siltstones. However, the member contains a relatively high percentage of fossiliferous debris, including fragments of the major component types: crinoid ossicles, brachiopods, bivalves and bryozoans, bivalves, brachiopods, gastropods, echinoderms. Other less common grains include moravamminids, calcispheres (*Mendipsia leesi*), *Koninckopora*, ostracods and possibly *Aoujgaliids*. In addition, the following foraminifera are commonly encountered: *Endothyra*, *Earlandia*, *Eostaffella*, *Eoparastaffella*, *Brunsia*, *Tetrataxis*, *Mediocris*, *Dainella* and *Palaeospiroplectammina*.

Refer to Appendices 1 and 4 for further information, regarding location and grain component analysis of these and other thin-sections.

Sevastopulo in Higgs and Sevastopulo (1983) reported that Sample 74-1012 (from east-north-east of Donegal Town) comprised recrystallised, peloidal skeletal packstone/calcarenite. The skeletal grains are mainly fine sand-grade spicules, ostracods, calcispheres, crinoids and foraminifera. The authors noted a microbiota of *Calcisphaera*, *Diplosphaerina*, *Earlandia elegans*, *Earlandia* sp., *Eoparastaffella* sp., *Endothyra* spp. and kamenids. Sevastopulo suggested a Chadian to Arundian age for this sample.

5.3.3.2 Conodont analysis

Two samples from the Donegal Limestone Member (Localities 96-65 and 96-81 - refer to Appendix 1 for locality details) were processed for conodont extraction However, no conodonts were yielded. Sample 96-81 is relatively argillaceous which may be a contributing factor. However, Sample 96-65 is a relatively clean, sparry limestone which should have yielded some conodonts.

5.3.4 LOCALITY DESCRIPTIONS OF THE DONEGAL LIMESTONE MBR

Exposure of the Donegal Limestone Member is poor in the low lands south of Lough Eske and is generally confined to the shores of Lough Eske, Lough Eske River, and small stream exposures towards Donegal Town.

5.3.4.1 Clady River

A traverse through the Clady River from Lough Eske to Clady Bridge (refer to Enclosure 5.1) exposes an interbedded sequence (calcareous sandstones, sandy limestone, calcareous shale and argillaceous limestones) assigned to the Lough Eske Sandstone Formation and the Donegal Limestone Member. The sequence west of the Clady River Bridge (L263, GR19583 38429) continues upstream as the Donegal Limestone Member. The log (Figure 53) commences at Clady Bridge and comprises dominantly fissile, calcareous siltstone with an interbed of tabular, compact, argillaceous limestone. The overlying compact, sandy limestone bed with muddy flasers forms the basal pavement for cattle crossing the river. This pavement is overlain

by interbedded fissile, calcareous siltstones and tabular bedded, compact, argillaceous limestones. The degree of bioturbation is variable within different beds. The boundaries are often gradational, and the micaceous content tends to increase upsection. Some of these more arenaceous units are assigned to thin lenses of the Lough Eske Sandstone Formation, which interfinger southwards. Fossiliferous debris is quite uncommon, with crinoids appearing to be the only macrofossils present in these beds. Interbedded fissile, calcareous siltstone and tabular, argillaceous limestones are exposed at two small waterfalls (10 and 10.8 metres, respectively from the base of the logged section in Figure 53). Fossils are absent to rare, although this may be a factor of exposure. This sequence is followed by hard, sandy, tabular limestone with mostly fissile, argillaceous interbeds (14 m to 17.5 m). Bioturbation is common and crinoidal debris is present. The Donegal Limestone Member continues to circa 23.6 metres upsection, where the Clady Limestone Member overlies it. The latter part of the log (comprising the Clady Limestone Member) will be discussed in Section 5.4.4.1.

5.3.4.2 Lough Eske shore and demesne area

Locality 266 (GR19634 38306 to GR19623 38284) on the western shore of Lough Eske, displays a good section of the Donegal Limestone Member (Enclosure 5.2). This locality comprises a nearly forty-metre section (if faulting is ignored), which extends from near Grania's Island to the Boat Slip further south. The sequence consists of thin bedded, brown-grey coloured, generally quite fissile, argillaceous limestone and calcareous shales containing both *Syringopora* and caninioid corals, and crinoidal debris. Some beds are quite micaceous and silty. At least three faults may be present within jointed, disturbed rocks. An E/W trending fault is interpreted north of the Boatslip, where the exposure comprises discontinuous, irregularly bedded, argillaceous limestone. The fault appears to extend to the west and is cut by the Burns Mountain Fault further west. The amount of displacement on this fault is not known, as further south from the Boat Slip after a gap, argillaceous limestones (often fissile) with horizontal burrows are noted. These argillaceous limestones do not appear lithologically different to the rocks north of the fault.

After another horizontal gap (c.300 metres), the Ross dhu area (L300, GR19639 38221) comprises brown-grey coloured argillaceous, micaceous limestone with crinoids. The

vicinity of Lough Eske Demesne is scarcely exposed. An isolated exposure at Locality 269 (GR19560 38265) comprises argillaceous, micaceous limestone. L299 (GR19606 38272 – circa 400 metres southeast of Lough Eske Castle) comprises hard, sandy limestones with crinoid debris. It is unclear whether this outcrop should be assigned to the Clady Limestone Member or the Donegal Limestone Member, as the former member become unmappable in this area (refer to Enclosure 5.2).

A stream, which drains Burns Mountain and runs through Lough Eske Demesne, contains some exposure (refer to Enclosure 5.2 in the area where the E/W fault extends inland from Lough Eske). A waterfall within the stream exposes several metres of south dipping, thinly bedded, medium-grained, buff sandstones and calcareous siltstones. Further west, L280 (GR19498 38248) comprises micaceous siltstone (with two crinoid fragments), lying beneath coarse-grained buff sandstone. The siltstone- and sandstone-dominant rocks described here are not exposed along the shores of Lough Eske. This difference may be due to the sequence in the western Lough Eske Demesne area forming under a more proximal environment, compared to the less proximal, more marine-influenced argillaceous sequence observed at Lough Eske shore. The sandstones at L280 and L282 (GR19518 38254) are likely to be south-extending lenses of a less coarse-grained Banagher Sandstone Formation sequence (in the Burns Mountain area), extending into the Donegal Limestone Member.

5.3.4.3 River Eske (from Lough Eske to Donegal Town)

The rocks beneath the bridge at River Eske where it opens into Lough Eske (exposed during summer low water level conditions), comprises thin bedded (1-2 cm), fissile, argillaceous limestones and calcareous shales. Several beds of hard, micaceous, relatively clean limestones are also present (L301/265, GR19686 38204). Relatively rich, fossiliferous debris horizons are common. Crinoidal debris and caninioid corals dominate the horizons.

The rocks within River Eske from Lough Eske Bridge to Drumnacarry (GR19656 38153) display a west-dipping sequence. Exposure is not continuous south along the river from Lough Eske Bridge. However, interbeds of relatively clean limestone, fossiliferous, argillaceous limestones and fissile, calcareous shales are observed (Plate

95). The contacts between the beds are generally gradational. At McGadden's Island (GR19670 38162), the argillaceous limestone sequence displays a much higher (26^{0}) southwesterly dip. A gap in exposure separates these rocks from rocks at the Mill, 100 metres to the southwest. A north-north-east trending, west-dipping fault is interpreted within the sequence at the Mill. On either side of this fault, shallower dipping, argillaceous limestones and fissile calcareous shales and siltstone are present. After another horizontal gap (c. 200 metres) the river exposes several metres of irregularly bedded rocks at Clarlougheask. The dips of the beds vary due to several faults. At (locality 96-67) GR19650 38127, a northwest dipping (60^{0}) fault cuts through the fissile, argillaceous limestone and calcareous shales. This fault appears to link up with a fault (of same northeast trend and northwest dip) exposed further east at Foxes Hole (GR19580 38112). This fault is named the River Eske Fault. A northwest trending dolerite dyke also cuts through the exposure.

The River Eske also exposes several beds of clean, relatively pure crinoidal limestone at Foxes Hole (Localities 96-65, 96-66, GR19576 38109) and Clarlougheask (localities 96-67, GR19648 38127). These clean limestones are interbedded with the argillaceous limestone and fissile, calcareous shale sequence described above. It is possible that the cleaner limestones may be lenses of the Clady Limestone Member, interfingering with the Donegal Limestone Member, although this hypothesis cannot be tested. Thus, they are assigned to the Donegal Limestone Member.

Further southwest along the river, at Drumlaght (circa GR19405 37952), scattered outcrops of generally horizontal bedded, fissile silty limestone, calcareous siltstones and shales are observed. Subordinate exposures of similar lithologies are also observed in the river from Drumlaght to the Corn Mill at Mill Town. Milltown (GR19380 37900) comprises south to southeast dipping, thin interbeds of fissile, calcareous siltstone and shale with minor argillaceous limestones. Bioturbation and crinoidal debris are present.

5.3.4.4 Donegal Town area

The river under Castle Bridge at Donegal Town (GR19298 38753) exposes variable lithologies at low tide. Immediately beneath the bridge, disturbed calcareous sandstones display an apparent open fold. After a gap to the east, approximately eight metres of

calcareous, pebbly quartz to coarse-grained sandstones are exposed. The sandstones are steeply jointed in the western section in the vicinity of the bridge pillar. Some silty flasers and crinoids were noted. After a one metre gap, an intensively jointed, calcareous siltstone and silty limestone sequence is exposed. Cross-strata are present although exposure is not sufficient to justify measurements. After a 4.5 metre gap, irregularly bedded, calcareous siltstones and fine sandstone with some quartz pebbles display an irregular contact with thin interbeds of calcareous sandstone and siltstone further southeast. The coarse-grained and pebbly calcareous sandstones are interpreted to represent a lateral facies change from the coarse pebbly sandstones and conglomerates of the Banagher Sandstone Formation. The silty limestones and calcareous siltstones are assigned to the Donegal Limestone Member. Argillaceous rocks are exposed at low tide along the northern banks of the mouth of the estuary (Locality 96-81, GR19279 37844), opposite the two hotels in Donegal Town. The sequence comprises interbeds of compact, argillaceous limestone and fissile calcareous siltstones and shales. The argillaceous content is quite high. Contacts between the various lithologies are gradational. The sequence is quite faulted, resulting in the beds displaying joints and variable strikes. Bedding dips range from 6^0 to 22^0 to the northeast, east and south. In previous maps (George and Oswald 1957, Al Rawi 1972) a large fault, trending NE/SW cuts through this vicinity. This 'Donegal Town Fault' appears to cut through the town, in parallel with the trend of the main estuary. The small faults exposed along the banks may be splays of this main fault. Smaller exposures of argillaceous limestone and fissile calcareous shales are seen along the northern banks of the estuary. There is no exposure between the northwestern side of the estuary at Donegal Town and the eastern shores of Rossylongan Strand.

5.3.4.5 Rossylongan Strand

The eastern shore of Rossylongan Strand (SW of Donegal Town – refer to Figure 2) comprises several metres of west to southwest dipping, interbedded (3 cm thick) relatively clean, compact limestone and fissile argillaceous limestone and calcareous shales. The sequence appears jointed and disrupted, which may indicate the proximity of a fault. These rocks are part of the Donegal Limestone Member. The northwestern shore of Rossylongan Strand (circa GR19133 37787) comprises twelve metres of exposed rock, dipping gently to the southwest (thus younger than the sequence on the

eastern shore). Refer to Figure 54 for a log of this section. The basal circa 5.3 metres of the sequence constitutes compact, non-fissile, argillaceous limestone, interbedded with fissile calcareous siltstones and shales and are also assigned to the Donegal Limestone Member. Sample 97-03 was sampled 1.6 metres from the base. No archaediscid foraminifera (indicative of an Arundian age) were noted. From 5.3 metres upwards, the sequence becomes dominated by fissile calcareous fine-grained siltstones and shales. Beds of compact, argillaceous limestones are also present, though to a lesser extent than observed lower in the sequence.

The thin-section TCD No. 50709, (Locality 96-82, GR19163 37822) was sampled within a limestone bed at 4 metres and contains poorly preserved archaediscid foraminiferan. Archaediscid foraminifera have not been observed in the Donegal Limestone Member at Donegal Town or further north at Lough Eske. Archaediscids are confined to the Bundoran Shale Formation elsewhere in the Donegal Basin. From the log (Figure 54), it would appear that a lithologic boundary between the Donegal Limestone Member and the overlying Bundoran Shale Formation might be placed near the 5.3 metre marker. The Bundoran Shale Formation would then extend from this locality at Rossylongan, southwestwards towards Doorin Point. If archaediscids are present at this locality, a biostratigraphical boundary (between Lower Viséan and the Arundian) may be placed at the 3-metre marker, although this is purely based on the absence of archaediscids from the lower section.

It may be also be possible that more of the Donegal Limestone Member within the Donegal Basin should be assigned to the Arundian. It must be emphasised that the absence of a particular biota should not be the constraining factor on age. The upper part of the Ballyshannon Limestone Formation is assigned an Arundian age further south from the study area. Archaediscid foraminifera are noted within the Penarroya Boreholes (69/16, 69/4 and 69/3) towards Ballyshannon (see below in Section 5.3.6) within the 'Ballyshannon Limestone Unit' (Sevastopulo in Higgs and Sevastopulo 1983).

5.3.5 THICKNESS OF THE DONEGAL LIMESTONE MBR

Incomplete exposure renders it difficult to assign a thickness value for the Donegal Limestone Member. Several large north-east/south-west trending faults cut through the Member, and this may have resulted in repeated stratigraphy. The thickest near-

continuous section of Donegal Limestone Member is exposed along the western shore of Lough Eske, totalling forty metres (this value does not take faulting into account).

Within this study it is estimated that at least 120 metres of the Donegal Limestone Member is present from the Lough Eske area to the Donegal Town Fault (this latter area limits the southeastern boundary of this study).

5.3.6 AGE OF THE DONEGAL LIMESTONE MBR

The Donegal Limestone Member extends from the southeastern boundary of the thesis area (north of the Donegal Town Fault) towards the Greenan/Lough Eske area. It is likely that the age of this member is diachronous, with the northern parts of the member assigned an older age compared to the southern part near Donegal Town. Sevastopulo (in Higgs and Sevastopulo 1983) divided the 'Ballyshannon Limestone Unit' into three zones. 'The earliest (Zone 1) corresponds to the range of *Koninckopora* up to the entry of archaediscid forams... Zone 2 corresponds to the range of early archaediscid forams up to the entry of *Archaediscus* s.s., and Zone 3 the remainder of the Ballyshannon Limestone with *Archaediscus* exhibiting oscillating and skewed coiling. The age of Zones 2 and 3 is clearly Arundian on the evidence of archaediscid forams.' Sevastopulo assigned Zone 1 to the upper part of the Chadian Stage (*Koninckopora* enters within, rather than at the base of the Chadian).

No archaediscid foraminifera were observed within the thin-sections sampled in the Donegal Town to Lough Eske area. From this study and earlier work by Sevastopulo (in Higgs and Sevastopulo 1983), the microbiota within the limestones in the Lough Eske area confirms a Lower Viséan age (thus assigned as Zone 1 in age).

The Donegal Limestone Member appears to underlie the Clady Limestone Member; thus, the former is assigned a comparatively older age. The Donegal Limestone Member at Aghlem Bridge is approximately 4 km to the southeast of Lough Eske. Sevastopulo (in Higgs and Sevastopulo 1983) stated that the fauna at Aghlem Bridge was not diagnostically Tournaisian (as proposed by Sheridan 1972), and amended it to a late Chadian age (Lower Viséan). It appears that the Donegal Limestone Member youngs as it thickens southwards. The presence of archaediscids within the

Rossylongan section immediately beneath the Bundoran Shale Formation, (thus being assigned an Arundian age) would confirm this.

5.3.7 DEPOSITIONAL ENVIRONMENT OF THE DONEGAL LIMESTONE MBR

During the deposition of the Donegal Limestone Member, fully marine conditions are inferred, due to the abundance of crinoid debris and frequently rich coral and brachiopod fauna (as noted along the southwestern shores of Lough Eske). However, the relatively high clastic input (in the northern areas) in terms of the argillaceous, micaceous and sandy material within the member, would imply that the terrestrial area to the north was still influential in contributing a significant amount of fine-grained sediment. Further south (Donegal Town area), a more distal marine setting is envisaged as the member is shalier in content.

Figure 52 displays a schematic cross-section of the eastern part of the Donegal Basin. A lateral facies change is depicted, where the relatively clean shelf limestones of the Ballyshannon Limestone Formation in the Ballyshannon area merge with the Donegal Limestone Member in the Donegal Town area. The lateral facies changes continue 5 to 7 km northwards to the Lough Eske area, where marine-deposited argillaceous limestones and shales of the Donegal Limestone Member are interbedded with tidally-influenced calcareous sandstones of the Lough Eske Sandstone Formation. The transgressive pulses extend northwards as lenses. Further north, towards the northern boundary of the Donegal Basin, fluvial deposits are observed. This process mirrors what is observed towards the western part of the Donegal Basin, where lateral facies changes (Figure 10) are also observed over similar distances.

5.4 THE CLADY LIMESTONE MEMBER

5.4.1 INTRODUCTION

The Clady Limestone Member is a relatively clean, fossiliferous limestone which is exposed along the eastern slopes of Banagher Hill. In this study, the Clady Limestone Member is given member status and placed along with the Donegal Limestone Member within the Ballyshannon Limestone Formation (refer to Section 5.3.1, Figures 48 and 52). George and Oswald (1957) recognised variations in this particular sequence of rocks within the main 'Ballyshannon Limestone Group' and referred to them as the 'Clady beds' and the 'Clady section'. Philcox in MacDermot *et al.* (1983) referred to this unit as the 'Clady River Limestone'.

5.4.2 LITHOFACIES OF THE CLADY LIMESTONE MBR

The type section of the Clady Limestone Member is at Clady River (see Enclosure 5.1), which rises south of Banagher Hill, and runs into Lough Eske. The Clady Limestone Member comprises variable interbeds of wavy bedded, sandy limestones (Facies M) and tabular beds of relatively pure fossiliferous limestone, sandy limestone, calcareous sandstone (Facies N), with subordinate to rare amounts of argillaceous limestone (Facies K) and calcareous siltstone. It differs from the Donegal Limestone Member in containing more cleaner and sandier limestones. However, when traced towards the Donegal Town area, exposure is too limited to distinguish these two members with confidence.

Bed thickness within the limestones varies from several centimetres to circa 60 cm. Units comprising wavy, parallel horizons separated by argillaceous partings, are the most common bed types within the Clady Limestone Member (Plates 96). These wavy bedded limestones are well-exposed in crags along the eastern base of Banagher Hill. Beds of this nature are not seen within the Clady River, due to lack of good exposure. Stylolites and pseudo bedding have also been noted within the crags on the hill. The flasered horizons are discerned as slightly dark grey, calcareous, argillaceous material, compared to the lighter grey sandy limestones. Most of the horizons are continuous along the length of the exposure, with vertical separations ranging from 2 cm to 8 cm,

while other horizons appear to bifurcate. This may be the result of differential compaction between the already compacted limestones and the argillaceous flasers.

Rounded quartz pebbles (up to 1.5 cm in diameter) have been noted within the otherwise generally clean, sandy limestones. The amount of fossiliferous debris (dominantly crinoids and some gastropods) varies within each bed. However, the purer, sparry limestones appear to contain more of the above named fossils. These fossils (Plate 97) are commonly silicified out as protrusions on the surfaces of well washed sparry and sandy limestones. In comparison with the sandy limestones and calcareous sandstones of the Lough Eske Sandstone Formation, similar rock types with the Clady Limestone Member display pocked weathering surfaces probably due to diagenetic dolomitisation.

5.4.3 MICROFACIES OF THE CLADY LIMESTONE MBR

5.4.3.1 Thin-section analysis

The Clady Limestone Member is described as predominantly packstone with some wackestone. Under Folk's (1962) classification, they are assigned biomicrite to poorly washed biosparite.

The following thin-sections (refer to Appendix 4) outline a brief analysis of the Clady Limestone Member:

TCD No.50534, L234ii East of Banagher Hill (GR19520 38598)
TCD No.50561, L297 East of Banagher Hill (GR19532 38515)
TCD No.50563, L299 Lough Eske Demesne (GR19606 38172)

The Clady Limestone Member comprises common to abundant biodebris including gastropods, bivalves, brachiopods, bryozoans, echinoderms, ostracods, *Girvanella*, *Koninckopora*, moravamminids, *Mendipsia*, ostracods and sponge spicules and salebrids. Foraminifers include *Earlandia*, *Endothyra*, *Eostaffella*, *Eoparastaffella, Brunsia, Dainella* and *Pseudoammodiscus*, *Urbanella* and possibly *Eblania*.

Refer to Appendices 1 and 4 for further information regarding location and grain component analysis on these and other samples within this member.

Samples 74-1010 and 74-1011 from the Clady Limestone Member were described by Sevastopulo (in Higgs and Sevastopulo 1983). Sample 74-1010 is from the top good limestone within the Clady River. The sample is burrowed, argillaceous, micaceous, spicule rich packstone and wackestone calcisiltite. The bioclasts include bivalves, ostracods and foraminifers, which comprise *Earlandia* and indeterminate endothyrids. The fauna did not allow a precise age determination but appears consistent with the fauna noted in this study. Sample 74-1011 is from the top limestone pavement of the Clady River. It comprises recrystallised peloidal and skeletal packstone/fine calcarenite. Skeletal grains include foraminifers, algae and ostracods. The fauna is rich but poorly preserved: *Diplosphaerina*, *Earlandia*, *Pseudoammodiscus*, *Brunsia* sf. *pseudopulchra*, *Eoparastaffella simplex*, *Endothyra* spp., *Scalebrina* spp. including an encrusting form, ? *Koninckopora* with a single layered wall, *Rectangulina*, and kamenids.

5.4.3.2 Conodont analysis

TCD No. 50561, Sample L297 (GR19532 38515) yielded well-preserved conodonts including *Gnathodus homopunctatus*, *Mestognathus beckmanni* (both juvenile and adult stages), and possibly *Apatognathus*. The above conodonts are consistent with those noted within the Rinn Point Limestone Formation from the western areas of the Donegal Basin.

5.4.4 LOCALITY DESCRIPTIONS OF THE CLADY LIMESTONE MBR

The best exposures of the Clady Limestone Member are seen in parts of the Clady River, the Eglish River, and along the western bases of Banagher Hill and Burns Mountain (refer to Enclosure 5.1).

5.4.4.1 Clady River

The Clady Limestone Member is exposed towards the upper section of the Clady River (from approximately 120 to 160 metres topographically above sea level). George and Oswald (1957) noted that "the Clady Gorge is cut through about 700 feet (circa 210 metres) of the Ballyshannon Limestone group, revealing an intermediate stage in the onset of the quartzose facies". The river (upstream) is accessible from Clady Bridge (GR19583 38429), and can be traced up-section to the steep gorge (marked "Alt" on the Six Inch Ordnance Survey maps – GR19538 38418, Enclosure 5.1). The top of this gorge coincides with the termination of the western boundary of the forest.

Figure 53 displays a logged section westwards from Clady Bridge. The lower part of this log is discussed in Section 5.3.4.1. The basal boundary of the Clady Limestone Member with the Donegal Limestone Member is placed at 23.6 metres from the base of the section.

Although several beds of clean limestone and sandy limestone have been observed lower than this level (e.g. at 6m, 14.2m, and 16.5 m from base of logged section), these specific lithologies are more dominant from 23.6 metres upwards. Clean, hard, crinoidal limestone beds are present from 23.5 to 25.2 metres. The sequence above this (from 26.6 to 46.2 metres) comprises dominantly bioturbated, sandy limestone and calcareous sandstone, with several thin argillaceous interbeds and flasers. Fine-grained, well sorted, laminated sandstone beds are also present. Four metres from the base of the gorge, calcareous sandstone with rounded quartz pebbles is located. The diameter of the individual quartz grains range from 2 mm to 6 mm. This sandstone bed (c. 2 metres thick) is overlain by approximately two metres of very bioturbated, fine-grained, calcareous sandstone. Twenty centimetres of pure, hard sandy limestone is located at the base of the inaccessible gorge. No gastropod fauna has been observed within the river section. At high water levels, the gorge tends to be inaccessible, although it appears to comprise (approximately 6 to 8 metres) interbedded calcareous siltstone and argillaceous limestone units. Pure crinoidal limestone may also be present here, as noted by George and Oswald (1957). These authors maintained that 'the highest 80 to 100 feet (approx. 25 to 30 m) are granular limestones and thin shales... containing a rich fossil fauna with abundantly and exceptionally large foraminifera. But the bulk of the underlying beds

becomes increasingly sandy in descending sequence'. It appears that the granular limestones and thin shales may constitute some of the rocks within the gorge. From mapping information, the clean, crinoidal limestone exposed along Banagher Hill would have to pass through the gorge at this section.

Approximately two metres of argillaceous limestone and calcareous siltstone are exposed above the gorge (Sample L303, GR19538 38418). This is the locality where the stream veers sharply to the north. A one metre vertical gap in exposure separates this unit with circa one metre of quite argillaceous, micaceous limestone. The limestone contains subordinate crinoidal debris. A 1-1.5 metre vertical gap is followed by 4.2 metres of thin bedded, calcareous siltstones, containing sparse fossiliferous debris. The sequence becomes progressively more micaceous towards the top. Feldspar grains are rare to absent in this sequence. An approximately four-metre gap separates this unit from the waterfall section above on the hillside. The amount of calcareous content within the Clady Limestone Member decreases upwards and is replaced by an increasing amount of micaceous siltstone. The unexposed upper boundary of the Clady Limestone Member with the Banagher Sandstone Formation would be in this vicinity. An east/west trending fault (cutting through the Clady River at GR19516 38415) appears to sinistrally offset the boundary of the Clady Limestone Member with the Banagher Sandstone Formation. Thus, this contact is placed further west on the northern side of the fault, compared to contact on the southern side of the fault.

The argillaceous content within the Clady Limestone Member appears greater in the Clady River section, compared to that observed along the eastern crags at Banagher Hill (c. 1 km further north). However, the unexposed gaps between the crags probably contain more argillaceous, less resistant material, whilst the cleaner, sandier units are more resistant, resulting in selective erosion.

5.4.4.2 East of Burns Mountain

The lakeshore from Grania's Island to Ross dhu is exposed in argillaceous, fossiliferous limestone with *Syringopora* corals and crinoidal debris (refer to Enclosure 5.2). This unit is part of the Donegal Limestone Member and lies stratigraphically beneath the Clady Limestone Member. Exposure from here westwards is very sparse. Five hundred metres to the northwest (in the southern Tawnyvorgal area – including L290 at

GR19572 38333), generally pure, crinoidal limestone with argillaceous partings crops out. These beds dip towards the southwest. Solitary corals and gastropods are observed. Variations in the locality include sandy limestone and fine to medium-grained, calcareous sandstone. The Burns Mountain Fault and the Lough Eske Fault separate the sequence from the main Clady Limestone Member exposures along Banagher Hill (see Enclosures 5.1 and 5.2).

A disused quarry at Friary (L294/L302 GR19583 38371) exposes rubbly, argillaceous limestone with irregular bedding. The irregular bedding may indicate the close proximity of the Burns Mountain Fault, which trends in a northeast to southwest direction. Along strike further north, clean crinoidal limestones are noted. These are all assigned to the Clady Limestone Member. The upper contact of the Clady Limestone Member is roughly constrained at Ardinarvar, where coarse-grained, pebbly sandstones and conglomerates of Banagher Sandstone Formation are exposed. The Clady Limestone Member then continues as a mappable band, northwestwards onto the Clady River.

5.4.4.3 Clady River to Eglish River

The Clady Limestone Member extends northwards as a mappable unit from the Clady River around the base of Banagher Hill to Eglish River. However, the exposure is not always continuous (refer to Enclosure 5.1). At L308, GR19529 38438 (immediately west of the coniferous forest), thin beds of generally clean, fossiliferous limestones with crinoidal and brachiopod debris are present. Argillaceous flasers and interbeds distinguish the apparent bedding. The unit is bioturbated and horizontal burrows were noted. At L310 (GR19528 38516), similar limestone beds are exposed to the west of the barbed wire fence, and sandstones of the Banagher Sandstone Formation are exposed within a horizontal gap of two metres. Although it may be a factor of exposure, the contact appears to be quite abrupt, in comparison to the boundary within the Clady River. Scattered exposures of generally clean, sandy limestones are located along the base of Banagher hill as small crags. Several loose blocks are also present.

A westwards (ascending) traverse from the road at L233 (GR19539 38584) displays a series of calcareous sandstone and sandy limestone cliffs, separated by several metres of grass covered vertical gaps (Plate 98). Locality 234 (GR19520 38598) comprises

several cliffs eroded in sandy limestone, which become more fossiliferous, cleaner and well washed towards the top of the cliff section. An approximately twenty metre vertical gap separates the uppermost limestone cliff and L235 (GR19508 38604), which is described below. Several smaller limestone exposures are located within gaps further up-section. These outcrops comprise fossiliferous limestone (commonly wavy) with muddy flasers, overlain by a thin, patchy sandy limestone bed. As observed further south in the Clady River, variants of the pure crinoidal and gastropod rich limestones comprise sandy limestone, impure argillaceous limestones and calcareous medium to coarse-grained sandstone. Pebbles and coarse grains of quartz are common. Loose coarse sandstone boulders are scattered in the vicinity. A large cliff section at the last big break in slope (L235, GR19508 38604) comprises coarse to pebbly, unsorted, grey sandstones and conglomerates of the Banagher Sandstone Formation. Therefore, the contact between the Clady Limestone Member and the Banagher Sandstone Formation at Banagher Hill is obscured and can be outlined only by estimating the upper exposures of the limestones.

The topographical contact around Banagher Hill, between the Clady Limestone Member and the Banagher Sandstone Formation, is not continuous along one contour. To the north of the hill, the contact is at 335 metres. To the east of Lough Fad, the contact is at 243 metres and at the Clady River, the contact is at 167 metres. Most of this variation may be explained by faulting. A fault is inferred trending east to west from Lough Fad, and there is also evidence of a smaller east-west fault (with a sinistral offset) at Clady River. The beds dip relatively constant (10 to 14^0 to the east) along this slope. To the north of Sand Lough, the contact between the Banagher Sandstone Formation and the Clady Limestone Member curves northwestwards. However, a northwest-southeast trending fault (the Caldragh Fault) cuts through the contact. This fault is exposed at a small stream section at Caldragh (L240, GR19540 38645) and at Eglish River. The fault is thought to extend southeastwards, onto Ardnamona and Lough Eske.

The map from George and Oswald (1957) (refer to Figure 42) shows the limestone unit in this area as a continuation of the limestones exposed further south towards Donegal Town and Laghy with no differentiation between different limestone types or members. However, they did note that 'the inter-layering of sandstones and limestones in the

Ballyshannon group about Lough Eske and Dunkineely is too rigidly delineated by conventional shading; there is a lateral passage of the one facies to the other'. The limestone shading on their map displays exposures on the southwestern shores of Lough Eske, which continue across the Burns Mountain Fault. To the north of the Burns Mountain Fault, one band swings around the base of Banagher Hill and the other band inter-fingers with the calcareous clastics further north.

5.4.4.4 Eglish Valley - Faulted contact

The rocks exposed within a small stream (L245, GR19475 38679) (north of the Caldragh Fault) comprise interbeds of fissile calcareous siltstones, tabular, argillaceous limestones, and fossiliferous pure, sparry limestones of the Clady Limestone Member. Other exposures are noted in the stream section north of here. Locality 244 (GR19427 38707) at Eglish River, displays the faulted contact between the Clady Limestone Member and the Banagher Sandstone Formation. A limestone unit to the north (cut by a 2.5 metre wide dyke, slightly further north), comprises well-bedded, argillaceous limestones and calcareous shales (similar in nature to the limestones exposed at Kiln Port in the western part of the Donegal Basin). The northwest-southeast normal Caldragh Fault, (dipping 58^0 towards the southeast), results in variable (20 to 60 cm thick) bedded, coarse-grained to pebbly sandstones, being placed in contact with the limestones.

5.4.4.5 Southwest of Lough Eske

The Clady Limestone Member is not a mappable unit in the low-lying area southwest of Lough Eske (refer to Enclosure 5.2). Small scattered hard, slightly arenaceous, sparry crinoidal limestone (L299, GR19606 38175) crop out within the grounds of Lough Eske Demesne, which may be assigned to this Member.

Several metres of pure, sparry, crinoidal limestone are exposed west of the River Eske, to the south of Christy's Bridge (GR19570 38137). On the northern banks of the river (south of Foxes Hole, Location 96-65, GR19577 38109), two metres of sparry crinoidal limestone are interbedded with bioturbated, micaceous, calcareous siltstone. Green and white coloured calcite veins and joints cut through the exposure, indicating the

possibility of a fault. The rock is grey in colour and the surface crinoids and gastropods are etched out on the surface (similar to that displayed within the Clady Limestone Member in the Banagher Hill area). The southern side of the river comprises approximately five metres of mainly calcareous siltstone and silty limestone. Ten metres further northwest (at the waterfall), the rocks are folded into an open anticline. At least one steep fault and a possible second thrust fault cuts through the exposure. The folded units comprise pure crinoidal limestone, with thin argillaceous limestone interbeds. Three metres of pure crinoidal limestone are observed on the steep ridges to the northwest. This limestone band appears to continue to trend northwestwards onto Clarlougheask (south of Lough Eske), although it is questionable whether it is part of the Clady Limestone Member. There are several faults within the River Eske vicinity, so there is a possibility that this is a faulted block of the Clady Limestone Member.

5.4.5 THICKNESS OF THE CLADY LIMESTONE MBR

There is no completely exposed section of the Clady Limestone Member. However, from mapping information, the Clady Limestone Member (in the northeastern Banagher Hill area) is exposed within the 707 feet and 1007 feet contours. Thus, an estimated thickness of 90 m to 120 metres is allocated to this member.

5.4.6 AGE OF THE CLADY LIMESTONE MBR

The Donegal Limestone Member is exposed in the lowland areas of Lough Eske and is overlain by the Clady Limestone Member. The latter member comprises a typical Lower Viséan fauna (including the foraminifers *Endothyra*, *Eostaffella*, *Eoparastaffella*, and also *Koninckopora* algae). Sevastopulo (in Higgs and Sevastopulo 1983) proposed a similar 'late Chadian' age for Sample 74/1011 from the top pavement of the Clady River, 'rather than Arundian or Holkerian as suggested by Sheridan's (1972) zonal assignments'. From mapping information along the Banagher Hill, it is implied that the Clady Limestone Member is younger than the Donegal Limestone Member. The correlatives to the Clady Limestone Member towards the west of the Donegal Basin are not apparent. It may correlate with the Rinn Point Limestone Formation; thus, is younger than the Calhame Limestone Member and the '*Syringopora* Bed' in western part of the Donegal Basin.

5.4.7 DEPOSITIONAL ENVIRONMENT OF THE CLADY LIMESTONE MBR

The Clady Limestone Member comprises variable beds of clean, sparry limestone, sandy limestone, calcareous sandstones, argillaceous limestone and calcareous shale beds, although the former two are more characteristic of this member. The best-exposed section along the Clady River displays a cleaning upward sequence from argillaceous limestones to sandy, clean limestones with crinoids and gastropods. This would most likely imply some kind of regressive event, resulting in a shallowing upwards from the normal marine depositional environment of the Donegal Limestone Member. This relationship is similar to that noted in the western part of the Donegal Basin where the St. John's Point Limestone Formation (oolite limestones and well washed sandstones) overlies the Rinn Point Limestone Formation (argillaceous limestones and calcareous shales).

As Figure 52 depicts, the Clady Limestone Member is a younger, cleaner, more washed lens of the carbonate pulse, which extends northwards toward the Lough Eske area. The wavy bedded limestones, which are observed along the eastern basal slopes of Banagher Hill, are very common in shelf environments (Wilson & Jordan 1983). The deposits on a shelf are formed predominantly from carbonate sediments produced in shallow-water environments (e.g. oolite bars). Periods of relatively high energy are inferred by the well-washed nature of the sandy limestones.

It is most likely that the Clady Limestone Member was deposited within an inner-shelf setting, which received variable amounts of sandy and argillaceous material. The faunal presence of crinoids, algae, brachiopods and gastropods (the latter can also be associated with normal marine deposition), may offer only limited depth constraints, as do the physical structures one can see. However, algae are restricted to the photic zone (depths down to about 100 metres) and some restrictions (possibly saline waters) may also be inferred from the presence of gastropods and ostracods. It would appear that this carbonate shoaling event was relatively short lived, as it is replaced rather abruptly by the coarse-grained clastic influx of the Banagher Sandstone Formation, due to either progradation or base level fall.

5.5 BANAGHER SANDSTONE FORMATION

5.5.1 INTRODUCTION

The Banagher Sandstone Formation was previously designated the 'Banagher Grits' by George and Oswald (1957) and Graham and Clayton (1994). Al-Rawi (1972) correlated the sandstones at both Killin Hill (refer to Section 6.4.5) and at Banagher Hill as the 'Banagher Formation'. The Banagher Sandstone Formation has a mappable basal contact with the Clady Limestone Member and an upper gradational contact with the Bundoran Shale Formation.

The Banagher Sandstone Formation is named after Banagher Hill (refer to Enclosure 5.1), which forms the highest peak in the Carboniferous Donegal Basin. The Banagher escarpment is 2.5 km^2 in aerial view and is situated to the west of Lough Eske. It is approximately 2.6 km in length, from north-northeast to south-southwest, and its thickest distance is 1.4 km (from west to east). On topographical maps, Banagher Hill is asymmetrical in appearance, with the northern end tapering off quite sharply. The highest peak (at Lough Fad) is at 392 metres. The overall top surface is generally quite irregular (varying from some flat areas to craggy, south-western dipping strata). Several lakes are exposed at the top of the hill, the largest being Lough Cam, which is situated towards the centre of the generally flat-surfaced area. Banagher Lough is situated further south, away from the main topographical high. The Clady River drains eastwards from Banagher Lough and enters Lough Eske. Several smaller streams drain the northwestern section, and continue onto the Eglish River. The southern slope comprises south-flowing streams, which eventually join tributaries of the River Eske. The hilltop and scarps (where rock is not exposed), are covered in bog and heather, with coniferous forests radiating down the hillside. Exposure is generally good on the hilltop and there are good cliff exposures (though not always continuous) on the eastern side of the hill. The western areas of the hill comprise gentler slopes with exposure confined to several streams.

5.5.2 LITHOFACIES OF THE BANAGHER SANDSTONE FM.

The Banagher Sandstone Formation comprises uniformly light-grey coloured, generally coarse-grained, feldspathic sandstones and pebbly conglomerates. This unit is designated Facies A3 and displays enough differences in its overall composition and appearance to merit it a separate subfacies from Facies A1 and A2. The clasts comprise dominantly quartzite and vein-quartz, with subordinate psammite. The matrix comprises quartz grains, white feldspar and rare mica flakes. No granite clasts have been observed in this study. The degree of roundness of the clasts varies from subrounded to angular (Plate 9). The less coarse grains (less than 6 mm in size) within the matrix are more angular. Clast size ranges from 1 cm to 15 cm, with the average clast approximately 6 cm in width. Clasts up to 40 cm long have been observed; however, these are exceptional. Maximum particle size varies from 12.3 cm to 10.6 cm.

Many of the exposures display a poorly sorted texture with pebbles surrounded in places by a sandier matrix rather than occurring as discrete, sorted segregations. Clast supported conglomerates are confined to irregular lenses and pebbly lags. A pebbly lag is seen to overlie thin (2 cm), well-bedded, feldspathic sandstone. Some examples of graded bedding are observed. Unsorted pebbly to coarse-grained sandstones grade up into coarse-grained, poorly sorted sandstones.

Bedding planes are not always well defined and are often exposed as discontinuous erosional structures. The beds dip generally to the southwest, at approximately twelve to eighteen degrees and are tabular to lensoid in geometry. It appears that the basal beds of the Banagher Sandstone Formation are more tabular, whilst the units further up-section (and uphill) are more lensoid to irregular. Cross-stratification is present within coarse-grained to pebbly, relatively thick, lensoid beds. Set thickness often exceeds a metre (Plate 10). The less coarse-grained and thinner beds also comprise cross-strata. Palaeocurrent flow direction forms a radial pattern to the southeast, south, southwest and northwest - Figure 56). Imbrication is also seen in some of these pebbly sandstones and conglomerates.

To the south of Banagher Hill (in the Burn's Mountain area), the Banagher Sandstone Formation is less coarse-grained (refer to Section 5.5.3.6). Thus, a fining-southwards

from the main influx area is envisaged. An irregular (fining southwards) boundary between the pebbly conglomerates and the medium to coarse-grained sandstones (both of the Banagher Sandstone Formation may be drawn south of the Burn's Mountain area.

5.5.3 LOCALITY DESCRIPTIONS OF THE BANAGHER SANDSTONE FM.

5.5.3.1 Clady River – basal contact

As noted in Section 5.4 (Clady Limestone Member), the Clady River exposes variable calcareous sandstones, sandy limestones and argillaceous limestones. The junction between the Clady Limestone Member and the Banagher Sandstone Formation appears to be a gradational, coarsening-upwards sequence along the eastern slopes of Banagher Hill. Locality 303 (GR19538 38418) appears to be the uppermost exposure of the Clady Limestone Member within the Clady River. This would presumably equate with the highest section of George and Oswald's (1957) '80 to 100 feet of granular limestones'.

The tabular nature of the basal sandstones can be observed further upriver (westwards) after a gap in exposure. At a waterfall (L309, GR19528 38414), seven to eight metres of sandstone are exposed. The base of the waterfall contains thin (2-5 cm) bedded to lensoid, generally medium-grained, feldspathic sandstone. From one to four metres up section, coarser grained thicker bedded (40 to 60 cm) units, interbedded with the thinner units, are exposed. Internal structures within the sandstones vary from parallel laminae to angle cross-strata. Towards the top of the waterfall, thick (up to 80 cm) more irregular lenses of coarse, pebbly sandstones are present. This characteristic coarse to pebbly sandstone continues further up-section and forms Banagher Hill. Some of the beds appear to dip irregularly and small faults may exist.

5.5.3.2 North of Clady River – basal contact

Further north of Clady River, the contact with the underlying Clady Limestone Member is less well-exposed (Enclosure 5.1). The approximate contact on this eastern edge of the hill can be detected by a change in colour in the landscape due to vegetation (Plate 98). The Banagher Sandstone Formation is mostly covered by brown heather and bog.

The Clady Limestone Member is covered by green grass and low bushes. Also, loose blocks of the sandstones and limestones are scattered on the hillside; thus, allowing an approximate limit to be placed at the topmost limestone blocks along Localities 306 (GR19530 38505), L308 (GR19529 38438) and L310 (GR19528 38516) – refer to Enclosure 5.1. The unsorted, feldspathic sandstones of the Banagher Sandstone Formation are coarse to pebbly in grain size at this locality. Bedding is quite tabular. The limestones (of the Clady Limestone Member) beneath vary from pure limestone (with gastropods etched on the surface), to impure sandy and argillaceous limestone. Bedding is regularly wavy and parallel within the limestones. The vertical gap between the sandstone and limestone boundary is often no more than a metre (although the sandstone is not always *in situ*). In contrast to the contact in the Clady River, the medium-grained, thin bedded sandstones appear to be absent from this. The absence may be explained by this locality being in a more proximal position than that at Clady River. Other explanations may be of unexposed rock, lateral facies change or an unexposed fault in the vicinity. The uniformly grey conglomerates and pebbly sandstones are variably bedded. Tabular cross-stratification and imbrication display comparable southerly-directed palaeocurrent flows. Maximum particle size in the conglomerates in this area is 10.6 cm. Low-angled cross-strata and parallel beds are more dominant within the less coarse-grained clastics.

5.5.3.3 North of coniferous forest and east of Sand Lough

A small stream section, north of the coniferous forest (refer to Enclosure 5.1) exposes a sandstone sequence (of variable grained sizes), from close to the base of the Banagher Sandstone Formation. A metre-plus unit of coarse, generally sorted, feldspathic sandstone is overlain by approximately 40 cm of coarse-grained siltstone, interbedded with medium-grained sandstones. The siltstone contains plant material and was sampled for palynology. Unfortunately, the sampling proved to be inconclusive, as the spores disintegrated during processing. The internal structure of the beds comprises parallel laminae and very low angled cross-strata. A ten centimetre thick lens, containing parallel lamination, (above the 40 cm sandstone and siltstone unit) pinches out abruptly to the north, and is replaced by a thicker (25 cm) sandstone lens. Above this unit, low-angled cross strata (15 cm thick set) are displayed with medium grained sandstone. The entire siltstone and medium to slightly coarse-grained sandstone unit is approximately

two metres thick. Two metres of thick bedded, coarse-grained sandstone overlies the described unit, and this in turn, is overlain by roughly four metres of coarse-grained, often pebbly sandstone. The latter unit displays palaeocurrent direction to the southwest.

This part of the exposure appears tilted (in parts up to 26^0) to the west, possibly indicating proximity to a fault. Approximately six metres of matrix-supported conglomerates and coarse to pebbly sandstones, overlie the basal sequence described above. Cross strata from this coarse unit appear to show palaeocurrents towards the north but there is only limited three-dimensional exposure. This latter unit persists up-section onto Banagher Hill (L235, GR19508 38604), with an approximately six metre coarse-grained to pebbly sandstone exposure. The clasts are generally of quartzite and quartz, with subordinate psammite clasts. The matrix comprises quartz, and white and orange-pink feldspar. Average grain size within the matrix is 2 to 4 mm. The degree of roundness varies from angular to subangular. The quartzite clasts are quite angular and appear to be etched out on the surface. Lenticular and tabular beds contain unidirectional cross-strata, indicating palaeocurrents from the north. Imbrication information agrees with this direction. A ten-metre cliff face above this displays irregular bedding with clasts often marking out the bedding planes. Some units appear to have a steep dip (up to 30^0). However, these are very localised. It could be a factor of syn-sedimentary faulting. Set thickness within the lensoid beds range from several centimetres up to 1.4 metre thick.

5.5.3.4 East of Meenataggart

The Banagher Sandstone Formation exposure is generally poorly exposed along the northern 'nose' of the hill. A stream section, east of Meenataggart (GR19287 38609), displays an approximately ten-metre section. (This sequence may be repeated due to faulting). The section comprises coarse, pebbly, non-calcareous sandstones and calcareous sandstones and fossiliferous sandy limestone. Figure 55 shows the three basal beds, comprising variable sandy, pebbly limestones and calcareous, pebbly sandstone. This latter bed (Locations 96-79, 96-89) (containing a *Michelinia* coral), is draped in places by a thin limestone unit. Over two metres of thin bedded, quite micaceous, variable units of coarse-grained siltstone to coarse-grained sandstone, overlie the calcareous unit. A fault may be present at this section. Above this, one and a

half metres of pebbly to coarse-grained sandstones and conglomerates are present. The pebbly, matrix supported conglomerate contains an irregular base, and is slightly calcareous. This unit is overlain by sandy limestone with a rich biodebris. The biodebris includes crinoids and brachiopods. Pebbly quartz is also present. This unit is overlain by tabular beds of well sorted, medium-grained, calcareous sandstone. A waterfall above this section exposes well-sorted, slightly calcareous sandstone, interbedded with thin (3 cm) bedded, calcareous siltstone, overlain by pebbly calcareous sandstones. The top contact with the Bundoran Shale Formation is not seen. However, the presence of calcareous content and fossils (which is not characteristic of the Banagher Sandstone Formation), indicates that the contact with the Bundoran Shale Formation must be in close proximity to the west.

5.5.3.5 Northwest of Banagher Lough

Unsorted, coarse-grained to pebbly sandstones crop out in the vicinity of the road through the forest at Altilow. At L304 (GR19353 38470), a small channel margin is exposed west of the forest road (Plate 99). Coarse grained to pebbly, unsorted, feldspathic sandstone is observed, which appears to have cut down into thin, well-bedded, medium-grained, cross-stratified sandstones. The southern wing (from the thinnest section to the channel base) of the sandstone fill is three metres wide. The channel base is approximately 1.5 m wide and the thickest section of the channel fill is 90 cm. Approximately two metres of green to brown coloured, coarse-grained, quartz rich sandstones underlie the channel. Lenticular cross-strata with 15 to 20 cm set thickness, indicate palaeocurrent flow from the north. Further north, quarry exposes two metres of variable fine to coarse-grained, buff coloured sandstone. Several coarse siltstone beds with mica-rich horizons are also present. Close to this locality, loose boulders of coarse to pebbly sandstone and conglomerates contain clasts of reworked siltstone.

5.5.3.6 Burns Mountain area

The Banagher Sandstone Formation continues southwards towards Burns Mountain (refer to Enclosure 5.2). However, as its extends south of Burns Mountain, an increase in less coarse-grained sediments becomes apparent. Medium-grained, well sorted,

feldspathic sandstones (L270, GR19485 38312 and L274, GR19468 38304), sandstones and siltstones with plant debris (L275, GR19450 38307), and calcareous pebbly sandstone (L272, GR19492 38318) appear to dominate over the coarse-grained, unsorted sandstones and conglomerates of the Banagher Sandstone Formation. A significant north-east/south-west trending fault (the Burns Mountain Fault) results in a repeat of the coarse-grained sandstone and pebbly conglomerate sequence at two rounded hillocks to crop out south of the fault. The area east of the river, which drains Lough Avaddy comprises low-lying land (between L274 and L277). Although exposure is absent in this area, a wide gully (approximately 30 m) may indicate that the 'Burns Mountain Fault' cuts through it. The 'Burns Mountain Fault' is exposed at L305 (GR19378 38256), where the Bundoran Shale Formation is terminated abruptly against the Banagher Sandstone Formation. A second (east/west trending) fault is thought to extend from Lough Eske and is terminated by the Burns Mountain Fault in this area.

5.5.3.7 Limestone Brook to Donegal Town area

Locality 284 (GR19546 38215) (refer to Enclosure 5.2, north of Limestone Brook and the boundary between the Banagher Sandstone Formation and the Donegal Limestone Member) comprises coarse-grained sandstones with subrounded to sub-angular quartz pebbles. Mica flakes and feldspar grains are also present. This sequence may correlate with the Banagher Sandstone Formation extending south from Burns Mountain. Other sandstone units are exposed in the Heneys area. Disused overgrown quarries comprise coarse-grained, unsorted buff coloured sandstones. This unit is interpreted as a southerly-fining part of the Banagher Sandstone Formation.

Sandstone lenses of the Banagher Sandstone Formation may extend as far south as Donegal Town. Exposure is quite poor in the area between Banagher Hill and Donegal Town, so this hypothesis is difficult to test. However occasional outcrops of variably feldspathic to quartz rich sandstone, interbedded within the argillaceous, fossiliferous limestones and calcareous shales of the Donegal Limestone Member lend support to this theory.

To the southwest of Ballydevitt School, a stream exposes calcareous siltstone. These rocks display variable bedding dips to the east, west and southwest. In a field north of

the last houses on the track way, several metres of calcareous, coarse-grained sandstones crop out. The latter rocks appear to be disturbed and dip to the north. A fault may trend through this locality. In the vicinity of the last house, loose sandstone cobbles are exposed. Further north upstream, at Drumroosk a scrappy exposure of sandstones is observed. Most of the sandstone is loose, but some *in situ* rocks are present. Although these rocks show immense differences to the lithologies described in the type area at Banagher Hill, they are included within this formation as lateral facies changes towards the south. Irregular variable rocks are exposed (at low tide) under the bridge east of the Castle at Donegal Town. As discussed in Section 5.3.4.4, coarse-grained, calcareous sandstones (represent a lateral facies change of the Banagher Sandstone Formation) are interbedded with silty limestones of the Donegal Limestone Member.

Apart from the isolated localities discussed above, sandstone sequences are otherwise absent from the Donegal Town area. Interbeds of argillaceous limestones and fissile calcareous shales of the Donegal Limestone Member generally dominate the Donegal Town area. George and Oswald (1957) stated that 'a rapid replacement of arenaceous by argillaceous rocks takes place in the low ground towards Donegal Town'. The sandstone sequences exposed at the bridge by the castle cannot be traced inland, making it impossible to assess the trend of the unit and correlate with other sandstone sequences further north at Ballydevitt and Burns Mountain. Several faults are also present in the Donegal Town area, which may affect the sequence. The Banagher Sandstone Formation contains less coarse-grained sandstone lenses, which extends south from Banagher Hill. This resulted in pulses of clastics being incorporated into the marine environment of Donegal Limestone Member.

5.5.4 THICKNESS OF THE BANAGHER SANDSTONE FM.

Due to the incompleteness of the exposure, it is often difficult to trace individual beds or marker horizons laterally across the Banagher Hill. It is estimated from this study that a minimum thickness for the Banagher Sandstone Formation is 80 metres. This is roughly calculated from the topographical contact with the Clady Limestone Member east of Lough Fad at 335 metres, to the peak of the hill at 392 metres. The beds dip towards the southwest, and are generally parallel to the western slope of Banagher Hill.

There is substantial space to accommodate further section, from the top of Banagher Hill - Lough Cam area, southwards to where the base of the Bundoran Shale Formation is exposed in the Altilow area. Altilow is topographically lower, at less than 300m.

This study proposes a maximum thickness for the Banagher Sandstone Formation in region of 200 to 250 metres. George and Oswald (1957) predicted 'a maximum thickness for the sandstones (in their northern slopes) of about 1200 to 1300 feet'. Their estimation (circa 400 metres) exceeds the predicted figure of this study significantly.

5.5.5 PALAEOCURRENT ANALYSIS OF THE BANAGHER SANDSTONE FM.

Palaeocurrent data were taken from the tabular to lensoid cross-stratified pebbly sandstones. Directions show a radial, flow direction predominantly to the south and southwest (the pattern shows flow to the southeast, south, southwest, and northwest). This information is matched by the imbrication of the clasts. Refer to Figure 56 for a rose diagram of the cross-strata data.

5.5.6 PROVENANCE OF THE BANAGHER SANDSTONE FM.

The Banagher Sandstone Formation is a northerly-derived, variably coarse-grained to pebbly sandstone and conglomerate. The formation is dominated by poorly sorted quartzite clasts, which vary from subangular to subrounded. The finer grained material is relatively angular, indicating a relatively proximal source. The Dalradian hinterlands to the north comprise quartzites from the Easdale Group (Hutton & Alsop 1996). It is interesting to note that although the Barnesmore Granite is situated within 2 to 3 km to the north, no granite clasts were observed within the Banagher Sandstone Formation. Thus, the Barnesmore Granite did not provide any source material to the Banagher drainage basin.

5.5.7 AGE OF THE BANAGHER SANDSTONE FM.

No palynological data has been obtained from the Banagher Sandstone Formation. The underlying Clady Limestone Member is assigned a Lower Viséan age. The Banagher

Sandstone Formation is overlain by the Bundoran Shale Formation, which is confirmed as Arundian in age. Thus, in this study the Banagher Sandstone Formation is assigned a stratigraphical position beneath the Arundian datum plane, similar to the St. John's Point Sandy Limestone Formation and the Muckros Sandstone Formation. George and Oswald (1957) also inferred its deposition 'during a comparatively brief interval of late Ballyshannon and early Doorin-Coolmore times'.

5.5.8 DEPOSITIONAL ENVIRONMENT OF THE BANAGHER SANDSTONE FM.

A striking observation Member along Banagher Hill is the transition from the relatively clean, fossiliferous limestones of the Clady Limestone to the pebbly sandstones and conglomerates of the Banagher Sandstone Formation. This relatively abrupt, sharp change towards the relatively thick clastic beds (commonly greater than one metre thick) occurs vertically over 3 to 4 metres. As noted in Clady River, the basal two metres of the Banagher Sandstone Formation display a coarsening-upwards sequence from non-calcareous siltstones and fine-grained sandstones to the coarser clastics characteristic of the formation. There is no evidence of marine influence within this basal section. In an isolated section (such as a borehole), this transition would have all the appearance of a sequence boundary, indicating a major facies shift from shallow marine carbonates to coastal sands to an apparently non-marine facies (Van Wagoner *et al.* 1990).

The presence of relatively large dunes (displaying tabular and lensoid cross-stratification) is not typical of a fan. The presence of abundant cross-strata and comparatively well-bedded nature would rule out debris flows. Thus, in conjunction with the unidirectional palaeocurrents, a fluvial depositional environment is inferred. The finer-grained, tabular geometries at the base are interpreted as shoreline sands passing up into more fluvial-dominated sequences above. As discussed in Section 5.5.6, provenance indicates a northerly-derived proximal source.

Major base level fall is not likely as the clastics are generally confined to the Banagher Hill area, and not recognised over the entire Donegal Basin. The unit must represent some rejuvenation of source area or major stream capture to produce this type of clastic

deposition. The former seems more likely as the 'streams' are not large. Also, the general poor size segregation would lend support to the rejuvenation theory. It is most likely that the deposits of the Banagher Sandstone Formation represent local syn-sedimentary fault activity. Further west, the coarse-grained, pink, clastic unit dominated by granite debris at Sallows (assigned to the Killin Sandstone Member - GR18824 38668) is also interpreted as a product of localised fault activity. However, these are not entirely of similar age as the Banagher Sandstone Formation underlies the Bundoran Shale Formation; whereas, the Killin Sandstone Member is part of the Bundoran Shale Formation. In addition, the Sallows area would have been sourced from the granitic area further north.

The flow rate in the rivers would have decreased as they continued to deposit their load towards the south. This is noted in the less-coarser grained sandstones in the Burn's Mountain area. A lateral facies change is observed from the Banagher Hill area towards Donegal Town (over a distance of 8 to 9 kms) where interbedded silty limestones and sandstones are observed in the latter area.

CHAPTER 6 BUNDORAN SHALE FORMATION

6.1 INTRODUCTION

The Bundoran Shale Formation represents the extensive shale sequence that is exposed towards the core of the Donegal Basin and overlain by the Mullaghmore Sandstone Formation (Figures 2 and 48). The Bundoran Shale Formation has previously been termed the 'Lower Calp Shales' by the Geological Survey in the last century and subsequently received local names within various parts of the Northwest Carboniferous Basin of Ireland. Several authors have designated this unit the 'Bundoran Shales' in the Bundoran area, the 'Coolmore Shales' in the Coolmore area and the 'Doorin Shales' in this present study area in south Donegal (George and Oswald 1957, Sheridan 1972, Millar 1990 and Buckman 1992). The term Bundoran Shale Formation is preferred here as the regionally accepted name.

Two dominantly arenaceous members have also been noted within the formation:

- the Ramp Hole Sandstone Member (southeast of Doorin Peninsula)
- the Killin Sandstone Member (south of the Northern Boundary Fault) – refer to Enclosure 6.1

These members will be discussed more in detail in Sections 6.4.3.1 and 6.4.5 respectively).

6.2 LITHOFACIES OF THE BUNDORAN SHALE FORMATION

The Bundoran Shale Formation comprises predominantly calcareous shales (Facies P2 of this study) with subordinate beds of limestone (Facies K) and calcareous siltstone (Facies Q).

The calcareous shales of the Bundoran Shale Formation are generally uniformly dark grey in colour (Plate 46). Bed thickness is variable from tens of centimetres to several metres. In general, the well-exposed coastal sections of shale are laterally extensive. However, some inland exposures of these shales display more lateral variations with calcareous siltstones and limestones. The shales are commonly laminated, but rarely

display sedimentary structures apart from chaotic slumps and syn-sedimentary folds. Although the absence of ripples and cross-strata often implies a general lack of current action, in this case, it is most likely a function of grain size. Ripples are unlikely to form within such a fine-grain sediment. Within this study, these calcareous shales of the Bundoran Shale Formation correspond to Facies P2. They differ from P1 calcareous shales (predominantly within the Rinn Point Limestone Formation) in their less bioturbated nature and overall reduced fossiliferous content within the Donegal area.

Calcareous nodules (ranging up to 15 cm in diameter along bedding) are commonly observed within the shales along the Doorin Peninsula (Figures 57 and 58). The nodules contain subordinate ostracods, gastropods, and cephalopods. Other fossils (horn corals, spiriferid brachiopods and bivalves) are preserved, commonly in pyrite within the shales. Minute flakes of muscovite and disseminated pyrites are also noted. The shales within the older, eastern section of the Doorin Peninsula contain only rare horn corals and small brachiopods. No foraminifers have been identified in thin-sections of samples between Blind Rock and Murles Point, and only minor amounts of skeletal material were noted. In contrast, the shales become richer in macro- and microfossils up-section from Murles Point westwards to Doorin Point. This increase coincides with the incoming of argillaceous limestone beds. Individual exposures are discussed later in Section 6.4.3. The most abundant macrofossils within the shales in the upper sections of the Doorin Point area include spiriferid brachiopods, bivalves, disarticulated crinoids and horn corals.

Inland exposures of the Bundoran Shale Formation also contain variable amounts of disarticulated crinoids, gastropods, ostracods, cephalopods, brachiopods and bivalves. A trilobite was noted in micaceous calcareous shales within the Bunlacky River exposure at Drumrainy, north of Dunkineely (L197, GR17757 37918). Hill and Smyth (1938) identified the colonial tabulate coral *Cladochonous* spp. M'Coy in shales within the Doorin Point area. 'The fragments usually consist of one or two corallites, the second arising through the side of the calyx of the first, but occasionally several corallites may be found attached, forming either an erect zig-zag branch or a reptant coil round a crinoid stem, or other organic basis'. They do not appear to have any biostratigraphical significance. The degree of preservation of the echinoderm material within the shales is poor. This predominance of solely ossicle fragments in the Donegal area contrasts with the

disarticulated, but little transported echinoderms, abundant ossicles and the rare occurrence of articulated specimens located within the lower part of the Bundoran Shale Formation at Bundoran. A discussion on long stemmed crinoids (up to 2 metres long) from the Bundoran section is presented in Mannifield and Sevastopulo (1998). The Bundoran section is also different in that fossils become rare in the upper part of the formation. The Doorin Point section is within the upper part of the formation (approximately 180 metres from the base) and this coincides with an increase in the fossil presence. Bioturbation is not normally apparent within Facies P2 shales.

Thin beds of calcareous siltstone (generally less than 10 cm thick) are commonly interbedded with the shales. These siltstone beds are assigned to Facies Q in this study. They are typically laterally continuous (across 10's of metres on cliff exposures), brown-grey in colour, and appear slightly more resistant to weathering, compared to the shales. The siltstones commonly display cross-laminations and small ripples (as exposed along the Doorin Peninsula - Plate 47). The laminations are commonly disturbed as a result of bioturbation, thus, the type of ripple (current or wave) is not easy to determine. However, the basal bounding surface of the ripples appears to be irregular, a feature indicative of wave ripples. The basal and top contacts between shale and siltstone beds are dominantly sharp where exposure is good, although this distinction is not so apparent in scrappy inland exposures. The calcareous siltstones are a minor constituent within the Bundoran Shale Formation along the Doorin Peninsula. Microfossils (including ostracods and foraminifers) were observed within thin-sections of some siltstone samples. The majority of samples from the Doorin Peninsula contain only a small amount of shell debris (including bivalves, echinoderms and brachiopods). Facies Q comprises a more significant component of the Bundoran Shale Formation inland (in the Eanymore and Garrafada areas - refer to Figure 2 for locations), in areas considered to have been closer to the palaeoshoreline at this time. The fossils could have been transported into the area. Inland from Dunkineely/Inver area (i.e. towards the Garrafada area), fossils (generally crinoids and brachiopods) are more common within the siltstones, compared to Doorin Point exposures. Calcareous siltstone/fine-grained sandstones with gastropod and ostracod fauna were located at Lough Muilt (L193, GR17680 38054).

The shales and siltstones are regularly interbedded with argillaceous limestones (Facies K - ranging from several centimetres to 40 cm thick). The limestones are also commonly bioturbated and are similar to those observed within the Rinn Point Limestone Formation. The limestones appear to occur more frequently within the inland exposures further north, than in sections along the Doorin Peninsula exposure. Within the Doorin Peninsula area, limestones are absent in the lower sections and increase in proportion towards Doorin Point. Fossils within these limestones include crinoid ossicles, spiriferid brachiopods, bivalves and ostracods. As noted by Buckman (1992), the Bundoran Shale Formation contains various types of trace fossils (see Table 6.1 below for the trace fossils within the Doorin Point area). Several well preserved examples of *Zoophycus* burrows have been observed within the limestones in the Bundoran Shale Formation along the Doorin Peninsula. These burrows appear on the shale surfaces (and less commonly on the limestone beds) as planar to gently inclined spreiten distributed in delicate sheets, ribbons or spirals. The diameter of the burrows range from 15 to 40 cm, although most are between 25 to 30 cm wide.

ICHNOTAXA		STRUCTURES
ANCONICHNUS	*Anconichnus* ? Ichnosp.	Feeding
ARENICOLITES	*Arenicolites* ? Ichnosp. Type-B	Dwelling
CRUZIANA	*Cruziana* ichnosp. Type-C	Crawling
HELMINTHOPSIS	*Helminopthopsis* ? Ichnosp.	Grazing
PALAEOPHYCUS	*Palaeophycus* ? Ichnosp. Type-A	Dwelling
	Palaeophycus ? Ichnosp. Type-B	Dwelling
SCHAUBCYLINCRICHNUS	*Schaubcyclindirchnus coronus*	Feeding
ZOOPHYCUS	*Zoophycus* ichnospp.	Feeding

Table 6.1 Formally named ichnotaxa observed within the Bundoran Shale Formation at Doorin Point by Buckman (1992).

6.3 MICROFACIES OF THE BUNDORAN SHALE FORMATION

6.3.1 Thin-section analysis

The presence of microfossils is generally difficult to establish within the shales, since this lithology is too fissile and argillaceous to examine as thin-sections. Hence, the majority of the thin-sections from this formation were sampled from the more compact

calcareous siltstone and limestone beds. The limestone samples are classified as wackestones and packstones (biosparite to biomicrite). The amount of muddy and silty material varies within different areas. The northwestern areas of the Donegal Basin which contain the Bundoran Shale Formation (i.e. Garrafada) comprise more siltstones.

The following thin-sections samples from the Bundoran Shale Formation are extracted from Appendix 4 to display the overall microbiotic characteristics of the formation:

TCD No.50527, L218	Garrafada area (GR17994 38166)
TCD No.50537, L237ii	West of Banagher Hill (GR19260 38472)
TCD No.50541, L248	Eglish River (GR19254 38600)
TCD No.50545, L255i	Tullynaha (west of Banagher Hill) (GR18986 38473)
TCD No.50673, 96-30	Doorin Point (GR18100 37272)
TCD No.50678, 96-35	Bunlacky Waterfall (GR17787 37727)
TCD No.50679, 96-36	Bunlacky River (GR17792 37717)
TCD No.50692, 96-57	Ball Hill, SE of Donegal Town (GR19033 37637)
TCD No. 50701, 96-69	Killin Hill (GR18322 38311)

The Bundoran Shale Formation within the Donegal Basin contains fragments of brachiopods, bivalves, echinoderms, ostracods, and *Koninckopora*, moravamminids, bryozoa, *Mendipsia leesi*, ostracods, gastropods, *Girvanella*, and possibly salebrids. A fragment of a conodont was also observed. The samples display variable degrees of bioturbation.

The foraminifers include *Archaediscus*, *Uralodiscus*, *Brunsia*, *Eoparastaffella*, *Eostaffella*, *Earlandia*, *Endothyra*, *Tetrataxis* and possibly *Glomodiscus, Dainella*, *Forschia*, *Pseudotaxis*, *Mediocris*, *Urbanella, Eblania*, *Uralodiscus* and possibly *Valvulinella* and *Pseudoammadiscus*? and possibly *Viseidiscus*? One important observation is the presence of archaediscid foraminifers within the Bundoran Shale Formation (refer to Plate 108). Apart from its presence at one other locality close to the top of the Donegal Limestone Member (refer to Section 5.3.4.5), this foraminifer is otherwise exclusive to the Bundoran Shale Formation within the Donegal Basin.

6.3.2 Conodont analysis

Samples from several localities (e.g. 96-49, 97-03) within the Bundoran Shale Formation were processed for conodonts. However, none were yielded. This absence is most likely due to the extremely high argillaceous (mud and silt) content, which is characteristic throughout the formation. Shales would not have been favourable for the conodont animal.

6.4 LOCALITY DESCRIPTIONS OF THE BUNDORAN SHALE FM.

The Bundoran Shale Formation overlies various sequences within the Donegal Basin (refer to Figure 2). The formation overlaps the poorly exposed Shalwy Formation, and possibly the St. John's Point Sandy Limestone Formation to the north of Dunkineely. The base may represent a flooding surface. The Bundoran Shale Formation is relatively coarser-grained and more micaceous in this area (in contrast with the finer-grained lithologies along the Doorin Peninsula). This is due to lateral facies changes from southeast to northwest.

At Rossylongan (southwest of Donegal Town), a lithological contact between the Bundoran Shale Formation and the Donegal Limestone Member (of the Ballyshannon Limestone Formation) is gradational over several metres (refer to Section 5.3.4.5 and Figure 54). In addition, the base of the Bundoran Shale Formation appears to be supported by biostratigraphical data (see Section 6.4.4).

The contact of the Bundoran Shale Formation with the Banagher Sandstone Formation (which underlies it in the northeastern area of the Donegal Basin) is not exposed. However, a stream section towards the north of Banagher Hill, may comprise the uppermost beds of the Banagher Sandstone Formation (pebbly and coarse-grained sandy limestones are observed - Refer to Sections 5.5.3.4 and 6.4.4.1.

A gradational upper contact with the Mullaghmore Sandstone Formation was located in a small stream section at Dromore (GR18527 37593), inland from Doorin Point (refer to Figure 59 and Section 6.4.4.5). This contact has not been previously documented. The Bundoran Shale Formation is best exposed along the Doorin Peninsula. Other (less

extensive) exposures include the coastal area from Rossylongan to Summerhill (west of Donegal Town); on the western flanks of Banagher Hill; and scattered exposures within the Bunlacky River, Eglish River, Eanymore Water, Eanywater and Edrim River (Refer to Figure 2 for localities).

The localities discussed below display the essential character of the Bundoran Shale Formation and its two coarser clastic members. The section is divided into key areas:

6.4.1 - the western limb of the Donegal Basin,

6.4.2 - the southeastern area of the basin,

6.4.3 - the Doorin Peninsula (including the Ramp Hole Sandstone Member),

6.4.4 - the eastern parts of the basin,

6.4.5 - central parts of the basin (including the Killin Sandstone Member).

6.4.1 Western Limb of the Donegal Basin

6.4.1.1 Bunlacky River area

The Bundoran Shale Formation is exposed along the Bunlacky river (from Garrafada area (GR17924 38167) to the coast at Dunkineely (Figure 2). The western basal contact of the formation is difficult to interpret as lateral changes dominate the Bruckless - Dunkineely - Garrafada area (Figure 10). Within calcareous siltstones, the sample 96-35 (TCD No.50678) yielded archaediscid foraminifers (refer to Plate 108). At Meenabrock (L194, GR17765 38051), the northern section of a stream exposes interbeds of calcareous sandstone and siltstone, and gradually fines up to beds of fissile, calcareous shale and argillaceous limestones. To the northwest of Dunkineely Village, the Bunlacky River veers to the east around a drumlin hill. Four faults are observed within approximately 30 metres of section (refer to Figure 9 for locality). The lithologies within this section comprise fine-grained, calcareous sandstones; laminated, calcareous siltstone; argillaceous to micaceous limestones and calcareous shales. Several irregular erosion surfaces are present. Fossils are rare, as only crinoidal debris has been noted. Most of the lithologies are bioturbated.

An exposure east of Cashelfean (within a small tributary of the Bunlacky River - GR17787 37727) comprises approximately one metre of bioturbated, calcareous

siltstone, calcareous shales and minor beds of silty limestones. Gastropods, crinoid debris and fragments of plants were observed. A small waterfall (approximately fifty metres to the north) is cut in generally, well-bedded, calcareous siltstone, argillaceous limestone and minor shales. Approximately two metres of variably bedded sandstones (further south) are cut by a fault, which would probably link up with one of the faults exposed in Bunlacky River. Although the sequence within Bunlacky River is faulted, the general younging direction is to the southeast. At Bunlacky Bridge, a four-metre cliff section comprises calcareous shales and argillaceous limestones with brachiopods, crinoid debris and bivalves. These beds appear richer in fossiliferous material than the older beds to the north.

6.4.1.2 Mullanbane to Port Pier area

The main coastal outcrop of the Bundoran Shale Formation commences to the east of the area where the Bunlacky River reaches the shore at Mullanbane (GR c.17918 37614), after a gap of pebbly coastline from the Cavan Sandstone Member exposure (refer to Figures 2 and 45). The Bundoran Shale Formation exposures comprise several metres of (southeast younging) calcareous shales and minor argillaceous limestone beds. A part of the section (to the east of Mullanbane) is slumped, with several faults and folds cutting through the shales. The shale exposure continues eastwards for at least a kilometre to Port (GR18048 37669). The sheltered pier at Port (GR18101 37737) is cut into the shales. The area comprises extensive cliff sections of the Bundoran Shale Formation, which young eastwards. Variable amounts of crinoid debris, bioturbation and calcareous nodules are observed within the calcareous shales. A distinctive erosional surface is observed along the base of the cliff. Low angled laminations and thin interbeds of calcareous siltstone and shales overlie this surface.

6.4.2 Southeastern area of the Donegal Basin

6.4.2.1 Rossylongan

The rocks in the Donegal Town area comprise argillaceous limestones, calcareous siltstones and shales and minor clean sparry limestones. Some authors (George and Oswald 1957, Al Rawi 1972, Avbovbo 1973) believe these rocks to comprise part of

the Bundoran Shale Formation. However, in this study, it is thought that these rocks are lithologically more similar to the rocks exposed between Lough Eske and Donegal Town and would thus belong to the older, argillaceous Donegal Limestone Member (part of the Ballyshannon Limestone Formation). The boundary between the Donegal Limestone Member and the Bundoran Shale Formation would, therefore, probably occurs further west in the region between Donegal Town and Edrim Bridge. The latter area comprises calcareous shales, characteristic of the Bundoran Shale Formation.

As discussed previously in Section 5.3.4.5, the coastal area along Rossylongan Strand (southwest of Donegal Town) contains several exposures of thin-bedded, sparry to argillaceous limestones and calcareous shales. A cliff section towards the northwestern end of Rossylongan Strand (GR19164 37825) comprises twelve metres of section (Figure 54). The basal five metres of the section (dominated by limestones) are assigned to the Donegal Limestone Member. The overlying seven metres are dominated by calcareous shales, with minor beds of argillaceous limestones are assigned to the Bundoran Shale Formation. The significant change of lithology in this cliff section (from limestone to shale dominance) might infer the formational boundary between these two units.

The thin-section TCD No.50709 (Locality 96-82, GR19163 37822) sampled four metres from the base (within the relatively clean limestone bed), yielded archaediscid foraminifera (which would indicate an Arundian age). Another thin-section (TCD No.50761, Locality 97-03, GR19133 37787 - sampled close to two metres from the base) did not contain archaediscids, although the absence of a fauna should not be taken directly as evidence of a different age (in this case, the Lower Viséan). It would seem; however, that the first appearance of archaediscids might occur lower in the sequence (i.e. within the Donegal Limestone Member). Thus, the lithological formational boundary between the Donegal Limestone Member and the Bundoran Shale Formation may not coincide exactly with the biostratigraphical boundary between the Lower Viséan and the Arundian.

6.4.2.2 Summerhill

In the Summerhill area (GR19078 37683), interbedded calcareous shales and minor sparry limestones (younging to southwest) of the Bundoran Shale Formation crop out. Approximately 12 metres of shales and limestones extend from Ballyboyle in the east, to a gap east of the ruined castle. Approximately seven metres of rock extend from this gap, westwards to the area containing folded rocks, (immediately beneath the site of the old castle). Most of the shales are bioturbated. Crinoids appear to be the only macrofossils throughout the sequence. Several beds (40 to 70 cm thick) of sparry crystalline-micritic limestones are also present. The sequence beneath the site of the old castle is folded and disturbed. Several of the crystalline limestone beds alter to a more lensoid geometry within the folds, some form 'fold noses'. The beds above the folded limestone lens can be traced laterally both east and west of the slumped area.

6.4.3 The Doorin Peninsula

The most westerly exposure of the Bundoran Shale Formation on the Doorin Peninsula is at Jack's Quay (southeast of Mountcharles Village - refer to Figure 58 for location), where several metres of calcareous, fissile laminated shales crop out on a cliff along the beach. There is no exposure (southwestwards) from Jack's Quay to Burn Foot, a distance of approximately three kilometres.

At Burn Foot (GR18518 37502) approximately three metres of shallowly southeast dipping, calcareous shales crop out along the boulder clay embankment. A north-west/south-east trending, two-metre wide dolerite dyke crosscuts these shales. Fossils are generally uncommon within the shales, with the exception of rare horn corals and small brachiopods. The shales are relatively micaceous and contain only one 10 cm thick prominent layer of calcareous siltstone (weathered light brown in colour).

There is another gap in exposure along the boulder clay embankment to half way between Burn Foot and Holme. Approximately 16 metres of calcareous shales are exposed at Holme. Two dolerite dykes (trending north-west/south-east) crosscut the shales at the northern end of Holme. At this locality, the fissile calcareous shales dip gently to the north. The only fossils visible within the shales are solitary horn corals.

Refer to Figure 58 for localities referred to in the following section.

Blind Rock comprises a fifteen-metre wide, north-west/south east trending dolerite dyke, which protrudes into the sea. This dyke also extends inland as a ridge, northwestwards to Doorin Rock. The measured logged section (in Figure 57) from Blind Rock to Doorin Point (totalling 185.5 metres) commences at this contact. The basal sequence at Blind Rock comprises calcareous shales and siltstones with calcareous nodules. Thin (<10 cm) laminated beds of calcareous siltstone (weathered brown) are present throughout. Orthocones, nautiloids and horn corals are present among the loose scattered rocks found along the base of the cliffs. The exposed section from Blind Rock to Craig Shore is approximately 33.5 metres thick. Disturbed calcareous shales are exposed along the cliffs at Craig Shore. This disturbed area is inferred to be a result of syn-sedimentary folding and faulting, as it is confined to within tens of metres squared and several metres thick. The structures have been further complicated by later crosscutting faults. Beyond the slumped area, the general dip of the shales is 5 to 6^0 to the north. The calcareous shales exposed at Craig Shore young southwestwards to Ramp Hole.

6.4.3.1 RAMP HOLE SANDSTONE MEMBER

6.4.3.1.1 INTRODUCTION

At Ramp Hole (refer to Figure 58 for location and Figures 57 for a logged section), the shales display irregular bedding and are deformed due to slumping. The shales are cut by a prominent erosion surface at this locality and are overlain by a heterogeneous channel fill. The Ramp Hole Sandstone Member is proposed for this 'channel fill' (overlying the erosion surface) at Ramp Hole. Figures 60 and 61 displays the sandstone unit overlying the shales.

6.4.3.1.2 LITHOFACIES OF THE RAMP HOLE SANDSTONE MBR

The basal section at Ramp Hole comprises up to two metres of calcareous pebbly to coarse-grained, buff to white coloured, unsorted, (often irregularly bedded) sandstone (assigned to Facies H). A 70 cm thick black, organic rich, fissile shale bed (comprising ostracod-rich horizons) overlies the pebbly sandstone unit. This unit may be assigned to Facies J. The typical calcareous shales of the Bundoran Shale Formation appear to resume conformably above this.

A thicker section is observed to the west at Coppers Bank-Portachurry (Figure 61). The sequence at this latter locality comprises bioturbated calcareous siltstones and calcareous sandstones, overlain by coarse-grained to pebbly cross-stratified, calcareous sandstones.

6.4.3.1.3 LOCALITY DESCRIPTIONS OF THE RAMP HOLE SANDSTONE MBR

6.4.3.1.3.1 Ramp Hole

Although the sandstone unit may be mapped as one entity at Ramp Hole, it appears to comprise three laterally connecting elements. Refer to Figure 60:

- The western element displays a large, cut-bank channel geometry (approximately 15 metres wide x 2.5 metres deep). The base of this sandstone is disturbed and is in

contact with disturbed, calcareous shales (with calcareous nodules) beneath (Plate 100). (The contact dips at 16^0 to the southeast). The pebbles within this basal sandstone comprise vein-quartz, angular feldspar, and reworked calcareous siltstones. Parallel laminated bedding is observed towards the top of the coarse-grained sandstone.

- The middle sandstone element is a smaller unit (approximately 6 metres wide x 2 metres thick), and the erosional geometries with the underlying shales are not as clearly defined.
- The eastern element is an irregularly bedded, pebbly sandstone and shale unit, which is three metres thick at its maximum. A bed of slumped shales underlies the main sandstone, and is in turn underlain by another coarse to pebbly calcareous sandstone lens. Within the upper sandstone unit, a 'ball and pillow' structure is exhibited (Plate 101). These are most likely caused by instability during deposition of the sandstone sediment above a muddy layer. The sandstone contains pebbly lags and appears to be bioturbated and slumped in places. Groove marks on the base of the sandstone display current directions to the northeast or southwest, and a foreset is also measured to the southwest. The unit thins laterally to about 20 cm, and thickens again to the east and west. Above the sandstone unit, microfolds are observed within the ostracod-rich shales (Plate 102). A small horn coral was observed within the pebbly, calcareous sandstone (beneath the compass in the photograph); thus, indicating some degree of marine influence.

The cliffs to the southwest of Ramp Hole are covered mostly in trees, but a sandstone unit can be traced (along the cliffs) south-south-west to Coppers Bank and Portachurry (see below). It presumably equates with the sandstone at Ramp Hole. Thus, between Ramp Hole and Portachurry, the Ramp Hole Sandstone Member is approximately 100 metres wide and at least 14 metres thick.

6.4.3.1.3.2 Coppers Bank - Portachurry

The cliffs south of the sandstone boulder covered area at Coppers Bank-Portachurry (GR18350 37385), display a well-exposed section of the Ramp Hole Sandstone Member. Approximately twelve metres of section are exposed from the foreshore to the

top of the cliff (refer to top part of log in Figure 57 and Figure 61, the latter displays more detail). The base of the cliff section comprises calcareous shales (Facies P2 of the Bundoran Shale Formation), which are overlain by thin interbeds of coarse-grained, calcareous siltstones (Facies Q), fine-grained sandstone and some ostracod-bearing, calcareous nodules. Bioturbation and burrows are observed in this unit. An irregular lens of pebbly to coarse-grained sandstone, fining-up to medium grained sandstone (Facies H), overlies the siltstones. The sandstones are overlain by a 1.6 metre thick unit of interbeds and lenses, comprising thin beds of calcareous, fine-grained sandstone (Facies G) and coarse-grained siltstone (0.9 m to 2.5 metres on the logged section in Figure 61). The interbeds are overlain by fissile, calcareous siltstone with some muddy flasers, and contain ostracods. Calcareous nodules (present towards the top of the siltstone unit) also contain ostracods (2.5 to 3.6 metres on logged section).

Overlying the siltstones are two thin beds (10 cm and 3 cm) of fine-grained, well-sorted calcareous sandstones displaying distinctive ripples and siltstone lenses (Plate 103). No foreset laminae are visible within the rippled sandstone. A wavy mudstone layer drapes the ripple troughs, making a thin cover over the ripple crests. Most of the ripples show asymmetrical tops and are characteristic of wave ripples. Above the rippled section, there is a one-metre thick unit of calcareous quartzose sandstone (from 2.65 to 3.7 metres on logged section). The basal part displays thin parallel laminations. These sandstones equate with Facies G within this study. Within the cliff section, two beds of calcareous medium- to fine-grained, generally well sorted sandstone (lenses of siltstone, bioturbation and low-angled cross-strata) overlie the metre-thick sandstone unit discussed above. Cross-beds are observed within these sandstones. However, lack of good 3D surfaces hindered accurate measurement of the sections. Towards the top of the cliff section, over six metres of coarse-grained to pebbly sandstones (Facies H) are present (from circa 5.5 to 11.7 metres on logged section), although access is difficult. Some quartz and feldspar pebbles within the sandstones range up to 3 cm in diameter, and the smaller grains are generally angular. Cross-strata along the base of the bed (Plate 104) indicate a general palaeocurrent direction towards the north. There is a possibility of bi-polar cross-strata within this section, although this is not distinct. The top contact of the Ramp Hole Sandstone Member with the shales is not exposed at the cliff. The inferred top has to be extrapolated across to the southwest (along the

foreshore) where the sandstone displays an irregular top contact with calcareous shales of the Bundoran Shale Formation (Plate 105).

6.4.3.1.4 DISCUSSION ON THE RAMP HOLE SANDSTONE MBR

The channelled unit at Ramp Hole comprises immature, poorly sorted, quartzose to feldspathic sandstones. Grain size is variable from medium-grained to pebbly, although the coarser end of the spectrum dominates. The geometry of the channel margin suggests a source derivation from the fluvial hinterlands to the north to northeast. There is insufficient section to confidently determine the cause of these clastics i.e. the product of a prograding shoreline or an incised fill. Uplift and increased sedimentation (due to renewed local tectonism) could give progradation. This activity would have resulted in an influx of clastic material prograding south onto the palaeoshoreline, and cutting into the inferred prodeltaic shales of the Bundoran Shale Formation. Base level fall could result in progradation or incision.

Leeder (1982) stated that asymmetric wave current ripples might be formed in shallow water near the breaker zone. 'There is a net landward transport of water superimposed upon any surface wave pattern ... thus giving rise to small-scale cross-laminations similar to that produced by current ripples'. Planar lamination in sand-grade sediment is formed by turbulent flows at high velocities, which are most easily sustained in shallow water (Tucker 1991). The association of bioturbation, wave ripples and parallel laminations may suggest deposition within a shoreface to offshore zone (refer to Walker 1984, his Fig 9 and Reading 1996, his Fig. 6.6). Thus, a shoreface environment is proposed for the Portachurry section and is similar to that described for the Cavan Sandstone Member, within the St. John's Point Sandy Limestone Formation.

The depth of water column needed to deposit the shales out of suspension (prior to the clastic input) would be tens of metres. A significant drop in sea level would have been necessary to lower the base level to permit the sandstones to incise the shales at Doorin, as noted by the angular bank-cut geometry at Ramp Hole. The Portachurry section comprises several marine indicators: some well sorted, well washed, calcareous sediments; asymmetrical wave ripples; the groove marks, cross-strata displaying foresets from the southwest - (opposing the channel direction), and possible bi-polar

currents. Thus, at least some incision below sea level is implied (Schumm and Ethridge 1994). The sediments at Ramp Hole are sufficiently coarse-grained to imply transportation by bed load. This tends to reduce the amount of lateral spreading observed in fine-grained deltas. This incision would probably imply a non-sequence event within the shales. However, no evidence relating to significant depth changes has been noted within the lateral shale sections along the Doorin peninsula further west.

The sandstones exposed between Ramp Hole and Portachurry display a channelled margin and sheet-like structures. Although the lateral extent of the Ramp Hole (circa 100 metres) is very limited, the sandstones may have been deposited as an incised valley fill. Incised valleys occur where rivers have eroded delta plain or shelf sediments as a result of a fall in relative sea level (Reading 1996). The valleys are commonly filled by tidal and fluvial sediments. Dalrymple *et al.* (1994) stated that the term 'incised valleys' should be restricted to fluvially eroded features that are larger than a single channel.

The Ramp Hole Sandstone Member might represent the transgressive systems tract formed during the subsequent sea level rise. However, despite lateral exposure at the appropriate levels in the Bundoran Shale Formation, there is no evidence for any surface that might equate to the incised valley. A maximum flooding surface could not be defined in the area. The Ramp Hole Sandstone Member was most likely formed by an incision process. However, it is not known if the boundary displayed by the incision at Ramp Hole (Figure 60) is a type-1 sequence boundary, reflecting a sea-level fall or whether it represents the progradation of a distributary channel that was subsequently abandoned.

Cotter and Driese (1998) present a sequence stratigraphic analysis for the streams within the Catskill Formation (Upper Devonian) in the Appalachian Foreland Basin in Pennsylvania. In the lowstand phases, Catskill streams erosionally incised their courses into the coastal-alluvial plain, bypassing coarser sediment to the shelf, where it accumulated as lowstand shelf fans. In the transgressive phase, the transgressive surfaces moved upvalley, drowning the incised valleys. The fluvial system was altered to storm-wave-influenced marginal marine sand environments, followed by the

establishment of deeper estuarine conditions. On the shelf, transgressions restored to muddy conditions of low energy and anoxia.

6.4.3 Doorin Peninsula (continued)

The Bundoran Shale Formation resumes again west of Portachurry. There are approximately seventy metres of shale between Portachurry (from the top of the sandstone beds of the Ramp Hole Sandstone Member to Murles Point – refer to Figure 58). A fault west of Portachurry results in the sandstones of the Ramp Hole Sandstone Member being repeated along the foreshore at Blackrock. The section along the cliffs to Murles Point comprises interbeds of calcareous shales with small brachiopods and thin layers of cross- and parallel-laminated (often bioturbated), calcareous siltstone.

At Murder Hole, several faults dip to the southwest. It is difficult to estimate displacement of the faults, due to the scarcity of marker horizons within the dominantly calcareous shale sequence. Calcareous nodules are present within the shales, towards the top of the seventy-metre section (near the roadway at Murles Point). From the roadway at Murles Point, the cliffs to the west consist solely of boulder clay. The foreshore (covered in boulders, seaweed and water, even at low tide) contains nearly horizontal beds of calcareous shales.

Approximately 16 metres of section (comprising calcareous shales and micaceous siltstones with evidence of burrows and fossiliferous debris) continue from west of the roadway Murles Point, up to the base of an anticline. Brachiopods and crinoids become more common in the shales from 18 metres above the base of Murles Point section. A cliff section of shales above this is laterally persistent across strike for approximately 100 metres. A fault (dipping 34^0 to the north) is exposed northwest of Loughanmore. It is difficult to estimate the displacement of the fault. The measured section commences at the base of the southern block. Sixteen metres of section separate the fault discussed above and the next fault to the west (which has a similar dip of 36^0 to the north). These faults are rather shallow, display associated calcite veining and may be associated with the slump faulting. This part of the shaly sequence contains spiriferid brachiopods, horn corals and bryozoa.

There is an estimated 10.5 metres of shales and minor calcareous siltstone intervals, extending up to the base of the first significant 40 cm argillaceous limestone unit on the western side of Doorin Point. Several faults are located in the lower part of the 10.5 metre section and further up in the section, a thin 2 cm coal horizon is located within the shales. This horizon comprises drifted material and thus not in-situ coal. Fossiliferous debris is quite common throughout the section. The thin-section TCD No.50674 (Locality 96-30, GR18100 37272) is taken from the 40 cm thick argillaceous limestone bed (mentioned above), which displays *Zoophycus* on the surface. Archaediscid foraminifers (*Archaediscus*, *Glomodiscus*) were observed in this sample. Seven metres of section (dominantly calcareous shale) separate this area from the next 40 cms thick argillaceous limestone unit to the west. This latter argillaceous limestone bed is faulted, with an apparent four metre normal displacement to the southeast.

Four metres further up-section towards Doorin Point a normal east/west trending fault (dipping 30^0 to the north) is exposed. The fault extends westwards and is visible south of Eagle's Nest. Although there is more rock further north, it is difficult to work out if there is any section younger than this. An open syncline is located east of Eagle's Nest and plunges very gently to the southeast. The beds to the north of Eagle's Nest dip to the south. Compared to older sections further east (at Burn Foot, Holme and Murles Point localities), the fossil content in the uppermost twenty metres of calcareous shales and argillaceous limestones at Doorin Point is markedly higher. This latter twenty-metre unit contains crinoid debris, stick bryozoans, small spiriferid brachiopods, horn corals, calcareous nodules and horizontal burrows. The sequence is variably bioturbated. George and Oswald (1957, p.158) also noted trilobites and '*Collenia*-like' algal growths in this vicinity, although their presence has not been substantiated in this study. The latter features have since been credited to spreiten in trace fossils (George Sevastopulo 1997, pers. comm.).

Avbovbo (1973) calculated a 135 metre thickness for the section from Ramp Hole to east of Doorin Point. This latter figure is relatively close to the value of 152 metres, which was measured in this study for the same section. The sum of exposed rock thickness from all the measured sections from Blind Rock to Doorin Point is approximately 186.5 metres.

6.4.4 Eastern and central parts of the Donegal Basin

6.4.4.1 North and west of Banagher Hill

The Bundoran Shale Formation conformably overlies the Banagher Sandstone Formation along the western slopes of Banagher Hill. Although this contact is not entirely exposed in this area, a stream section (refer to Enclosure 5.3 and Figure 2) on the northern slopes of Banagher Hill displays a gradual lithological change. Refer to Section 5.5.3.4 for a discussion on this lithological contact to the east of Meenataggart. It is probable that the rocks exposed in the stream section represent a brief interval, immediately post-Banagher deposition. The clastic rocks would now have been deposited within a shallow marine environment (instead of the inferred wholly non-marine deposition of the Banagher Sandstone Formation). The deposition of the calcareous sandstone sediments would have probably occurred prior to the deposition of the prodeltaic sediments of the Bundoran Shale Formation.

Small stream sections in the Altilow and Lacktrom area expose several metres of fossiliferous, calcareous shales and siltstone. Macrofossils include caninioids, large brachiopods and crinoid debris, whilst archaediscid foraminifers have been recognised in thin-sectioned samples.

6.4.4.2 Eglish River

The Eglish River follows a significant northeast/southwest trending lineation (the Eglish Fault) from the Northern Boundary Fault (NBF) to Letterbarra (8 km to the southwest). The Eglish Fault separates the Banagher Sandstone Formation and the Bundoran Shale Formation (exposed south of the fault and within the Eglish River), from the older rocks of the Clady Limestone Member and the Lough Eske Sandstone Formation (exposed north of the fault). Refer to Enclosure 5.3.

The boundary between the Banagher Sandstone Formation and the Bundoran Shale Formation also appears to be gradational in this area. A river section (GR19254 38600 L248, TCD No.50541) comprises interbedded calcareous sandstones, siltstones and argillaceous limestones. A thin-section from this locality yielded archaediscid foraminifers (refer to Plate 108). The rocks young to the west; thus, this part of the river

section would appear to be located close to base of the Bundoran Shale Formation. Calcareous siltstones, shales and argillaceous limestones of the Bundoran Shale Formation (containing archaediscid fauna) continue west towards the central areas of the Donegal Basin.

6.4.4.3 Inver area

Approximately five metres of calcareous shales and minor, calcareous siltstones are observed in a waterfall section to the east of Tullynagreana. The region around Bonny Glen (north of Inver e.g. GR18273 37964, Locality 96-62, TCD No.50696) contains intermittent sections of calcareous shales and minor interbeds of calcareous siltstones, calcareous sandstones and argillaceous to sandy limestones. The limestones are regularly bioturbated and fossils include disarticulated crinoids, brachiopods and gastropods.

6.4.4.4 Eanymore Water

The river section from Drumagraa Bridge (GR18655 38204) to Letterbarra Bridge (GR18783 38272) contains shales characteristic of the Bundoran Shale Formation. However, a higher percentage of sandstones are also observed in this area. The sandstones are buff coloured, generally unsorted, feldspathic, and commonly coarse-grained to pebbly in size. A southerly-dipping fault is exposed in the river. Shallow dipping calcareous siltstones and shales lie north of the Eanymore Water Fault. To the south of the fault, steep-dipping variable beds of medium-grained to pebbly, calcareous and non-calcareous sandstones, and thin-bedded calcareous siltstones are exposed. A three-metre thick cliff section in this vicinity exposes similar lithologies. Cross-strata within 20 cm beds of fine- to medium-grained sandstones display palaeocurrent directions to the northeast.

Several hundred metres west (and slightly down-section) the river exposes horizontal to gently west-dipping, clast-supported conglomerates. The clasts are mainly of quartzite and vein-quartz, and vary from rounded to sub-angular in degree of roundness. Average clasts size is 5 cm, although some range up to 20 cm in diameter. The matrix comprises angular quartz grains and the conglomerate beds are interbedded with coarse-grained

sandstones. This unit is assigned to the Killin Sandstone Member (refer to Section 6.4.5) and appears to be faulted against interbedded medium-grained sandstones and calcareous siltstones further west. The fault trends east/west and appears to terminate the Eglish Fault, which is exposed close to Letterbarra.

6.4.4.5 Dromore area

The Doorin Peninsula is dominantly a drumlin countryside, which results in poor inland exposure. A limited section of the Bundoran Shale Formation crops out in a stream section near Dromore (GR18527 37593) (refer to Figure 59). In this vicinity, the transition from the Bundoran Shale Formation to the Mullaghmore Sandstone Formation is exposed.

The stream is located south of the dismantled railway station at Dromore and north of Drumaneary. The area is quite forested and hidden by brambles and overgrowth. Calcareous shales and siltstones are exposed along the southern and lower parts of the stream (assigned to the Bundoran Shale Formation). The clastic sequence is exposed further upstream close to a deciduous wooded area (presently used as a dump). The stream section is described from south to north. The lowest (oldest) parts of the stream comprises horizontally bedded, calcareous shales and argillaceous limestones (15 to 20 cm thick) which exhibit a prominent jointing pattern. Thinly bedded, parallel laminated siltstones lie above the shales and argillaceous limestones. Further north, loose cobbles of fine-grained, calcareous siltstone with ripples and sole structures are located in the stream. The beds in-situ comprise thin (centimetres thick) sets of cross-laminated, calcareous siltstones and fine-grained, calcareous sandstones. Indeterminate palaeocurrents are observed. A probable fault is located in the stream less than a metre north. The bedding of the calcareous siltstones in the stream is nearly vertical and strike in a north/south direction. The thin laminated fine sandstone at the western edge of the stream dip 22^0 to the north-northeast. Loose slabs of fine siltstone display groove marks. Flat-bedded laminated siltstones are in contact above with the fine sandstones and further up (after a gap), two metres of irregularly bedded, non-calcareous sandstones with minor siltstone layers are exposed in a small waterfall (see log below). This sandstone-dominated sequence is rich in plant debris and forms the base of the Mullaghmore Sandstone Formation (this latter formation is best exposed in quarries in the Mountcharles vicinity) – also discussed briefly in Section 7.3.8.

The stream section at Dromore represents a gradual shallowing event. This is shown by the transition of argillaceous limestones, through to calcareous siltstones, into plant-bearing siltstones and eventually overlain by coarse-grained, quartzose sandstones. This regressional event is widespread over the Northwest Carboniferous Basin and is interpreted by Graham (1996) as representing a Type-1 sequence boundary (after Wagoner *et al.* 1988). The Mullaghmore Sandstone Formation is also observed in north Mayo and within the Sligo Syncline and is known as the Clonelly Sandstone Formation within the Omagh Basin. The type-1 unconformable boundary documented from North Mayo has been taken to represent a significant drop in sea level (Graham 1996). However, within the Donegal Basin, there is no unconformity, hence this contact in Dromore would be a correlative conformity to the Type-1 sequence boundary.

6.4.4.6 Drumbaran

A stream section to the South of Drumbaran School (northeast of Frosses) exposes horizontally bedded, calcareous, medium-grained sandstones. Further east, a quarry (GR18596 38035) comprises interbedded non-calcareous, micaceous siltstones and sandstones and some muddy lenses. The sequence is thoroughly bioturbated and rich in plant debris. This sequence may correspond to part of the basal sequence of the Mullaghmore Sandstone Formation, as this latter formation continues south from here onto Mountcharles. This would probably indicate that the top contact of the northern section of the Bundoran Shale Formation occurs in the Drumbaran vicinity.

6.4.5 THE KILLIN SANDSTONE MEMBER

6.4.5.1 INTRODUCTION

The Killin Sandstone Member is assigned a member status within the Bundoran Shale Formation, as these units display an inter-fingering association in the Killin Hill and Tullynaha areas. This relationship is most likely due to lateral facies change, from a predominantly, non-marine clastic influx to a deltaic marine environment. Nevin (1973) had previously correlated the 'Killin Sandstones' with the 'Basal Beds' of the 'Ballyshannon Limestone'. However, this study does not agree with this. The Killin Sandstone Member is exposed towards the northern and central section of the Donegal Basin (refer to Figure 2 and Enclosure 6.1). The member appears to be laterally extensive across this area (approximately 20 km^2), and far exceeds the extent of the other clastic member (Ramp Hole Sandstone Member) within the Bundoran Shale Formation.

6.4.5.2 LITHOFACIES OF THE KILLIN SANDSTONE MBR

The base of the Killin Sandstone Member in the Killin area comprises a gradational, coarsening-up sequence. The calcareous, fossiliferous shales and siltstones of the Bundoran Shale Formation are eventually overlain by unsorted, coarse-grained to pebbly sandstones (corresponding to Facies A conglomerates & Facies B sandstones - refer to Plate 106). Within these two end-members of calcareous, fossiliferous siltstones and pebbly non-calcareous sandstones, there are several metres of sandstones. This interval may be assigned to either Facies C (tidally influenced channel deposition) or Facies G (generally well-sorted marine sandflat sandstones). Insufficient outcrop deters more concise interpretation. The clasts within the non-marine sandstones are predominantly of quartzite and veined quartz with subordinate darker pelitic clasts. Some of the clasts reach up to 10 cm in length, although most are from 1 cm to 4 cm.

6.4.5.3 LOCALITY DESCRIPTIONS OF THE KILLIN SANDSTONE MBR

6.4.5.3.1 Carraduffy/Killin Hill

A small stream section at Carraduffy (GR18322 38311) comprises fossiliferous, argillaceous limestones and calcareous shales. The fossil assemblage includes crinoid debris, *Michelinia* and horn corals, a cephalopod and a large brachiopod *(Delepinea* sp.). A thin-section (TCD No.50700, Locality 96-68, GR18212 38232) from this locality yielded archaediscid foraminifers.

To the north of Carraduffy, the southeastern flanks of Killin Hill contain several streams with intermittent exposures of calcareous shales and siltstones, overlying medium to coarse-grained sandstones. The most eastern stream displays shales overlain by the pebbly sandstones. Figure 62 displays a logged section of this stream. The fossiliferous siltstones of the Bundoran Shale Formation become interbedded with fine-grained, calcareous sandstones (probably Facies G?). This two metre thick unit is overlain by several metres of coarse-grained to pebbly, tabular bedded sandstones, with lenses of calcareous siltstones and mudstones. Above this are non-calcareous, thick-bedded pebbly sandstones, which continue up-section towards the summit of Killin Hill. The overall pattern within the basal section in this area is one of interfingering between the Killin Sandstone Member extending south into the Bundoran Shale Formation (refer to Enclosure 6.1).

6.4.5.3.2 Northern Boundary area

The northern boundary area (immediately south of the Northern Boundary Fault) extends from the Owenboy River in the east to Lettermore and Lough Namanfin in the west. It contains intermittent exposures of arenaceous rocks; thus, the basis for correlation in this area is relatively limited. George and Oswald (1957) grouped the rocks of this area as equivalents of what this study refers to as the Lough Eske Sandstone Formation. On George and Oswald's map, a stipple infill (corresponding to clastic and carbonate rocks) is displayed throughout this area. However, the river exposure at Owenboy appears to contain the only calcareous rocks within the whole northern region (with exception to the Bundoran Shale Formation). As discussed in

Section 5.2.3.7, in agreement with George and Oswald (1957) and Al Rawi (1972), the lower sequence within the Owenboy River (GR19081 38645) is assigned to the Lough Eske Sandstone Formation and the Clady Limestone Member. No archaediscid foraminifers were recovered from the Owenboy exposure. This study assigns the sandstone unit, which overlies the shales in the Owenboy River as a thin lens of the Banagher Sandstone Formation. The timing of this clastic influx occurred either immediately prior or in the initial stages of the deposition of the Bundoran Shale Formation. Archaediscid-bearing calcareous rocks (Bundoran Shale Formation) are exposed further south at Tullynaha (TCD No. 50545, Locality 255, GR18986 38473).

6.4.5.3.4 Sallows

Two kilometres to the west of Owenboy, the Eanybeg Water exposes several metres of a distinctly orange rock at Sallows (GR18824 38668). Some bedding is apparent, although the exposure is comparable to a granitic outcrop. This arkosic, coarse-grained to pebbly sandstone constitutes large (up to 2 cm in diameter) potassium feldspar and quartz grains, and is completely unsorted and immature (Plate 107). The beds dip between 16^0 and 24^0 to the west (striking nearly at right angles to the Owenboy exposure discussed above). This unit is not large enough to be mapped separately from the Killin Sandstone Member; thus, it is included within the Killin Sandstone Member.

However, a separate source history from the Killin Sandstone Member is inferred for the arkosic sandstones at Sallows. It is postulated that during the early Arundian, a relatively small (south-flowing) river had undergone a brief period of active erosion on a granitic mass. The nearest exposed granite (the Barnesmore Pluton) is situated immediately north of the NBF and several kilometres to the east of Sallows (Pitcher and Berger 1972, Alsop 1992 and 1994). The Barnesmore Pluton comprises at least three distinct granite members - G1, G2 and G3 (Leedal and Walker 1954, Pitcher and Berger 1972). The latter authors noted that the leucocratic members are all relatively similar in composition. The members all contain a sodic plagioclase, microcline, quartz, biotite and sometimes a little muscovite. Pitcher and Berger (1972) noted a reddening of the feldspars, as probably connected with north-east/south-west faulting. G3 comprises a sheet complex which contains 'irregular and regular bodies of simple pegmatite' (Pitcher and Berger 1972). It is postulated that significant erosion of the exposed Barnesmore

Granite provided the sediment (from the pegmatite bodies), which was later transported fluvially further south towards Sallows.

The 'Northern Boundary Fault' (NBF) can be delimited 800 metres to the northwest of Sallows, from several psammitic and sandstone exposures. The southerly-dipping (10^0) sandstone comprises clean, feldspathic, buff-coloured sandstones, and bears no relationship to the arkosic (granitic) sandstone (in Eanybeg Water). The trend of the NBF alters from a predominantly east/west direction to a northeast/southwest direction, in this area.

At Tullynaglack, loose but apparently local boulders of buff coloured, coarse-grained to pebbly sandstones have been mapped. They may be lateral equivalents to coarse-grained, feldspathic sandstones observed within Eanybeg Water (Locality 96-91, GR18748 38538), 1.5 km south of the pink arkosic sandstone exposure within the same river.

6.4.5.3.5 Lettermore

After a gap of two kilometres to the west of Tullynaglack, an old quarry south of Binbane Mountain (north of Lettermore – c.GR18499 38388) exposes grey coloured, coarse-grained to pebbly generally quartzitic sandstones of the Killin Sandstone Member. These unsorted, immature sandstones dip at a high angle (50^0) to the west; thus, indicating the proximity of a fault. This area is relatively close (several hundred metres) to the NBF. The southern base of Binbane Mountain comprises Dalradian rocks. Alsop (1994, his Fig.4) shows the Carnaween Fault (a splay from the Leannan Fault) striking through this area.

George and Oswald (1957) outlined an east-west boundary (between the equivalents of the Lough Eske Sandstone Formation and the Killin Sandstone Member - both nomenclatures of this study) in the Lettermore area (refer to Figure 2 for this locality). The Lettermore area comprises scattered exposures of south-dipping, non-calcareous sandstones of variable bed thicknesses and grain-sizes. Coarse-grained to pebbly sandstones overlie tabular beds of medium- to fine-grained sandstones. One 40 cm thick tabular sandstone bed displays a fining-up sequence (from pebbly, coarse-grained

sandstone to a medium-grained sandstone). Tabular cross-strata within the pebbly sandstones (towards the top of the crag) indicates a palaeocurrent direction to the southwest.

An exposure south of Lough Namanfin (GR18039 38142) displays steep dipping (50^0 to the SE), generally well sorted sandstone with occasional quartz pebbles. The Northern Boundary Fault (not exposed) separates these sandstones from Dalradian quartzites exposed approximately 40 metres to the northwest (Enclosure 6.1).

6.4.5.4 THICKNESS OF THE KILLIN SANDSTONE MBR

It is generally difficult to estimate the thickness of the Killin Sandstone Member, due to lack of continuous exposure. Although this unit covers an extensive area in the northern part of the Donegal Basin, significant thicknesses have not been noted. It is thought that the unit is at least 40 metres thick. This figure is estimated geometrically at Carraduffy from the basal contact of the Killin Sandstone Member with the Bundoran Shale Formation to the top of Killin Hill.

6.4.5.5 DISCUSSION OF THE KILLIN SANDSTONE MBR

During the Arundian, a large south-flowing river would have eroded a dominantly Dalradian source and deposited the Killin Sandstone Member. The Northern Boundary Fault cuts through this unit (as shown by bedding striking at right-angle to the fault). At variance with George and Oswald's 1957 Geological map (refer to Figure 42), it would seem more appropriate to group all the clastic rocks intermittently exposed from Sallows (the pink arkosic sandstone), to south of Binbane Mountain (and further west towards Lough Namanfin) as part of the Killin Sandstone Member. This is based on the absence of calcareous rocks in this northern area, and the interfingering nature of this unit with the Bundoran Shale Formation displayed further south (at Killin Hill, Tullynaha and Eanymore Water). A lateral facies change (fining southwards) may explain the relatively well sorted and less coarse-grained nature of the sandstones in the Letterfad and Letterbarra areas, compared to the exposures along Killin Hill.

George and Oswald (1957, their Fig.11B) deduced that the 'Killin grits' (Killin Sandstone Member) would probably equate stratigraphically with the Ramp Hole Sandstone Member (of this study). It is inferred that during the Arundian, at least one river prograded much further south onto the present-day coastal area at Ramp Hole, on Doorin Point, possibly at a time of sea level fall. As presented earlier, this southward prograding clastic tongue (unfortunately, not mappable) was at least partially submerged within the sea when it cut into the shales. This relationshipis displayed in the palaeogeographical map in Figure 68b.

6.5 SYN-SEDIMENTARY DEFORMATION SLUMPS IN THE BUNDORAN SHALE FM.

Throughout the Donegal Basin, the calcareous shales of the Bundoran Shale Formation are generally well-bedded. However, in the Craig Shore and Pollahack areas within the Doorin Peninsula (refer to Figure 58 for location) and also at Summer Hill (GR19078 37683) and Mullanbane (c.GR17918 37614), there is evidence of localised chaotic slumping, with irregular folds and faults cutting through the shales. The upper and lower contacts are commonly deformed and the internal bedding may display an angular discordance to the enclosing strata due to rotation. The slumps are relatively small-scale, with the disturbed area confined laterally to tens of metres.

Millar (1990, his Fig.4.19) noted a low-angle reverse fault exhibiting fault drag within the 'Doorin Shales' at Port (GR18048 37669). (The grid reference of 18603765 appears to be erroneous as the value refers to a locality in Mountcharles). Millar (1990) postulated the fault 'to be a local feature since there is no evidence for major thrusting elsewhere in the NW Basin'. The thrust fault exhibits 'sediment slumping indicative of water entrapment (and possible tectonic instability) prior to diagenesis. Normal diagenetic processes could result in this becoming an over-pressured zone hence favouring thrust faulting'. Millar (1990) stated that the slumping (within the shales of the Northwest Carboniferous Basin of Ireland) was probably caused by water entrapment and tectonic instability prior to diagenesis.

Reading (1996) noted that prodeltaic regions are commonly disturbed by soft sediment failure. Coleman (1981) suggested that in the Mississippi, '40 % of the sediment supplied

to the delta is involved in some kind of mass movement after initial deposition'. Reading (1996) outlined three principal reasons for sediment-induced deformation:

i) the very high sedimentation rate on the delta front which does not allow pore fluids to escape during burial, eventually leading to a loss in shear strength,

ii) biodegradation of organic debris producing free methane which weakens the sediments, and,

iii) shocking of accumulated sediment by storm wave action.

The first factor, (a high sedimentation rate resulting in instability) would be considered the most important factor associated with slumping within the Bundoran Shale Formation The areas of slumping (Craig Shore, Summerhill and Mullanbane) are associated with a low content of organic debris. Plant material is rare to absent from these horizons. However, organic matter might be fairly particulate and unrecognisable of degradation. Apart from the Ramp Hole Sandstone Member (which may be influenced by storm wave action and overlies the slumped shales at Craig Shore), the slumped areas are not generally associated with strong wave action. Thus, the second and third reasons outlined by Reading (1996) are not necessarily viable in this case.

6.6 THICKNESS OF THE BUNDORAN SHALE FORMATION

The logged section along the Doorin Peninsula measures circa 186 metres. Within the Donegal Basin, it is estimated that the Bundoran Shale is 200 metres thick at least, if not thicker. This value contrasts with the 61 metres (Oswald 1955) and 90 metres (Avbovbo 1973, Higgs 1984) for the Coolmore and Bundoran localities of the Bundoran Shale Formation further south, respectively. The Bundoran Shale Formation is at its thickest in the Donegal Basin and decreases significantly towards Bundoran.

6.7 AGE OF THE BUNDORAN SHALE FORMATION

Higgs in Higgs and Sevastopulo (1983) reported a microspore assemblage (Sample 81-3663) from the Bundoran Shale Formation at Doorin Point, which includes *Lycospora pusilla*. Higgs noted that 'sample yielded a small number of spores, which were poorly preserved. The assemblage is tentatively assigned to the Pu Biozone (early Viséan)'.

The Bundoran Shale Formation contains the archaediscid foraminifers, which confirms an Arundian age for this formation (Davies *et al.* 1989, Riley 1993, Sevastopulo in Higgs and Sevastopulo 1993). Some uncertainty exists over the presence of *Viseidiscus* foraminifer. Within the Donegal Basin, this foraminiferan has been observed at several locations within the lower part of the Bundoran Shale Formation. *Viseidiscus* implies the earliest Arundian (Sevastopulo, pers. comm. 1999).

6.8 DEPOSITIONAL ENVIRONMENTS OF THE BUNDORAN SHALE FM.

This section on depositional environments is divided into three parts. The first deals with an overall summary on the facies interpretation. The second part discusses the deltaic associations, which are relevant to the Bundoran Shale Formation in the Donegal Basin. The latter part analyses the dimensions of the river system that could have produced the Bundoran Shale Formation.

6.8.1 Interpretation of facies

As discussed in Section 6.2.1, the Bundoran Shale Formation comprises Facies P2 generally unbioturbated calcareous shales, Facies Q calcareous siltstones and Facies K limestones.

As discussed in Section 3.3.14.2, the extensive calcareous, laminated shales of Facies P2 are interpreted to have formed from rapid deposition of suspended material in quiescent prodeltaic to offshore muddy shelf environments. The rapidity commonly lead to instability and slumping of the wet uncompacted material, as noted within several shale exposures within the Donegal Basin. Periods of oxygenated and anoxic conditions are inferred in the presence and absence of fossils, respectively (Byers 1977).

The calcareous siltstones (Facies Q) were probably also deposited out of suspension. However, a more active environment (compared to the shales) is implied for the siltstones, due to their bioturbation. This more aerobic environment was probably influenced by current action. It must also be considered that the siltstones might represent pulsed input of coarser sediment, rather than any change in energy level at the

site of deposition. Restricted gastropod and ostracod faunas (as observed within calcareous siltstones and sandstones in the Garrafada area) are commonly associated with brackish waters and lagoonal settings.

The fossils (brachiopods, crinoids and corals) within the bioturbated, argillaceous limestones of Facies K fossiliferous imply marine conditions as they all require normal marine salinity. Brachiopods corals and crinoids are benthic and sessile, respectively. Cephalopods are nektonic and trilobites were vagile benthos. Thus, all the macrofossils listed above suggest a shallow marine depositional environment. It is not generally possible to present precise depth ranges for the fauna discussed above, as some of the assemblages comprise death assemblages; thus, possibly having been transported a significant distance. The trace fossils listed in Table 6.1 are all generally formed by marine animals, with the exception of *Cruziana*, which has also been reported from non-marine settings. Depositional environments for *Cruziana* include estuaries, bays, lagoons and continental shelves or epeiric slopes. Frey (1975) fixed a shallow sublittoral zone in a moderate to relatively low-energy environment to *Cruziana* crawling traces (characteristic trace fossil of the *Cruziana* ichnofacies). The argillaceous limestones commonly display *Zoophycus* on surfaces. The burrow producer for the trace fossil *Zoophycus* is unknown, although Buckman (1992) suggested the possibility of crustaceans. *Zoophycus* traces are characteristic trace fossils of the *Zoophycus* ichnofacies with the producing animals being mostly deposit feeders (Frey 1975, Frey and Seilacher 1980). This ichnofacies represents a typical benthic environment from circumlittoral to bathyal zones. Sediments may be deficient in oxygen, and may be deposited in areas free of turbidity flows or significant bottom currents. The assemblage of trace fossils in the Bundoran Shale Formation is thus consistent with a considerable range of depths and gives little assistance in interpreting the depositional environment with precision.

Thus, in summary, the presence of large amounts of calcareous, the laminated shales displaying evidence of quiescent marine deposition, the general lack of current and wave rippled surfaces, and the lack of vertically oriented trace fossils would support deposition below the storm wave base for the most part of the Bundoran Shale Formation. Several authors (George and Oswald 1957, Avbovbo 1973, MacDermot *et al.* 1983, Buckman 1992) have proposed a prodeltaic and muddy shelf environment for

this extensive shale sequence, deposited during Arundian times. Buckman (1992) proposed a 'distal, marine environment of deposition for the majority of the Bundoran Shale, although probably more proximal to the palaeocoastline than the Ballyshannon Limestone, or at least receiving a greater terrigenous input'. The Bundoran Shale Formation probably represents the first, distal expression of the sediment represented by the overlying Mullaghmore Sandstone Formation, which was interpreted as being of deltaic origin (Sevastopulo 1981a, Mannifield and Sevastopulo 1998).

The influxes of sandstone within the Bundoran Shale Formation onto the shales comprise several facies. The Facies H (pebbly to coarse-grained calcareous sandstones with fossiliferous debris) which cuts into the shales at Ramp Hole may characterise an incised valley fill. Facies G (parallel laminated, well-sorted sandstones) and H are observed within the Ramp Hole Sandstone Member at Portachurry. As discussed previously, these sediments were probably deposited within a wave-influenced shallow marine shoreface environment. These influxes of clastic material within the Bundoran Shale Formation may represent large storm events or periods of deposition during a relative fall in base level. These influxes of coarse arenaceous material onto a (normally calm) offshore water column would have temporarily ceased deposition of the shaley material of the Bundoran Shale Formation. During a drop in sea level, the coarser material would have been deposited in relatively shallow waters with variable current and tidal activity. The coarse-grained to pebbly, unsorted clastics (possibly Facies A and B) of the Killin Sandstone Member interfingers with the shales. The immature nature, the general lack of calcareous content and the gradual fining southwards of this Killin Sandstone Member would suggest deposition under more fluvial-dominant conditions compared to the former member

6.8.2 Discussions on deltaic associations

Deltaic facies sequences vary in composition and are primarily governed by the nature of the delta, its dominance by rivers, waves or tides or builds into shallow or deep water. The sediment-laden fluvial currents enter the basin at the delta front and interact with basinal processes. At the distributary mouth, river flows expand both laterally and vertically and decelerate; thus, decreasing flow competence and depositing sediment.

Where basinal processes are weak, fluvial processes predominate and deposit coarser sediment as distributary mouth bars and as sub aqueous levees (Reading 1996).

The section below includes a discussion on the associations within a delta sequence and the assignment of various exposures within the Donegal sequence to these associations.

6.8.2.1 Shelf Association

Calcareous, laminated shales of Facies P2 (this study) dominate the shelf association. The association also comprises interbeds of Facies K (argillaceous limestones), and minor amounts of interbedded Facies P2 and Facies Q (thin calcareous siltstone beds). Avbovbo (1973) noted that the basal 17 metres of the Doorin section (from Burn Foot to Ramp Hole) are included within this association, although this study proposes to also include the sections at Rossylongan and Summerhill within this group. Fossils are generally absent within the Donegal sections with the exception of subordinate horn corals and crinoid debris; and rare small brachiopods. Most of the shale beds are thinly laminated and the minor siltstone interbeds (Facies Q) comprise possible rippled laminations. The amount of bioturbation within this facies association is relatively low, (apart from the reworking within minor siltstone Q Facies).

It is interpreted that the facies association discussed above may be associated with open shelf, uniform mud deposits. Avbovbo (1973) noted that a modern analogue might be seen within the Niger Delta (Allen 1970), although the latter shows intensive bioturbation. Reading (1996) proposed a '*supply-dominated regime*' for this association as the regime is characterised by high rates of sediment supply. The offshore sediment transport is achieved mainly by fluvial flood discharge and possibly other processes, including rip currents, ebb-directed tidal currents or storm currents. Supply-dominated sedimentation results in large volumes of mainly fine-grained, river-delta sediment spreading rapidly across the shelf and building up thick, uniform accretionary units.
Examples of modern, supply-dominated shelves include the Bering Sea (Nelson 1982), and German Bight (Aigner and Reineck 1982). Modern marine basins are characterised by a seaward decrease in wave action. The shelf facies association of the Bundoran Shale Formation displays this seaward trend by a general decrease in grain-size from

micaceous siltstones to a fine-grained, shaly facies which predominantly lacks sedimentary structures and rare to absent body and trace fossils.

6.8.2.2 Prodelta Association

Reading (1996) proposed that a prodelta is 'that part of the delta unaffected by wave or tidal processes, though many workers include it within the delta front' (Reading 1996, his Figure 6.15). The prodelta comprises a zone where mud and fine silt are deposited (at an apparently high rate) from suspension to form well-laminated sediments. If bottom waters are anoxic, the lamination is preserved, whereas in aerobic waters, the laminae are disturbed by bioturbation. Although the presence of pyrite and the general absence of marine fossils in some sections within the Bundoran Shale Formation (i.e. east Doorin Peninsula) may indicate anoxic conditions, laminations within the thin siltstone beds are regularly disturbed. This could imply a constant interchange from aerobic to anaerobic conditions within the prodeltaic sequence, or that anaerobic conditions may develop during shallow burial. The main control on fossil diversity may be the amount of sediment in the water column rather than the degree of oxygenation of the bottom. Turbidity in the water column is unlikely to be important so far offshore, but soft, poorly cohesive sediment can cause problems to benthic animals.

This association comprises interbedded Facies P2 (calcareous shales) and Facies Q (calcareous siltstones), minor interbeds of Facies K (limestone) and subordinate to rare Facies G and H (parallel laminated medium-grained sandstones and coarse-grained bioturbated sandstones, respectively).

Within the Bundoran and Coolmore sequences, body fossils are common within the Bundoran Shale Formation, especially of crinoid debris within the latter area. The basal Doorin Peninsula section (from Ramp Hole to Murles Point) is relatively depleted of body fossils, although the younger Doorin Point section comprises more abundant fossiliferous horizons.

The relative increase of calcareous siltstone (Q) and limestone (K) beds within the relatively dominant calcareous shales (Facies P2) imply a greater distance from the sediment-input points. The increase of fossil and trace fossil material would support this

observation. The facies are thus interpreted to have formed within a prodeltaic environment. Avbovbo (1973) outlined a maximum development of 137 metres for this prodeltaic association within the Doorin area (from Ramp Hole to Doorin Point), which is much greater than the 53 metres and 28 metres assigned to the Bundoran and Coolmore sections. Avbovbo (1973) attributed the thickness as result factor of sedimentation rate, rather than compaction. Thus, greater subsidence would have occurred in the Doorin area to accommodate this thickness.

The depth of water during Bundoran Shale times would have varied. This is evident in the variable fauna present within the sequence, although depth would not have been the only control. An ostracod and gastropod fauna dominates some calcareous shale-siltstone exposures (e.g. Garrafada - refer to Figure 2, and Ramp Hole - Section 6.4.3.1.3). These faunas are regularly associated with deposition within the shallower waters of brackish bays and lagoons. The deposition of such a large amount of shales may reflect the cutting-off of the carbonate-rich material, which had formed the Rinn Point Limestone Formation and the Ballyshannon Limestone Formation. The Bundoran Shale Formation may also represent a deepening event, in which the deposition of fine material occurred further offshore, probably within the distal areas of the shelf.

6.8.2.3 Distributary Mouth/Delta Front Association

Avbovbo (1973) outlined that this facies association is confined to the Mullaghmore Sandstone Formation. However, in this study it is proposed that sections within the Ramp Hole Sandstone Member would also be included within this association. This is where the sediment-laden fluvial currents enter the basin and interact with basinal processes.

At the distributary mouth, river flows expand both laterally and vertically and decelerate; thus, decreasing flow competence and depositing sediment. Mouth bars typically produce coarsening-upwards sequences, however, none have been observed in the Doorin area. The effects of waves at the delta front vary according to the grain size and amount of river-borne sediment, the gradient of the delta front, the direction of wave approach and the relative durations and power of normal and storm waves. Deltas affected by a combination of fluvial and wave processes (e.g. Ebro and Rhône) all of

which occur in enclosed seas with moderate wave power and negligible tides, have smooth cuspate or arcuate shorelines. They are cut locally by distributary channel sands, beneath the delta plain (Reading 1996). Facies G (laminated, medium-grained sandstones) and Facies H (coarse-grained, bioturbated sandstones with fossiliferous debris) are represented at Coppers Bank and Ramp Hole within the Ramp Hole Sandstone Member. Trace fossils and commonly intensive bioturbation indicate sediment reworking. Sedimentary structures include wave-rippled lamination, parallel lamination and possible trough cross-strata. The abundance of coarse-grained, unsorted sandstone in association with marine fossils would indicate deposition within a relatively shallow marine environment (shoreface to shelf zone). The fossil *Rhizocorallium* is associated with the *Cruziana* ichnofacies, which would suggest rather shallow depths on offshore shelves.

6.8.3 Dimensions of river systems to prograde and deposit the shale material

Reading (1996) outlined that the nature and volume of (deltaic) sediment is primarily determined by the alluvial catchment area, its size, relief, tectonic, climate, vegetation and the character of the bedrock. These factors govern the amount, grain size and the manner of delivery of the sediment to the shoreline. The majority of clay minerals and silt-grade quartz in the shales is derived from the erosion of contemporary landmasses. These fine, terrigenous, clastic particles are largely transported (by rivers) in suspension by water, with deposition taking place in quiet, low-energy environments. Large catchment areas are associated with greater sediment volumes, generally finer-grained material (coarser material being stored within the alluvial system), more steady water, sediment discharge, and lower coastal-plain gradients. These factors are all relevant to the features observed within the Bundoran Shale Formation.

The extensive nature of the shale sequence within the Bundoran Shale Formation would imply that the distribution system (resulting in the shale deposition) was quite different to the relatively smaller calcareous mud facies observed in older Carboniferous units of south Donegal (for example, within the Shalwy Formation).

The total exposure area of the Bundoran Shale Formation within the Donegal Basin is approximately 80 km^2. A conservative figure for the thickness is 150 metres, although

the true figure would appear to be greater. An estimated cubic volume for the shales is 12, 000,000 m^3. Reading (1996) outlines that the Shoalhaven deltaic system (in southeast Australia) comprises a delta plain of 80 km^2. This delta covers a drainage area of 7.25 X 10^3 km^2. A theoretically similar sized drainage basin might have been operational in the Donegal area during Arundian times. This inferred drainage area would extend farther north beyond the present limit of the Carboniferous Basin and raises the question of the location of the source area and the extent of the fluvial portion of the Doorin area delta.

A significant transport history is required to allow such a large volume of fine-grained material to be deposited offshore. The regional deposition of the Bundoran-Coolmore-Doorin depositional event (within the Northwest Carboniferous Basin of Ireland) must be considered in unity. This prodeltaic sequence is extensive and encompasses a present-day area up to 300 km^2. The decreasing thickness (of the Doorin to Bundoran sections) from north to south, indicates that the deltaic sequence thins southwards from its source north of the present Carboniferous outcrop. A sizeable drainage basin (several hundred km^2 in area) would have existed to the north of the present Donegal area during the Arundian. It is envisaged that a south-flowing river system probably up to 100 km in length, with moderate to low gradients (allowing for greater effectiveness of basinal reworking processes), would have been operational. This distance should be sufficient to produce the size segregation from relatively immature, coarse-grained, fluvial sandstones within the initial hinterland to the deltaic marine shales seen within the Doorin and Bundoran sections.

However, there is no evidence to suggest that the location of the fine-grained material influx occurred within the Doorin area. It may exist to the east or west of this area; thus, not exposed today. The small pebbly river systems that produced the Killin Sandstone Member and the Ramp Hole Sandstone Member are not the appropriate delivery sources to this large amount of sand; thus, a separate drainage basin is inferred. Thus, the location of this 'missing' coarse-grained part of the delivery source (which eventually prograded basinward to deposits the shales of the Bundoran Shale Formation) remains unanswered.

CHAPTER 7 MULLAGHMORE SANDSTONE FORMATION

7.1 INTRODUCTION

The Mullaghmore Sandstone Formation comprises the youngest rocks exposed in the core of the syncline within the main outcrop of the Donegal Basin (refer to Figure 2). A gradational lower contact with the Bundoran Shale Formation is observed at Dromore (GR18527 37593) – refer to Section 6.4.4.5). Avbovbo (1973) noted that 'despite...lithologic variation in the Mountcharles area, the stratigraphic position with rocks exposed in the Mullaghmore -Kildoney area (in County Sligo) justifies its retention within the formation status'. The Mullaghmore Sandstone Formation within Donegal had previously been allocated variable terminology by various authors:

UNIT NAME	AUTHOR	DATE
Mountcharles sandstone	GSI memoirs	1891
Mountcharles Sst./ Calp Sandstone	George & Oswald	1958
Mountcharles Formation	Al-Rawi	1972
Upper Calp Sandstone	Sheridan	1972
Mullaghmore Formation	Avbovbo	1973
Mountcharles section of Calp sandstone	Chandra	1974
Mountcharles Sandstone	Higgs, Buckman	1984, 1992

Table 7.1 The nomenclature used in previous work referring to the Mullaghmore Sandstone Formation in the Mountcharles area of the Donegal Carboniferous Basin.

The Mullaghmore Sandstone Formation may be correlated with other sequences within the Carboniferous Northwest Basin of Ireland, some of which will be referred to later in the chapter (refer to Section 7.9.3 and Table 7.4).

7.2 LITHOFACIES OF THE MULLAGHMORE SANDSTONE FM.

The Mullaghmore Sandstone Formation within the Donegal Basin is generally uniform in overall composition, texture and appearance. Freshly cut surfaces are buff, grey to off-white in colour (Plates 48 and 49), whilst weathered surfaces are brown in colour and are commonly oxidised or leached (Plate 50). The sandstones are generally

medium-grained, well-sorted and relatively well washed. However, some of the feldspars have been altered to sericite and clay particles. Variations of the Mullaghmore Sandstone Formation within the Mountcharles area include pebbly sandstone, coarse-grained sandstones with quartz pebble horizons, and fine-grained, micaceous silty sandstones. The latter tend to coincide with an abundance of plant debris. Three facies have been observed within this formation (R, S and T) at Mountcharles.

Facies R comprises buff coloured, structureless, predominantly pebbly sandstones (refer to upper part of the cliff face in Plate 48 and to upper part of logs in Figure 64). These sandstones are generally non-calcareous, although some calcite cementation, in addition to quartz cementation is present. The beds are commonly tabular and range between 50 cm to one metre thick. Internal stratifications are not very obvious but some parallel laminations may be present. Angular quartz grains are dominant, although feldspars and muscovite are also present. No body or trace fossils have been noted within this facies. During mining and quarrying in the Mountcharles area, this lithology was termed 'Sugar Granite' by the locals.

Facies S (comprising tabular beds of medium to coarse-grained sandstone) is the most common lithology within the Mountcharles area (refer to cross-stratified beds in Plate 48 and to logs in Figures 63 and 64). The sandstones are generally non-calcareous. However, some of the sandstones appear leached so any calcite that might have been present has probably been removed. The overall dip of the sandstones is between 6-10^0 to the south. There are no apparent cyclical patterns within these sandstone beds. Bedding contacts are normally sharp and distinct but not generally erosional. Individual bed thickness varies amongst the quarries. Some areas display relatively thick sandstone beds, commonly 40 to 60 cm and up to 1.6 metres thick. Other localities display sandstones of a much flaggier nature, where bed thickness is commonly several centimetres thick. Lateral facies change is not very evident in this formation, as most units appear to remain horizontally constant within individual exposures up to 20 metres. The Facies S sandstones display subordinate internal structures. However, several localities display examples of parallel laminations, tabular to wedge-bedded cross-stratified sandstones (Plate 48) and trough cross-stratified sandstones (refer to Log 5 in Figure 63 and Log iv in Figure 64). Palaeocurrent information indicates a dominantly northern source, although northerly directed flows have also been noted.

Within the several tens of metres of exposure in the Mountcharles area, no distinctive fluvial channelling has been noted in this study. However, several shallow and thin (commonly 60 cm thick and several metres wide) channels/rills have been observed. Plant material (refer to Plate 53), coalified wood and a possible upright (*in situ*?) rootlet have all been observed within the Facies S sandstones. The latter structure would indicate subaerial exposure. However, marine fossils are also present within these sandstones. Straight-hinged brachiopods, possible bivalves and gastropods were observed on sandstone surfaces in the Drumkeelan Quarry during this study. Horizontal burrows are common and some vertical burrows have also been noted. A well-preserved example of *Chondrites* burrow was located between bedding plane of a well-sorted feldspathic sandstone within the Murray-Drumconnor Quarry (refer to Figure 63). In addition, a possible *Phycodes* trace fossil was observed within well-sorted coarse-grained sandstones at Drumkeelan Quarry.

The interbedded non-calcareous, dark grey to dark brown siltstones and fine-grained sandstones of Facies T are commonly associated with Facies S. This unit is relatively thin-bedded ranging from several millimetre thick silty partings up to 20 cm thick. Siltstones of Facies T commonly drape over Facies S sandstone surfaces and are rich in mica. Plant debris is abundant and varying degrees of bioturbation and burrows may be present. This facies is more common in the basal beds of the Mullaghmore Sandstone Formation at Dromore (GR18527 37593) and Drumbaran (GR18596 38035), although it comprises a large proportion in one quarry to the west of Mountcharles Village (refer to Log 1 in Figure 63 and Section 7.3.2). This facies is also noted Drumkeelan (in Log i in Figure 64).

Scott (1863) noted 'a large number of well known carboniferous mollusca, such as *Orthis crenistria, Euomphalus calyx...* , a portion of a palatal tooth of a species of *Psammodus*, probably *P. porosus'* and 'some fossils which appear to be the remains of fish' from a quarry in Mountcharles. These are most likely located within Facies S sandstones. Scott also displays figures of 'three shells found in great abundance in the quarries under the town of Mountcharles'. The figures comprise '*Cuculloea griffithii* (Salter), probably a variety of *Cuculloea trapezium*; *Aricula dammoniensis*; *Orthis* (*streptorhynchus*) *crenistria'*.

Buckman (1992) recognised four ichnogenera in the Mullaghmore Sandstone Formation in the Mountcharles area. These comprise *Diplocraterion*, *Scolithos* and *Salarituba* and possibly *Aulichnites*. This number is low compared to the rich diversity which Buckman noted in the comparable Kildoney (23 ichnogenera) and Mullaghmore (45 ichnogenera) sections. However, Buckman attributed this as a factor of less fieldwork time being allocated to the Mountcharles area. The author also stated that 'as trace fossils are more common and diverse within thinly bedded sandstone and shales, the Mountcharles Sandstone would be expected to show low trace fossil diversity as it is predominantly exposed in quarries within the thicker masonry freestones'. Buckman (1992) compares the plots of ichnogenera of 'the three Mullaghmore Sandstone Formation outcrops' at Mountcharles, Kildoney and Mullaghmore. Two examples of domichnia and one each of fodinichnia and pascichnia are noted within the Mountcharles outcrop:

DOMICHNIA	**FODICHNIA**	**PASCICHNIA**
Dwelling structures	**Feeding structures**	**Grazing structures**
Skolithos ichnosp.	*Scalarituba* ichnospp.	*Aulichnites*
Diplocraterion		

Table 7.2 Trace fossils observed by Buckman (1992) from the Mullaghmore Sandstone Formation within the Mountcharles area.

7.3 LOCALITY DESCRIPTIONS OF THE MULLAGHMORE SANDSTONE FM.

Table 7.2 comprises a list of excavated sandstone quarries in the Mountcharles area, which have been examined during this study. Figure 63 shows a general map and lithological logs of some of the quarries within the Mountcharles area. The quarries in the Mountcharles area (which were excavated to provide building stones and paving slabs), display quite distinct, although limited sections. Several of the quarries, namely Upper Drumkeelan, McMonagle and Murray are still in use, while trade in other quarries has virtually ceased in the last few years.

LOCAL NAME	LOCALITY
Monaghan Quarry	Lower Drumkeelan
Amalgamated Owners Quarry	Upper Drumkeelan
McMonagle NW Quarry A	Corn Mill (Mountcharles-Killybegs Road)
McMonagle SE Quarry B	Corn Mill (Mountcharles-Killybegs Road)
West M'charles Quarry	West of Mountcharles Village
Unused County Council Quarry	Drumbeagh
Murray Quarry	Drumconnor House

Table 7.3 Localities of several quarries in the Mountcharles area. Refer to Figure 63 for a map of these localities.

7.3.1 Lower Drumkeelan (Monaghan) Quarry

The most prominent of the quarries in the Mountcharles area is owned by the Monaghan family and is situated in Lower Drumkeelan (north of Glencoagh Lough). Fossils from this quarry were described as far back as 1863 by Scott. An underground adit mine, (excavated into the bedrock as a maze of horizontal passages), provided easy access to the large sandstone blocks. These passages and openings were stoped and strengthened to enable work elsewhere in the mine. The 1890's were the most important years for the Monaghan Quarry, as St Eunan's Cathedral in Letterkenny, Co. Donegal and other large buildings were erected, using stones from this quarry (the Monaghan family 1996, pers. comm.). The National Museum and the National Library in Dublin were erected in 1890 and faced with Leinster Granite, while buff coloured Mountcharles sandstone was used on the upper storeys and for dressings around the doors and windows. However, this sandstone from the Mullaghmore Sandstone Formation in Donegal was badly affected by Dublin's polluted atmosphere. Thus, they were replaced in the 1960's by Ardbraccan limestone from Co. Meath. The decay and exfoliation of the sandstone rock at the National Museum was caused by the breakdown of the ferrous cement used to bind the sand grains together. A number of buildings in Donegal dating from as early as 1820, show that the rock has maintained its original facing and has not been affected by the atmosphere. In 1935, 10 miners and 12 cutters were employed at the quarry; however, mining eventually ceased in the late 1930's. Stone was cut and dressed until 1987 (the Monaghan family, 1996 pers. comm.).

The Monaghan Quarry is situated along a 100 metre contour north of Glencoagh Lake (see Figures 63 and 64). The quarry is approached from the road at the northern end. Approximately three metres of disturbed boulder clay and scattered rocks comprise the overburden of the quarry. Several metres of coarse-grained to pebbly, generally unsorted sandstone (Facies R - known locally as 'Sugar Granite') comprises the topmost exposed section within the quarry (Figure 64). The grains in the pebbly sandstone unit comprise quartz, white feldspar and mica. The quartz grains are rounded to angular and vary between 1 mm to 5 mm in size. The feldspars are dominantly sub-angular and range up to 4 mm, whilst the mica sheets range up to 3 mm in diameter. The underlying sandstones at the western end of the quarry are generally thick bedded, with no visible internal structures and silty beds or partings are not apparent. Inside the main gate entrance at the western end, there are large loose boulders of freshly cut buff sandstone. The surfaces of these boulders display brachiopods (Plate 51), bivalves, gastropods (Plate 52) and indeterminate shelly debris, silt-filled burrows, plant fragments and mica-rich horizons. No cross strata is evident in the in-situ exposure (Figure 64, Logs i and ii). Bedding is often irregular, with beds separated by thin silty horizons. The weathered sandstone is brown to grey in colour and the fresh material is a buff colour. Further east of the quarry, the pebbly unit ('Sugar Granite') forms the overhead roof to the horizontal mine (Plate 48 - upper part of cliff section). The well-sorted, buff coloured sandstone beneath the pebbly unit would have been the quarried rock.

Approximately five metres of section are exposed at the wide entrance without a passageway (see Figure 64, Log iii). A metre of the coarse-grained to pebbly unit is underlain by an interbedded unit of fine sandstone, silty sandstone with thin pebbly lenses. Several metres of medium-grained, well-sorted sandstones with a pebbly lag and a thin-bedded finer-grained unit are also exposed. A cliff face (approximately eight metres high) displays tabular cross strata at the western end of the quarry (Plate 48). The 1.6 metre thick unit is generally tabular and contains several low-angled (12^0) foresets. Foreset thickness varies from 20 cm to 40 cm. Plate 48 (with south to the left) shows cross-strata directed to the north. This appears to be opposite the dominant palaeocurrent direction for the sandstones within the Mullaghmore Sandstone Formation, as also observed by Avbovbo (1973). At the eastern end of this opened quarry, a coalified tree root is exposed within the buff sandstone.

The Monaghan family owns a second quarry situated to the northwest of the main quarry at Drumkeelan. It is now a scrappy exposure consisting of thin beds (4-8 cm thick) of medium-grained, flaggy sandstones (Plate 50). Some trough cross bedding may be present, although the exposure is greatly disturbed by weathering and erosion. The top part of the unit is approximately four metres thick and the lower part is three metres thick. This section of rock appears to lie beneath the main quarry. The thickness at Lower Drumkeelan is 5.45 metres in the upper quarry and 7 metres in lower quarry. Therefore, the total exposed thickness within the Monaghan Quarries is 12.45 metres.

7.3.2 Quarry west of Mountcharles – south of main road

The quarry west of Mountcharles Village (GR18623 37763) is the most southerly of all the quarries. It differs from the rest of the quarries in that it is the mostly silty, micaceous and fossil plant rich (dominated by Facies T). This is most likely due to its position within the succession as it is the closest of the quarries to the Bundoran Shale Formation contact at Dromore (refer to Section 7.3.8). The dip of the beds within the quarry is fairly constant at 7^0 to the south. The section is approximately five metres thick and comprises an overall sequence of sub-tabular to sub-lensoid sandstone units (Plate 54) separated by silty micaceous layers. The latter are rich in plant debris. Bed thickness varies from 10 cm to 100 cm. There is no evidence of cross-stratification. A section of a shallow channel/rill is exposed at one locality. The sandstone is generally medium-grained and well sorted.

The McMonagle family owns two quarries in the Corn Mill area of Mountcharles, and are accessed from the Donegal Town-Killybegs road (see Figure 63). The quarry to the north of the road has been labelled 'Quarry A' in this study and the southern quarry is 'Quarry B'.

7.3.3 McMonagle Quarry A

'McMonagle Quarry A' comprises a scrappy exposure with very little *in situ* bedrock displayed. Gravel and sand often obscure the contacts of beds. If faulting has not occurred, these rocks are the highest exposed rocks exposed in the Mountcharles area.

The beds in the 'McMonagle A quarry' dip gently at 7^0 to the southeast. Approximately eight metres of rock was logged (Figure 63, Log 3). Several metres of buff coloured, medium-grained, tabular bedded sandstones (Facies S) at the base are overlain by thin irregular beds of silty sandstone, which in turn are overlain by several more beds of tabular beds of medium-grained sandstone. A metre thick unit of irregular beds of medium-grained sandstone is seen at six metres from the base and contains with 2 cm thin silty horizons. It is overlain by thin, tabular, flaggy beds of sandstone with silty partings, rich in plant fragments (Facies T). Towards the top of the cliff face, there are several more metres of medium-grained, well-sorted flaggy buff sandstone. In the south of the quarry (towards the roadway) there is approximately two metres of sandstone exposed beneath that shown on the log. Therefore, the total thickness of rock exposed at 'McMonagle A' quarry is approximately ten metres. A horizontal trace fossil (*Phycodes*?) and a rootlet were observed among the loose boulders.

7.3.4 'McMonagle Quarry B'

'McMonagle Quarry B' (refer to Figure 63, Log 2) is currently used in supplying masonry blocks. The exposure is quite rubbly which makes the bedding planes difficult to decipher. However, the overall sequence comprises tabular beds of medium-grained, well-sorted sandstone (Facies S) with numerous thin interbedded silty horizons. These silty horizons contain plant fragments, mica sheets and possible rootlets. Individual sandstone bed thickness varies from 30 cm to 100 m. A total of 7.5 metres of rock are exposed. Large loose boulders contain plant debris, vertical and horizontal burrows, and badly preserved, possibly symmetrical ripples.

7.3.5 Abandoned County Council Quarry at Drumbeagh

A four-walled open quarry is exposed at Drumbeagh. It comprises six metre cliffs of generally horizontally bedded (3 cm to 10 cm thick), well-sorted, medium grained buff tabular sandstone (Facies S - refer to Figure 63, Log 4). However, some beds gradually become lensoid over several metres (Plate 49). At this location, there is evidence of a very shallow channel, 45 cm thick and approximately 6m wide from either end where it is 20 cm thick. There is no marked lithologic or grain-size change within the sandstones in the cliff face, apart from several siltstone and micaceous rich horizons between the

beds. The dip is generally horizontal. The cross-strata are not very distinct, but appear to dip to the southwest. Several horizontal burrows are displayed.

7.3.6 Upper Drumkeelan Quarry

Several people in the vicinity own the Upper Drumkeelan quarry (GR18671 37939). It comprises a large northeast/southwest trending quarried ridge, which lies topographically along the 110 and 125 metre contours. The beds dip gently ($3\text{-}6^0$) to the southeast. This quarry appears to overly the quarry owned by the Monaghan family in Lower Drumkeelan. Seven to eight metres of horizontally bedded, buff (now quite oxidised and weathered), well-sorted sandstones (Facies S) extend the length of the ridge. The quarried rocks are removed by open cast method. The Facies S sandstones contain numerous small burrows infilled with silty sediments, drifted plant fragments and subordinate interbeds of coarse-grained to pebbly sandstone. Some surfaces display straight-hinged brachiopods. The log (see Figure 63, Log 5) was taken at the southwestern end of the ridge. The sequence comprises well-sorted fine to medium-grained sandstones at the base, overlain by interbedded grey siltstone and buff medium-grained sandstone. Several tabular cross-stratal beds of medium-grained sandstone are exposed between 1.2 metres and three metres up-section. These beds were inaccessible for accurate measurement; however, the current appears to be from the southwest to the northeast. Several thin silty horizons and brachiopods are observed in a 90 cm thick unit. A 30 cm thin-bedded, well-sorted sandstone also contains northeast directed cross-strata, and is overlain by a grey coloured siltstone unit. Further north of the quarry face, these latter two units become interbedded. Above these units are several thin beds (10-15 cm each) of fine to medium-grained sandstones. Sample 96-93 (GR18671 37939) was taken from the generally fine-grained sandstone bed. Approximately 2.2 metres of several beds of well-sorted, medium to coarse-grained sandstones continue to six metres from the base and are overlain by coarse-grained, tabular sandstones.

7.3.7 Murray Quarry at Drumconnor

The Drumconnor-Murray quarry (see Locality 7 in Figure 63) comprises several cliffs of quite uniform tabular, medium-grained sandstone with several plant-bearing siltstone horizons. A well-preserved *Chondrites* burrow within a loose slab was located at this

quarry. The centre of some of blocks has a grey to light blue colour, which may indicate differential cementation. The cutters at the quarry have remarked that saw-cutting through these blocks is more difficult and time consuming.

7.3.8 Dromore

Several metres of the Mullaghmore Sandstone Formation's basal contact with the underlying Bundoran Shale Formation is observed in a scrappy stream outcrop at Dromore (GR18527 37593) (refer to Figure 59 and Section 6.4.4.5 within the Bundoran Shale Formation for a description on this locality).

7.3.9 St. Peter's Lough

The western shore of St. Peter's Lough near Mountcharles village contains several sandstone exposures. Bedding dip is quite variable to the southeast, south and southwest from 2 to 10^0. A northerly directed, trough cross bedding was observed within thin-bedded, medium-grained sandstones. The cross-stratal set is 15 cm thick, individual foresets vary from 5 mm to 2 cm. The palaeocurrent information for the sandstone exposures along the lough displays evidence of a southerly-directed flow.

7.3.10 Drumbaran

South of Drumbaran school, a stream section (GR18516 38032) exposes horizontally bedded fine-grained, well sorted, calcareous sandstones. Further west, the same stream exposes non-calcareous, interbedded micaceous sandstones, siltstones and shales with abundant plant debris and burrows. Some pebbly lenses are also observed. This latter locality (GR18596 38035) is located close to the lithological boundary between the Bundoran Shale Formation and the Mullaghmore Sandstone Formation.

7.3.11 Mountcharles Village

Mountcharles village contains some exposures of tabular bedded sandstone exposures towards the topographically higher (100 metre contour) western end of the village. The exposures are located along a partly exposed cliff to the rear of the north-facing houses,

roughly opposite the Glencoagh road. To the east of the village and lower down the hill (along the approximately 80 metre topographical contour), disturbed calcareous shales are cut by a dolerite dyke. The shale is from close to the top of the Bundoran Shale Formation. The contact with the sandstone is not exposed in the village. The Bundoran Shale Formation continues to the east from this locality.

7.4 CORRELATION WITHIN THE MOUNTCHARLES AREA

A lack of distinctive marker horizons within the sandstone curtails the correlation of individual quarries in the Mountcharles area. It would appear that the Monaghan Quarry (Lower Drumkeelan) is stratigraphically (and topographically) positioned beneath the Upper Drumkeelan quarry.

The 'McMonagle Quarry A' (at 105 metre contour) probably underlies 'McMonagle Quarry B' (at approximately 105 metre contour), as the dip in the quarries is quite shallow to the southeast and east, respectively. From mapping information, the exposures at St. Peter's Lough may underlie the above latter two quarries, as the sandstone exposure at the Lough is further north and at approximately the same topography (at 112 m contour). Both 'McMonagle Quarry B' and the west of Mountcharles quarry (see Figure 63) may be correlated together as they appear to be along or close to strike. It is also difficult to achieve a strict correlation between the exposures at Drumkeelan and that seen at Drumbeagh (the disused County Council Quarry) and the quarry at Drumconnor House (Murray Quarry). The distinctive coarse-grained to pebbly quartzose sandstone ('Sugar Granite') which is well-exposed at Lower Drumkeelan is absent from exposures in the Drumbeagh area.

It is likely that a northeast/southwest trending fault exists between the Monaghan-Drumkeelan, Murray-Drumconnor quarries and Glencoagh Lough to the northwest and the St Peter's Lough and McMonagle quarries vicinity to the southeast. The trend may be deduced from the pattern in the contours between Glencoagh Lough and St. Peter's Lough. The streams to the southwest of the two lakes are parallel to the above trend. This fault would seem to link up with the Burns Mountain Fault at Lough Eske (Figure 2). The fault is downthrown to the northwest. The exposure pattern of the Mullaghmore Sandstone Formation constitutes two semi-circles (with a smaller semi-circle to the

southeast of the fault-line). George and Oswald (1957) display four faults within the Mountcharles area. The Eglish Fault (of George and Oswald, 1957) extends southwest through Ballybrollaghan and onto the coast at Inver Bar. No high dips are shown in the vicinity of the fault on their map. The authors' extension of the Burns Mountain Fault cuts through Mountcharles Village and extends onto the north of Doorin Point. George and Oswald (1957) named this fault the Mountcharles Fault. This fault appears to cut two smaller faults trending north and northeast respectively. George and Oswald also place the area containing the lithological contact at Dromore between the Mullaghmore Sandstone Formation and the Bundoran Shale Formation as observed in this study, as just the Bundoran Shale Formation.

7.5 THICKNESS OF THE MULLAGHMORE SANDSTONE FM.

None of the quarry exposures within the Mountcharles area achieve a thickness greater than ten metres. The estimated thickness for the Mullaghmore Sandstone Formation from this study is 90 to 120 metres, based on the gentle dip of the strata, the area and topographical contours. Avbovbo (1973) stated that the Mullaghmore Sandstone Formation was 'approximately 115 m thick'. This is at variance with the thickness determination of George and Oswald (1957) of 800 to 1000 feet (244-305 metres). Sheridan (1972) estimated a thickness of 183 metres for the sandstones at Mountcharles.

7.6 PALAEOCURRENT ANALYSIS OF THE MULLAGHMORE SANDSTONE FM.

As discussed above, the sandstones within the Mullaghmore Sandstone Formation are relatively tabular. Cross-stratification, although present in some exposures is not easily measured due to lack of 3D surfaces. This scarcity of data did not allow for accurate palaeocurrent analysis. The scattered data that has been collected shows predominantly southerly to southeasterly directed palaeocurrents within planar and trough cross-stratified sandstones. Less common northerly directed palaeocurrents were also observed. Although the sandstones contain evidence of marine influence, bipolar cross-strata were not observed in this study. This maybe a factor of exposure, although it is also possible that tidal influences were not a dominant factor during deposition of these

sandstones. Palaeocurrent data within the type area at Mullaghmore, Co. Sligo indicates derivation from the north and northwest.

7.7 PROVENANCE OF THE MULLAGHMORE SANDSTONE FM.

The sandstones of the Mullaghmore Sandstone Formation in the Donegal Basin are predominantly feldspathic with plagioclase dominating over K-feldspars and perthite. Oswald (1955) in his discussion on the overall source area for the Mullaghmore Sandstone Formation, deduced that although 'microcline and albite are present in the Donegal granite to the north, the ubiquitous presence of strained quartz in the sandstone points to a metamorphic rocks of the Ox Mountains and of Donegal as the obvious source of the detrital material'. As discussed earlier, the plant material and the mica-rich horizons both indicate the proximity to a landmass.

7.8 AGE OF THE MULLAGHMORE SANDSTONE FM.

Whitaker (1976) reported a spore assemblage from a shale horizon (Sample 3128) in a roadside quarry approximately 2.5 kms west of Mountcharles. It appears to be either from the Corn Mill (McMonagle) Quarry or Drumconnor (Murray) Quarry. Higgs (1984) noted that the composition of the assemblage was diverse and the presence of *Knoxisporites stephanephorus* indicates an assignment to the TS Biozone. Higgs (1988) reported TS biozone assemblages from the Mountcharles, Mullaghmore Head and the Carrrowmoran sections. This places the formation within the late Arundian to Holkerian Stages, according to Riley (1993). Within the southern exposures of this unit (west of Ballycastle and Kilcummin Head, Co. Mayo), a foraminiferal fauna no older than late Arundian have been recovered (Graham 1996).

7.9 DEPOSITIONAL ENVIRONMENT OF THE MULLAGHMORE SANDSTONE FM.

7.9.1 Introduction

'Throughout the Donegal Bay area, there is a significant coarse clastic intercalation into the otherwise marine, carbonate-dominant Dinantian succession that overlies the basal rocks'

(Graham 1996). Thus, in discussing the depositional environment of the Mullaghmore Sandstone Formation at Mountcharles, it is relevant to also consider its correlatives within the Northwest Basin of Ireland. The Mullaghmore Sandstone Formation is recognised within the Sligo Syncline/North Mayo area where the type section is located at Mullaghmore Head (refer to Buckman 1992 and Graham 1996). Additional correlations are made with the Kildoney Sandstone (between Donegal Town and Ballyshannon), the Carrowmoran Sandstone in the Ballina Syncline (Hubbard 1966) and the Clonelly Sandstone in the Omagh Syncline (Simpson 1955).

UNIT NAME	AREA	AUTHOR	DATE
Calp Sandstone	Northwest Ireland	GSI memoirs	1891
		George	1953
Mullaghmore Sandstone Formation	Sligo Syncline/ & North Mayo & Lough Allen Basin	Oswald	1955
		Hubbard and Sheridan	1965
		Avbovbo	1973
		George *et al*.	1976
		Higgs and Sevastopulo	1983
		Higgs	1984
		Buckman	1992
		Philcox *et al*.	1992
		Graham	1996
Carrowmoran Sst	Ballina Syncline	Hubbard	1966
Clonelly Sandstone	Omagh Syncline	Simpson	1955
		George *et al.*	1958
		Brunton and Mason	1979
	Kesh-Omagh Basin	Mitchell and Owens	1990

Table 7.4 Review of previous work on the Mullaghmore Sandstone Formation within the Carboniferous Northwest Basin of Ireland (excluding the Donegal Basin).

7.9.2 The Mountcharles area

As discussed above in the Mountcharles area, the Mullaghmore Sandstone Formation comprises dominantly non-calcareous, well sorted and medium-grained buff coloured sandstones. Plant debris, coalified tree sediments and rootlets are present within the sequence in variable amounts. This would indicate proximity to a terrestrial landmass. However, no significant fluvial channels or trace fossils with fluvial affinities (for example *Taenidium* or *Diplocraterion*) have been observed in the Mountcharles area. This might be due to lack of lateral restriction as the sand enters the sea. The sandstones

are generally tabular with predominantly southerly-directed palaeocurrents. A northerly source, probably within the Dalradian rocks of Donegal is inferred.

The high degree of sorting within the sandstones at Mountcharles is most likely to be associated with a shallow marine environment, where the sandstones are well-washed and winnowed by wave action. There is an overall characteristic lack of internal structures within the Mullaghmore Sandstone Formation in the Mountcharles area. This lack of structures contrasts with the type area at Mullaghmore, where the common occurrence of hummocky cross-stratification/swaley cross-stratification (HCS/SCS) and wave rippled surfaces infer deposition above storm wavebase (Buckman 1992). Overall, the sequence displays a dominance of plane bedding. If this sequence was deposited within a shallow water setting, one would expect hummocky cross-stratification and wave ripples and also the trough cross bedded, erosive based channel facies. The trace fossils that exist within the formation all indicate marine influence. These trace fossils include *Chondrites* and possibly *Phycodes* (observed in this study), plus *Diplocraterion, Skolithos, Scalarituba and possibly Aulichnites* (presented in previous work by Buckman 1992 – from his Table 2.3).

A facies analysis by Avbovbo (1973) of the Bundoran Shale Formation and the Mullaghmore Sandstone Formation revealed twelve lithofacies, comprising variable sandstone and siltstone associations. Only seven of his facies would be relevant to the Mullaghmore Sandstone Formation in Donegal. Several of his facies are grouped together within the Facies S of this study. He placed the entire trace fossil spectrum within the *Glossifungites-Cruziana* ichnofacies of Seilacher (1967). This ichnofacies implies deposition in an area extending from the littoral zone to wave base. The presence of gastropods, brachiopods and bivalves, as noted during this study also attest to a marine setting. Chandra (1974) also analysed the facies of the Mullaghmore Sandstone Formation as part of his work on the ichnology of Viséan sandstones in northwestern Ireland. He outlined the various fossils and trace fossils, although he did not differentiate the individual exposures of the Mullaghmore Sandstone Formation (i.e. Mullaghmore, Kildoney and Mountcharles). Thus, it is not always clear which of these trace fossils are unique to the Mountcharles outcrop, apart from Chandra's 'Facies K' (Pebble Sandstone Facies) containing 'Poorly preserved specimens of *Palaeophycus* and possibly Crustacean burrows', which he assigns to an intertidal marine origin.

Within the Donegal Basin, the Mullaghmore Sandstone Formation overlies an extensive (at least 200 metre thick) prodeltaic sequence of the Bundoran Shale Formation. Although the contact is gradational in the Mountcharles area (from calcareous siltstones and silty limestones to plant rich, micaceous siltstones), it occurs over only a few metres. Assuming similar rates of deposition, this would indicate a rapid change in the depositional environment, reflecting a switch from a mainly calcareous, very fine-grained quiescent period during Bundoran Shale Formation times, to a dominantly well washed, marginal marine (fed by a northerly derived clastic influx) deposition. This will be discussed more below within the overall scheme of the Mullaghmore Sandstone Formation within the Northwest Carboniferous Basin of Ireland in Section 7.9.3.

7.9.3 Regional depositional environment of the Mullaghmore Sandstone Formation

Graham (1996) stated that 'the Mullaghmore Sandstone Formation is thickest and best developed north and west of the Ox Mountains basement block in the Donegal Bay area'. He reviewed the sedimentology of the Mullaghmore Sandstone Formation in the north Mayo area. The basal contacts of the Mullaghmore Sandstone Formation are well-exposed on coastal sections in North Mayo and Sligo. Graham (1996) described the contact west of Bundoran as 'a rapid gradation from highly fossiliferous calcareous shales to calcareous sandstones, locally with granules and small pebbles, displaying evidence of wave action'. The base of the Mullaghmore Sandstone Formation cuts down into the Moyny Limestone (west of Ballycastle) and is highly erosive. The basal erosion surface has over four metres of relief on the western limb of an open syncline. Only minor relief is seen on the eastern limb. Graham (1996) interpreted these basal beds as fluvial on the basis of their coarse-grained nature and the presence of unidirectional cross-strata. He estimated that the sea-level fall might range up to at least eight metres in this area. Unlike the significant downcutting of the correlative Mullaghmore Sandstone Formation into the Moyny Limestone Formation in north Mayo, no erosional surfaces has been observed within the Mullaghmore Sandstone Formation in the Donegal Basin. The Donegal Basin during Mullaghmore Sandstone times was situated in a generally shallow marine environment, compared to the more fluvial dominated correlative sandstones in Mayo and Sligo.

Palaeocurrent data from fluvial sandstones in the Mullaghmore Sandstone Formation at Ballycastle (Co. Mayo), Carrowmoran and Mullaghmore (Co. Sligo) display a dominant southeast-directed vector (refer to Graham 1996, Fig. 21). The Mullaghmore Sandstone Formation in Mayo comprises dominantly coarse-grained sandstones 'fluvial channel deposits'. As noted in Section 7.2, channel geometries are generally absent in the Mountcharles area. Palaeosols and rootlets are often associated with the fluvial channels in Mayo, whereas only one rootlet was observed within the Mountcharles outcrop. The Mayo outcrop also contains evidence of marine influence as bioclastic debris, wave ripples, hummocky cross-strata are also present. Channelling is also observed within the Carrowmoran outlier in Co. Sligo. Sets of Inclined Heterolithic Strata (IHS) observed within the Mullaghmore Sandstone Formation are interpreted by the Graham (1996) as 'former point bar surfaces'.

Graham also noted an increase in the scale of bankfull river width indicated by the channels within the Mullaghmore Sandstone Formation. This is on a scale of hundreds of metres compared to the scale of 'tens of metres indicated for the channels in the basal clastics'. Graham states two hypotheses for this increase in river size, including river capture which 'increased the drainage basin size....during the evolution of a relatively low landscape'. Another factor may be the 'exposure of previously shallow marine areas due to relatively rapid sea-level change'. He stated that 'sedimentation throughout the Mullaghmore Sandstone Formation was in coastal areas, probably in part estuarine'.

Philcox *et al.* (1992) in a review paper of the Lough Allen Basin, discussed the presence of the Mullaghmore Sandstone Formation within several boreholes. The Fig.2 in Philcox *et al.* displays the sandstone as nearly 200 metres thick within exposures on the coast at Sligo, and through to Kilcoo Cross, Big Dog and Slisgarrow. The sandstone unit thins significantly to nearly 90 metres at Macnean-2, and Dowra-1. A correlative silty mudstone at Drumkeeran-1 is only tens of metres thick. (The sandstone is absent from the southern limb of the Ballymote Syncline and the Carrick syncline within the Curlew Mountains Inlier). The authors agree with Sheridan (1972), that the pattern of thickness and grain size changes imply that the sandstone was derived from between the northwest and northeast. The Mullaghmore Sandstone Formation within Slisgarrow-1 yielded a *Knoxisporites triradiatus* - *K. stephanophorous* (TS). Biozone miospore assemblage indicated an Arundian-Holkerian age.

In the Omagh Syncline the equivalent of the Mullaghmore Sandstone Formation is termed the Clonelly Sandstone and comprises about 250 metres of deltaic and tidal-flat sediments (Simpson 1955). Mitchell and Owen (1990) assigned a late Arundian age to the comparable Aughnacloy Sandstone in the Fermanagh-Armagh area and an Arundian age is designated for the corresponding sandstones in the Derrygonnelly-Kesh area.

Hubbard (1966) and Avbovbo (1973) interpreted the Mullaghmore Sandstone Formation as representing a complex of delta sands which prograded from the north and northwest over the prodelta Bundoran Shale Formation. This formation is part of a regressive unit that can be widely traced. Graham (1996) estimated an area of at least 250 by 70 km for this progradational event. He also stated that 'the widespread progradation of clastic sediment in late Arundian, exemplified by the Mullaghmore Sandstone Formation, does suggest a change in sea level which was approximately synchronous throughout Ireland'. This topic will be discussed further in Chapter 10 with regard to the overall basin evolution.

It is inferred that the Mountcharles area during this time was situated within the fluvial in a shallow marine environment and not a deltaic area as such, as no fluviatile deposits were preserved. Relatively high gradient braided rivers, transporting material over short distances, would have deposited their load in a protected, shallow marine region. The sandstones represent progradational, shallow deltaic sands, which are reworked by marine processes at the delta front. This progradational event could be a factor of a lowering in sea level. Tectonic events may also have influenced the regressional sequence.

The delta front records the interplay of fluvial and basinal processes, in particular the effect of waves and tides on the fluvial input. The main characteristic of progradational deltaic sequences is that they shallow and coarsen upwards from offshore muds through silts to various sand-dominated facies.

Within individual deltas, the sequence varies according to the position of the advancing shoreline that it records (Reading 1996). *Fluvial-dominated delta* sequences are best documented in the present-day Mississippi (Coleman 1981). This could represent a

modern analogue to the north Mayo and Sligo outcrops of the Mullaghmore Sandstone Formation, although the grain size is probably finer within the Mississippi analogue.

The Mullaghmore Sandstone Formation in the Mountcharles area seems to lack the variability of a fluvially constructed delta-prodelta. *Fluvial-wave interaction deltas* such as the Rhône and Ebro (Oomkens 1970, Nelson and Maldonado 1990, respectively) might reflect modern analogues of the Mountcharles area. The sequences are similar to those of fluvial-dominated deltas, but differ in the degree of wave reworking and lateral variability towards the top. Another analogue may exist in the Nile Delta, within a wave constructed delta coastline. Nearshore wave power increases with decreasing river discharge, the delta shoreline become more regular and assumes the form of gentle, arcuate protrusions (Davis 1985). Prior to the erection of the Aswan Dam, the annual Nile flood brought large volumes of sand to the delta front, where it was deposited in the Daimetta mouth bar, and in other distributary mouth bars. During the rest of the year, it was resuspended, entrained into the wave driven littoral current, and redeposited on the flanking beaches of the distributary mouths (Sharaf El Din 1977, Swift *et al.* 1991). The flat-bedded sandstones at Mountcharles could well indicate a wave dominated coastline, but there is a general lack of wave ripples. Well-sorted, horizontally bedded sands deposited by nearshore wave processes occur preferentially, compared with fluvial influenced mouth-bar facies (Reading 1996).

The Mountcharles area in Donegal is considerably north of the sections in Sligo (Mullaghmore Head) and North Mayo (Ballycastle area - circa 25 and 80 km, respectively). The Mountcharles sequence would appear to have developed in a fluvial dominated system (with predominantly north to south flows), yet the North Mayo and Sligo sections display some well developed fluvial channels. It is unclear how this can be effectively explained when insufficient outcrop is available between these localities.

CHAPTER 8 BIOSTRATIGRAPHY OF THE DONEGAL BASIN

8.1 INTRODUCTION

This chapter deals with biostratigraphical information assembled from the Donegal Basin. One of the main objectives of this study was to conduct a biostratigraphical analysis of the area. This was in order to clarify the biostratigraphical position of many units whose position was previously in doubt. The results obtained from this study are discussed below, in conjunction with additional information from published work. Based on both biostratigraphical and lithological information, where possible, individual formations and members are assigned an age.

The Carboniferous of Europe is divided into the Dinantian (George *at al.* 1976) and the Silesian (Ramsbottom 1973) subsystems. The Dinantian subsystem is divided into the Tournaisian and the Viséan Series in Western Europe (refer to Figure 65). This division was recognised by the I.U.G.S 1989 Global Stratotype Chart. The term Avonian has been used in pre-1980's literature regarding the Northwest Basin of Ireland and elsewhere in the British Isles. This term was 'proposed by Vaughan (1905, p.264) as synonymous with Lower Carboniferous, its lower limit being at the base of Vaughan's *Cleistopora* (K) Zone...This limit is not equivalent to the base of the Dinantian' (George *et al.* 1976).

The degree to which Lower Carboniferous successions can be divided by biostratigraphical means varies, depending on which fossil groups are used and also the age and facies of the sequences under study (Sevastopulo 1981a). Vaughan (1905) published his own zonal scheme of coral and brachiopod faunas, which became utilized as assemblage biozones and were the basis of subdivisions until it was realised that many of the assemblages were strongly facies controlled. Garwood (1907, 1913) also produced a zonal scheme. However, as his zones 'were defined by faunal marker bands, they could only be used with precision in the limited area where such marker occurred' (George 1969). Biostratigraphical zonation of the Dinantian of Ireland and Britain is based on conodonts, foraminifers, miospores, rugose corals and brachiopods (refer to Riley 1993). Foraminifers, which are of little biostratigraphical use in the Courceyan,

allow better precision from the Chadian onwards, while conodonts give the most reliable zonation during the Courceyan (Sevastopulo 1981a).

The stages of the British Isles Dinantian were based largely on biostratigraphical assemblages, but the stage boundaries were often influenced by important changes in sea level. This scheme, based primarily on Ramsbottom (1973), embodied many of the concepts later used in sequence stratigraphy. Cope *et al.* (1992) held 'serious reservations about the suitability of several of the Dinantian stages, which closely coincide with the mesothemic boundaries of Ramsbottom (1973)'. Cope *et al.* (1992) alluded to the difficulty of defining 'some of the stage boundaries away from their stratotype, since the boundaries are not always drawn at biostratigraphically recognisable points'.

The lower boundary of the late Chadian Stage and the Viséan Series are commonly shown as correlative (refer to Figure 65). However, Conil *et al.* (1991) in a revision of the biostratigraphy of the Belgian Tournaisian-Viséan boundary, concluded that the Belgian Ivorian-Moliniacian Stage boundary and the Tournaisian-Viséan boundary are not isochronous (Conil *et al.* 1989). The latter boundary at the base of the Cf4α2 Subzone is in fact higher than the former. The base of the Moliniacian is correlated on the appearance of the conodonts and foraminifers characteristic of the Cf4α1 Subzone of the *Eoparastaffella* Cf4 Zone (Conil *et al.* 1991). The base of the Viséan coincides with the appearance of the conodont *Gnathodus homopunctatus* and of the foraminifera *Eoparastaffella*, which mark the base of the Cf4α2 Subzone (refer to Riley 1993, Dehantschutter 1995).

The base of the Courceyan stage is defined at the contact between the Old Head Sandstone Formation and the overlying Kinsale Formation in Kinsale, Co. Cork. The Courceyan stage has a wide span, including uppermost Old Red Sandstone and the K, Z, in addition to part of the C1 zones of Vaughan (George *et al.* 1976). The Chadian stage was defined in the Craven basin, at the first lithological change below the entry of the foraminiferan *Eoparastaffella*. However, Riley (1993) noted that subsequent workers failed to repeat this foraminiferal record. It appears that the real entry of *Eoparastaffella* is some 300 metres above the base of the Chadian at the stratotype. Riley (1993) also noted that there is no sequence boundary associated with the stage

boundary, and even local lithostratigraphical correlation cannot be traced. The Courceyan/Chadian stage boundary is therefore, unrecognisable biostratigraphically. The erroneous equation of the bases of the Chadian and the Viséan is still common practice. This is complicated further by the previous use of the conodont *Mestognathus beckmanni* as a basal Viséan marker and confusion of this latter species with slightly stratigraphically earlier appearance of *Mestognathus praebeckmanni* (Dehantschutter 1995).

Riley (1990b, 1993) suggested that the Chadian stage should be abandoned or restratotyped, as a significant part of the stage cannot be distinguished from the late Courceyan. Riley (1993) proposed that the term 'early Chadian' should be used to describe that part of the Chadian, which belongs with the Tournaisian. This is defined as the upper part of the Belgian Ivorian and the Freyrian (Sevastopulo 1997, pers. comm., Riley 1993 and Lees 1997). The 'late Chadian' should be used to convey the part of Chadian recognised by the presence of *Eoparastaffella* and assessory taxa, such as *Gnathodus homopunctatus*, both of which in Belgium first occur at the base of the Viséan. This coincides with the lower part of the Moliniacian Stage, which thus comprises the Lower Viséan and the Arundian. The 'Chadian' stage corresponds to the upper part of the former 'Upper *Caninia* (C2S1) Zone' in the South-Western province, to Hudson's 'upper C_2' of northern England, and in the shelf limestone areas approximately to Major Cycle 3 of Ramsbottom (1973).

Sevastopulo (1997, pers. comm. and in *A Geology of Ireland*: Holland, in press) proposes that the term the 'Lower Viséan' be used in place of the term 'late Chadian'. Thus, the term 'late Chadian' is not used in this study, except when referring to previous publications. This is also in accordance with other recent work on aspects of the Irish Dinantian including Dehantschutter (1995) and Geraghty (1996). The term 'Lower Viséan' is a temporary arrangement and it is hoped that a general consensus can be reached on this matter.

The Arundian stage was defined at Hobbyhorse Bay, Dyfed, South Wales, in a cliff section at the junction between the dolomitised Hobbyhorse Bay Limestone and the overlying Pen-y-holt Limestone. George *et al.* (1976) stated that the base of the Arundian is taken at the first lithological change occurring below the entry of typical

members of the foraminiferal genera Archaediscidae, especially *Permodiscus* (now referred to as *Uralodiscus*) (Sevastopulo 1999, pers. comm.). The lowest 16 metres of the Arundian stratotype lack fauna diagnostic of this stage (Ramsbottom 1981a). Riley (1993) observed that the earliest Arundian is thus indistinguishable biostratigraphically from the late Chadian, an assertion that has been confirmed by Simpson and Kalvoda (1987). Riley (1993) agrees with the proposal by Davies *et al.* (1989) to redefine the base of the Arundian at the first entry of primitive archaediscids, a procedure, which he believes, should be possible without relocating the stratotype. The stage corresponds to the upper part of the former 'Upper Caninia (C2S1) Zone' in the South-Western province, to Hudson's 'upper C2' of northern England. This approach of identifying the Arundian on the basis of the first entry of primitive archaediscids is utilized in this study.

8.2 BIOSTRATIGRAPHICAL SCHEMES

Most of the biozones can be traced in Western Europe and a large number of them throughout the Eurasian province (Conil *et al.* 1991). There is a change in relative utility from one microfossil biozonation scheme to another through the Dinantian. As noted by Jones *et al.* (1988) 'through the Courceyan the conodonts give the most reliable zonation and form the Chadian onwards the foraminiferal and algal biozonation is more useful'. The current status of various biostratigraphical schemes (foraminifers, conodonts and, miospores) are outlined below. Other useful biozonations and markers within the Dinantian include corals, brachiopods, ostracods and algae. However, these were found to be of limited use in this study.

MIOSPORES

Higgs (1984) reported that miospore zonation scheme of Western Europe can be applied in the Carboniferous of Northwest Ireland. The upper part of the Courceyan (Upper Tournaisian) is signified by the CM Biozone, with *Schopfites claviger* and *Auroraspora macra* as the zonal species. The Pu Biozone is relatively long-ranging and extends through the Early Chadian, Late Chadian (this latter part is renamed to Lower Viséan), and the Arundian stages. *Lycospora pusilla* represents the zonal species. The

TS spore Biozone defines the Holkerian and characteristic zonal species include *Knoxisporites triradiatus* and *K. stephanephorus*.

FORAMINIFERS

There is still no currently acceptable biostratigraphical scheme for Dinantian foraminifers in the British Isles. Within the Donegal Basin, the majority of carbonate divisions are assigned to the Lower Viséan (originally 'late Chadian'). This results in difficulty in establishing significant control on the presence or absence of individual families. Most of the foraminiferal groups (including the endothyrids, *Tournayella*, *Septabrunsia* and *Brunsia*) were established by the early Chadian. The base of the Cf42 Zone (= base of the Viséan) is defined by the first appearance of *Eoparastaffella*. The base of the Arundian is defined by the first appearance of the Archaediscidae genera (Riley 1993). The entry of this particularly distinctive and biostratigraphically important group is therefore a useful marker in correlating this boundary within the British Isles. Relatively little is known of foraminifers in mixed carbonate/clastic sequences. Each younger zone is essentially defined by incoming new taxa, which may be excluded by a certain type of facies. It is fortuitous in this study that the Archaediscidae genera is adaptable to arenaceous limestones and shales, as the observations of this assemblage within the Donegal Basin appear to be predominantly within calcareous shales and siltstones.

CONODONTS

Conodonts are present in nearly all Dinantian marine facies, but particular taxa are facies selective, leading to parallel zonation schemes in separate facies and regions (Riley 1993). Many conodont zonations of the Lower Carboniferous exist but none is universally accepted as a standard international zonation. The low yield of conodonts reported in this thesis and the narrow range of age rendered conodont zonation ineffective. The presence of the conodont *Polygnathus bischoffi* within the Donegal Basin gives an upper limit on their age, indicating that they are not younger than earliest Arundian (Sevastopulo, pers comm. 1997). They become extinct further up in the Arundian.

BRACHIOPOD/CORALS

In general, large, immobile benthos including corals and brachiopods are very susceptible to facies controls and are often distributed at discrete horizons, being absent from many of the rocks which lie within their zonal range (Riley 1993).

Delepinea carinata was assumed by George *et al.* (1976, p.39) to be characteristic of the Arundian. However, George *et al.* (1976, p15) reported the presence of *Delepinea carinata* on the top bed of the Blackrock Limestone at Halecombe Quarry, Burrington Combe in England and assigned the bed a 'Chadian' age. Dixon (1972) also reported this brachiopod within the Dargan Limestone in the Curlews-Ox Mountains area in Northwest Ireland. This limestone is also assigned a 'Chadian' age. These observations demonstrate the general difficulty of working with brachiopod faunas in detail.

ALGAE

Little is known of the stratigraphical distribution of calcareous algae, even though they are quite abundant in some Lower Carboniferous rocks. The only apparently biostratigraphically useful calcareous alga in the mid-Dinantian is the probable dasycladacean *Koninckopora*. Until very recently, monolaminar (i.e. with a single layered wall) Koninckopora has been used as a Chadian marker. *Koninckopora* is a green algae, indicative of shallow water environments less than 30 metres. It has never been recorded from strata below the Cf41 subzone (Dehantschutter 1995).

OSTRACODS

Ostracods are not considered to hold any great biostratigraphical importance within the Dinantian. However, ten Have (1982) carried out a detailed study of the ostracod fauna of the Irish Carboniferous, in order to determine their stratigraphical ranges. She did not attempt to set up a 'scheme of biozones' due to a lack of data from the Courceyan, and insufficient stratigraphical control by means of other fossil groups, especially in the Lower Viséan. Instead, she tested the 'English Ostracod Zones' as defined by Robinson (1978) against the Irish occurrences and proposed amendments.

Ostracod faunas from north of the jetty at Ballyederlan (on the eastern coast of St. John's Peninsula) and the Largy area (the western limb of the Shalwy Syncline) are of interest to this study. ten Have (1982) stated that taxonomy was very important when it came to correlation with other fauna. She reported 146 forms within 67 genera. She also reported a close connection between the British Isles faunas and those from mainland Europe, Russia, America and Australia. Therefore, 'despite their benthonic habit, many ostracod genera and species (especially those from platform faunas) managed to establish themselves worldwide'. ten Have (1982) observed a bias towards rocks of late Courceyan and Arundian, which yielded the largest and best faunas. Faunas were not so prolific within the Early Courceyan and Chadian. She assigned this lack of fauna to either an absence of silicified ostracods in limestone sequences or the presence of ostracod hostile facies, and concluded that 'no diagnostic faunas from undoubted Chadian rocks were found in Ireland'. Although the descriptive analysis in ten Have's study is very thorough, the validity of the 'occurrences' in her studies in the Donegal Basin is questioned. She assigned the greater part of the genera observed in Ballyederlan and Largy to the Arundian. This present study does not support this assertion. Based on foraminiferal evidence, both the Ballyederlan and Largy lithologies (as part of the Rinn Point Limestone Formation), are assigned a Lower Viséan age in this study (refer to Section 8.3).

8.3 REVIEW OF BIOSTRATIGRAPHY OF THE DONEGAL BASIN

The following section presents a review of the biostratigraphical information assembled within this study, with reference to relevant previous work. When referring to samples from previous publications, a lower font size is used. Appendix 4 contains a full list of the fauna observed within the thin-sections. The contents of several distinctive thin-sections are selected here in order to discuss their biostratigraphical significance. The results and age determinations are summarised for each formation in ascending order.

8.3.1 EDERGOLE FORMATION

On examination of siltstone samples in the Edergole Formation, Graham and Clayton (1994) noted the following miospores: *Schopfites claviger*, *Anaplanisporites atheticus* and *A. baccatus*. This assemblage, plus the absence of *Lycospora pusilla*, permits the assignment of the assemblage to the *Schopfites claviger-Auroraspora macra* (CM) Biozone. This biozone is latest Courceyan (latest Tournaisian) in age. The Edergole Formation thus comprises the oldest rocks within the Donegal Basin.

AGE: Latest Tournaisian

8.3.2 ROELOUGH CONGLOMERATE FORMATION & OILY RIVER CONGLOMERATE FORMATION

No productive spores were yielded from these units in this study. These fluvial conglomerates, sandstones and mudstones are thought to be no older than Lower Viséan in age.

AGE: Not determined, although most likely to be Lower Viséan

8.3.3 LARGYSILLAGH SANDSTONE FORMATION

No productive spores were yielded from samples in this study. Whittaker (1976) reported a spore assemblage (Sample 3101), from an unspecified level within the 'Bruckless Grits' (which equates with the Largysillagh Sandstone Formation in this study), along the western coast of McSwyne's Bay. The miospore assemblage includes *Lycospora pusilla.* Consequently, the assemblage is assigned to the Pu Biozone.

AGE: Lower Viséan

8.3.4 SHALWY FORMATION, '*SYRINGOPORA* BED' & CALHAME LIMESTONE MEMBER

No productive miospores were yielded from the Shalwy Formation in this study. Whitaker (1976) recorded a sparse assemblage of spores from a level close to the base of the overlying Rinn Point Limestone Formation (Sample 81-3658). The assemblage is indicative of the low Pu Biozone.

The Shalwy Formation comprises several limestone sequences (including the '*Syringopora* Bed' and the Calhame Limestone Member) in the western part of the main Donegal Basin. These limestone units represent the first conodont- and foraminiferal-bearing units; thus, allowing a more refined biostratigraphical determination compared to the underlying non-calcareous rocks.

The foraminiferal assemblages observed in this study for these and other carbonate rich units of the Shalwy Formation are contained within Appendix 4. They strongly correspond to the biota noted by Higgs in Higgs and Sevastopulo (1983) as outlined below.

The author of this thesis had access to the thin-sections examined by Sevastopulo (in Higgs and Sevastopulo 1983). These include Samples 74-1001 to 74-1003. Sevastopulo reported the presence of *Earlandia minor*, *Endothyra* spp., the algae *Girvanella staminea* and kamaenids within Sample 74/1003 of the '*Syringopora* Bed'. The conodont *Polygnathus* sp. was also yielded from this horizon. This conodont does not range higher than early Arundian. Sevastopulo and Higgs (1983) assigned the '*Syringopora* Bed' a Lower Viséan (formerly late Chadian) age.

Samples from the Calhame Limestone Member were also examined - 74-1001 (60 metres above base) and 74-1002. The assemblage included *Diplosphaerina*, *Earlandia* sp., scarcely preserved plurilocular foraminifers, *Girvanella problematica*, and *Koninckopora* with single layered wall and round pores. Several thin-sections from the Calhame Limestone Member (92NW57 and 92NW58), which were processed by John Graham (University of Dublin), were also examined during this study. The sections contain the single-layered algae *Koninckopora*, and are consistent in the absence of *Eoparastaffella*. It is not know whether this absence is facies related or time related.

Sheridan (1972) had assigned the Calhame Limestone Member to a zone equivalent to the Arundian Stage. Sevastopulo (in Higgs and Sevastopulo 1983, Volume 4) stated that there were no elements in the fauna recorded by Sheridan or in those observed by him to suggest an age younger than Chadian. Sevastopulo listed the distinctive *Koninckopora* sp. (which appears characteristic of the Calhame Limestone Member) to be typical 'late Chadian' (now renamed as Lower Viséan).
AGE: Lower Viséan

8.3.5 LOUGH ESKE SANDSTONE FORMATION

Higgs (1984) reported that preserved spores obtained from the 'Basal Sandy Beds' (122 metre depth from surface) in borehole DN 69-17 at Lough Eske comprised an assemblage that included *Schopfites claviger*, *Crassispora trychera* and *Convolutispora*. He stated that rare occurrences of the index species *Lycospora pusilla* indicated a position low in the Pu biozone. The 'Basal Sandy Beds' appear to correlate with the Lough Eske Sandstone Formation in this study. From this information, a lower Viséan age is assigned to the Lough Eske Sandstone Formation.
AGE: Lower Viséan

8.3.6 RINN POINT LIMESTONE FORMATION

As discussed in Section 4.6.3, the foraminiferal fauna within the Rinn Point Limestone Formation include *Earlandia minor*, *E. elegans*, *Endothyra* sp., *Eostaffella*, possibly *Pseudotaxis* sp., *Eoparastaffella*, *Brunsia, Forschia* and *Tetrataxis*. None of the sampled limestones yielded any foraminifers of the Archaediscidae genera.

The conodont assemblage from the Rinn Point Limestone Formation includes well preserved specimens of *Polygnathus bischoffi* (Pa element) and *Mestognathus beckmanni*. The presence of the conodont *Polygnathus bischoffi* within the Ballyederlan section gives an upper limit on the age of the Rinn Point Limestone Formation. This would indicate that the formation would not be younger than earliest Arundian (George Sevastopulo 1997, pers. comm.).
The Rinn Point Limestone Formation also contains moravamminids, *Koninckopora* and *Girvanella*. A distinctively large brachiopod called *Delepinea carinata* is observed

within the Rinn Point Limestone Formation, on surfaces at Kiln Port and Ballysaggart along St. John's Peninsula. This brachiopod was previously associated with an Arundian fauna (George *et al.* 1976). However, it has now been established (from the foraminiferal information in this study) that the presence of the brachiopod *Delepinea* within the Rinn Point Limestone Formation does not necessarily indicate that the sequence is Arundian. Refer to Section 4.6 for a discussion on the biostrome located within the Shalwy Syncline. In summary, this study replaces the observation of the tabulate coral *Lithostrotion* (as reported by Hubbard and Pocock 1972) with *Solenodendron hibernicum*. John Nudds (1997, pers. comm.) believes that the range of *Solenodendron hibernicum* should be lowered to the Lower Viséan to include this specimen (TCD No.49158) from the Shalwy Syncline. This contention is strengthened by the complete absence of archaediscid foraminifers from the Rinn Point Limestone Formation.

Thus, there is no evidence from this study to suggest that the Rinn Point Limestone Formation is Arundian in age, as had been previously reported by George *et al.* (1976, p58) and Sevastopulo (1981, p158). Sheridan (1972, p45) reported a 'Chadian age' (FZ 3 or possibly F4) for microfauna from the base Formation at Kiln Port. On the basis of the information presented above, the Rinn Point Limestone Formation is assigned to the Lower Viséan.

AGE: Lower Viséan

8.3.7 CLADY LIMESTONE MEMBER

Samples 74-1010 and 74-1011 from the Clady Limestone Member were discussed by Sevastopulo (in Higgs and Sevastopulo 1983). The microbiota in Sample 74-1010 (from the top limestone pavement of the Clady River) contained *Earlandia* and indeterminate endothyrids. Sample 74-1011 came from the top pavement in the river. Sevastopulo (in Sevastopulo and Higgs 1983) noted that this rich but poorly preserved fauna included *Diplosphaerina*, *Earlandia*, *Pseudoammodiscus*, *Brunsia* sf. *pseudopulchra*, *Eoparastaffella simplex*, *Endothyra* spp., *Scalebrina* spp. including an encrusting form, ? *Koninckopora* (with a single layered wall), *Rectangulina*, and kamenids. Sevastopulo stated that the assemblage was 'almost certainly of late Chadian age (renamed to Lower

Viséan in this study), rather than Arundian or Holkerian as suggested by Sheridan's zonal assignments'.

Analysis of thin-sections made from the Clady Limestone Member within this study produced a similar faunal assemblage (refer to samples TCD No. 50560 - Locality 294; TCD No. 50561 - Locality 297; TCD No. 50567 - Locality 303; and possibly TCD No. 50563 - Locality 299 in Appendix 4). Conodont extraction from Sample L297 in this study yielded well-preserved samples of *Gnathodus homopunctatus*, *Mestognathus beckmanni* (both juvenile and adult stages), and possibly *Apatognathus*. On the evidence presented above, the Clady Limestone Member is assigned a lower Viséan age.

AGE: Lower Viséan

8.3.8 DONEGAL LIMESTONE MEMBER

Sevastopulo in (Higgs and Sevastopulo 1983) reported that Sample 74-1012 (from east-north-east of Donegal Town) a microbiota of *Calcisphaera*, *Diplosphaerina*, *Earlandia elegans*, *Earlandia* sp., *Eoparastaffella* sp., *Endothyra* spp. and kamenids. A Chadian to Arundian age was suggested for this sample. Samples 74/1015 to 74/1018 (from south of Lough Eske area) did not yield any foraminifera or conodonts; thus, probably represent a restricted environment. This study yielded the following foraminifers from most of the samples in the Donegal Limestone Member: *Brunsia*, *Earlandia*, *Endothyra* and *Forschia*. The thin-section TCD No.50552 (Locality 265) contained a comparatively rich microbiota including *Earlandia*, *Endothyra*, *Brunsia*, *Dainella*, *Eostaffella*, *Forschia* and possibly *Glomospiranella, Palaeospiroplectammina, Mediocris* and *Pseudotaxis*. The Donegal Limestone Member also comprises *Koninckopor*a, *Girvanella* and moravamminids, in addition to the normal marine biodebris. Many of these samples are very argillaceous, hence foraminiferal presence is relatively low, especially in thin-section TCD No. 50707 (Locality 96-80) and TCD No. 50708 (Locality 96-81). The only possibility of an Arundian age is at Rossylongan, where archaediscids have been found in rocks lithologically assigned to the Donegal Limestone Member.

Higgs and Sevastopulo (1983), Philcox (1983) and Higgs (1984) state that the Penarroya boreholes (refer to Section 5.2.3) comprised two units: the 'Lower

Argillaceous Unit' and the younger 'Ballyshannon Limestone Unit'. Three biozones are present within the 'Ballyshannon Limestone Unit'. Zone 1 is Chadian in age due to the absence of Archaediscid foraminifers. Zones 2 and 3 are Arundian in age, as Archaediscid foraminifers are present. The 'Lower Shale Unit' is also present towards the top of Borehole DN 69-17, located several hundred metres south of Lough Eske (Philcox, 1982). This 'Lower Shale Unit' (from 73 metres to 15.6 metre depth) would therefore equate with the Donegal Limestone Member, which crops out in this vicinity. The thin-section TCD No. 50552 - Locality L265 (from the Donegal Limestone Member in this study), is the closest sampling locality to borehole DN 69-17, and has yielded a typical Lower Viséan fauna.

According to Higgs and Sevastopulo (1983, p4), 'the base of Zone 2 appears to occur progressively closer to the bottom of the Ballyshannon Limestone Formation from south to north'. However, no archaediscids have been recorded in this study, in the Lough Eske to Donegal Town area. Therefore, the latter area is assigned a Lower Viséan age, even though the sequences further south towards Ballyshannon are Arundian in age.

Sheridan (1972) recorded a microbiota of *Septatournayella*, *Septabrunsia krainica* and *Tournayella* at Aghlem Bridge (5 kms southeast of Lough Eske) and assigned a Tournaisian age to the sample. Sevastopulo in Higgs and Sevastopulo (1983) believed that Sheridan's fauna is not diagnostically Tournaisian and assigned a Chadian age to the sequence.
AGE: Lower Viséan to possibly lowest Arundian

8.3.9 ST JOHN'S POINT SANDY LIMESTONE FORMATION

The St. John's Point Sandy Limestone Formation yielded a microbiota similar to that of the Rinn Point Limestone Formation, including brachiopods, bivalves, echinoderms, calcispheres and bryozoans. Sample L209 yielded *Mestognathus beckmanni* and *Apatognathus*. These conodonts are not very significant in biostratigraphical assessment, except that they are commonly noted in Lower Viséan assemblages. The foraminiferal assemblage comprises predominantly *Earlandia*, *Endothyra, Brunsia, Dainella*, *Eostaffella, Eoparastaffella* and *Tetrataxis conica*. Subordinate *Palaeospiroplectammina* and *Glomospiranella* have also been noted. No archaediscid

fauna has been recognised within the St. John's Point Sandy Limestone Formation. Thus, in the absence of any conclusive data, the formation is assigned a Lower Viséan age.

AGE: Lower Viséan (to possibly lowest Arundian ?)

8.3.10 MUCKROS SANDSTONE FORMATION

As discussed earlier, Sevastopulo in George *et al.* (1976) recorded the presence of *Permodiscus* within the Muckros Sandstone Formation. This foraminiferan would indicate an Arundian age. The presence of this foraminifer within the Muckros Sandstone Formation has not been noted in the sections sampled in this study. It is difficult to assign an Arundian age to the Muckros Sandstone Formation on the basis of this one foraminifer. As with the St. John's Point Limestone Formation, the Muckros Sandstone Formation is assigned a Lower Viséan age, with a position most likely close to the base of the Arundian boundary.

AGE: Lower Viséan (to possibly lowest Arundian ?)

8.3.11 BANAGHER SANDSTONE FORMATION

In the absence of miospore data, the Banagher Sandstone Formation cannot be dated accurately. The age can only be constrained by the fact that it is younger than the underlying of Clady Limestone Member (which is assigned a lower Viséan age), and is older than the overlying Arundian age Bundoran Shale Formation.

AGE: Lower Viséan (to possibly lowest Arundian ?)

8.3.12 BUNDORAN SHALE FORMATION

Higgs and Sevastopulo (1983, p.48 & 83) reported a microspore assemblage (Sample 81-3664) from the Bundoran Shale Formation at Doorin Point, which included *Lycospora pusilla* and *Convolutispora*. The authors noted that 'sample yielded a small number of spores, which were poorly preserved. The assemblage is tentatively assigned to the Pu Biozone (early Viséan)'.

In this study of the Donegal Basin, the initial observations of the archaediscid fauna appear within the Bundoran Shale Formation. This fauna (which includes

Archaediscidae, *Glomodiscus* and *Uralodiscus*) has been observed within the majority of sampled localities of the Bundoran Shale Formation (TCD Nos.50512, 50524, 50527, 50528, 50535, 50536, 50540, equivalent to Localities 187, L215, L218, 223, L237, L238, and L246, respectively). Archaediscids have not been observed from samples along Doorin Point. This latter area is situated towards the core of the syncline; thus, overlies other rocks of the Bundoran Shale Formation that have been dated as Arundian.

Viseidiscus is normally located within the basal several metres of the Arundian. It was difficult to identify within this study, as sections of these foraminifera are similar in appearance to *Brunsia* and may have been misidentified. The presence of *Uralodiscus* and *Archaediscus* foraminifers within the Bundoran Shale Formation would certainly verify that the sequence is Arundian in age.
AGE: Arundian

8.3.13 MULLAGHMORE SANDSTONE FORMATION

Higgs and Sevastopulo (1983, p.50) reported that Whitaker (1976) identified a diverse microspore assemblage in Sample 3128, from a roadside quarry, 2.5 km WNW of Mountcharles (GR 848783). The assemblage (which includes *Lycospora pusilla* and *Knoxisporites stephanephorus*) is assigned to the Pu Biozone. A position in the upper part of the biozone is indicated by the presence of *Knoxisporites stephanephorus*. The Pu Biozone ranges from the late Courceyan to the Holkerian. The Mullaghmore Sandstone Formation overlies the Bundoran Shale Formation (which is Arundian in age). Thus, the Mullaghmore Sandstone Formation is probably Arundian, but could range up into the Holkerian.
AGE: Arundian to possibly Holkerian

CONCLUSION

A more refined biostratigraphical analysis of the Dinantian rocks in the Donegal Basin has been achieved. However, it must be stressed that the working data set is rather limited as the majority of rocks within the Donegal Basin are assigned to the Lower Viséan. In summary, the Donegal Basin comprises an age range from latest Tournaisian to Arundian (and possibly Holkerian). The Edergole Formation is late Tournaisian in age (Graham and Clayton 1994). The Bundoran Shale Formation is Arundian in age (on the basis of *Archaediscidae* foraminifers) and the overlying Mullaghmore Sandstone Formation is probably Arundian but could be as young as Holkerian.

8.4 CORRELATION WITHIN THE DONEGAL BASIN

Figure 66 displays the correlation of the formations and members within the Donegal Basin. This correlation has been achieved from lithostratigraphical and biostratigraphical data, and the identification of key surfaces compiled from this study. The base of the Arundian stage has been chosen as the datum plane. The basis of this correlation within a sequence stratigraphic framework is discussed briefly in Section 10.4.

The correlation attempted in this study encompasses five areas in the Donegal Basin and are displayed within the following columns in Figure 66 :

Column 1	The Shalwy area
Column 2	West Donegal (St John's Peninsula area)
Column 3	West Donegal (East Dunkineely area)
Column 4	Central Donegal (Inver-Mountcharles area)
Column 5	East Donegal (Lough Eske -Donegal Town area)

The Shalwy area (comprising the outliers of the Shalwy syncline, Roelough and Muckros Head) is isolated from the main Donegal outcrop. However, as discussed within Chapter 4, there is a strong similarity between the lithologies of the Shalwy area and those of the western limb of the main Donegal outcrop. The lithologies of the western (Columns 2 and 3) and eastern limbs (Column 5) of the main Donegal outcrop are difficult to correlate in detail. However, they are both overlain by the younger Bundoran Shale Formation and the Mullaghmore Sandstone Formation and thus, in a general way, are lateral correlatives. It is obvious from this lateral facies change that the environment of deposition varied from west to southeast within the Donegal Basin. The western and northern areas of the Donegal Basin comprise a clastic-dominated sequence, in comparison to the areas of dominantly carbonate sequences of the eastern and southeastern areas (from Lough Eske to Ballyshannon).

- EDERGOLE FORMATION

The Edergole Formation comprises an isolated, fault controlled, late Tournaisian clastic sequence (within east Donegal), which cannot be recognised elsewhere in the Donegal Basin.

- ROELOUGH CONGLOMERATE FORMATION
- OILY RIVER CONGLOMERATE FORMATION,
- CONGLOMERATES OF THE LOUGH ESKE SANDSTONE FORMATION

It is implied that the fluvial Roelough Conglomerate Formation and the Oily River Conglomerate Formation are comparable in age. The basal conglomerates of the Lough Eske Sandstone Formation (which unconformably overlie the conglomerates of Edergole Formation in eastern Donegal) may also be linked in with the two former formations mentioned above on the basis of its fluvial nature and overlying stratigraphy.

- LARGYSILLAGH SANDSTONE FORMATION,
- NON-CALCAREOUS SANDSTONES OF THE LOUGH ESKE SANDSTONE FORMATION

The Largysillagh Sandstone Formation of the Shalwy Syncline can also be recognised along the Bruckless coast. The gradational and conformable boundary between the non-marine Largysillagh Sandstone Formation and the overlying transitional marine Shalwy Formation is well-exposed at both Shalwy Point and at Castle Port. However, it is more difficult to delineate the boundary with the Shalwy Formation further inland from Bruckless, due to insufficient exposure. The non-calcareous sandstones within the Lough Eske Sandstone Formation (gradationally overlying the conglomerates and not containing any bipolar cross-strata) in east Donegal, may be correlated with the Largysillagh Sandstone Formation.

- SHALWY FORMATION,
- '*SYRINGOPORA* BED',
- CALHAME LIMESTONE MEMBER,
- CALCAREOUS SANDSTONES OF THE LOUGH ESKE SANDSTONE FORMATION

The Shalwy Formation (of the Shalwy area) can also be recognised within the McSwyne's Bay area, namely at Castle Port. However, several variations exist within both outcrops, namely the lack of Inclined Heterolithic Strata and extensive fusain beds within the Castle Port sequence. The '*Syringopora* Bed' (located towards the base of the Shalwy Formation at Castle Port) is not recognised at Shalwy. It is thought that the '*Syringopora* Bed' may be linked with the Calhame Limestone Member (located north of Dunkineely). Alternatively, the latter may represent a separate marine transgression within the area. The bipolar cross-stratified, calcareous sandstones exposed to the west of Lough Eske (gradationally overlying the non-calcareous sandstones and conglomerates) are included within the undifferentiated Lough Eske Sandstone Formation. These calcareous sandstones appear to be analogous sandstones of the Shalwy Formation and signify the first indication of a northward trending marine influence within the Lough Eske area.

- RINN POINT LIMESTONE FORMATION,
- DONEGAL LIMESTONE MEMBER,
- CLADY LIMESTONE MEMBER

The normal marine carbonates of the Rinn Point Limestone Formation (displaying a gradational boundary with the Shalwy Formation) are recognised within the Shalwy syncline and along St. John's Peninsula. The lithologies within both areas are comparable, although the Rinn Point Limestone Formation within the St. John's Peninsula area is thicker than in the latter area. The Rinn Point Limestone Formation may also extend as thin lenses northwards from the Dunkineely area, eventually pinching out further north.

The Rinn Point Limestone Formation may correlate with the Donegal Limestone Member in the Lough Eske to Donegal Town area. No archaediscid foraminifers have been recognised within the former rocks. Archaediscid foraminifers were noted within the Donegal Limestone Member at one location only (Rossylongan) – towards the top of the stratigraphical boundary with the Bundoran Shale Formation. Boreholes further south from the Donegal area (Boreholes DN-69-2 and DN-69-16, refer to Philcox 1982), have yielded archaediscid foraminifers within the Ballyshannon Limestone Formation. The lack of archaediscids further north in the Lough Eske area might imply that the Donegal Limestone Member is older towards the north in Lough Eske area and youngs southwards towards Ballyshannon.

The Clady Limestone Member in eastern Donegal is a generally clean, well washed, crinoidal limestone, unlike the more argillaceous and arenaceous limestones of the Donegal Limestone Member. The Clady Limestone Member cannot be traced any further south than the Lough Eske area.

- ST. JOHN'S POINT SANDY LIMESTONE FORMATION
- MUCKROS SANDSTONE FORMATION

The high-energy clastics and carbonates of the Muckros Sandstone Formation conformably overlies the Rinn Point Limestone Formation within the core of the Shalwy Syncline. The boundary is relatively sharp, indicating a shoaling event as clastics are introduced into the system. *Permodiscus* foraminifers (from the Archaediscidae genera were reported from the Muckros Sandstone Formation by George *et al.* (1976). If confirmed, this would imply that the formation is Arundian in age.

The high-energy carbonates of the St. John's Point Sandy Limestone Formation overlies the Rinn Point Limestone Formation along St. John's Peninsula, although the contacts are always faulted. The St. John's Point Sandy Limestone Formation did not yielded any archaediscid foraminifers or Lithostrotionid coral fauna. Both formations (the St. John's Point Sandy Limestone Formation and the Muckros Sandstone

Formation) overlie the Rinn Point Limestone Formation (at Shalwy and St. John's Peninsula, respectively). It would appear that they are coeval, with the former assigned a more distal shelf association compared to the latter's clastic-rich, more proximal position.

- BANAGHER SANDSTONE FORMATION

The Banagher Sandstone formation is only recognised in the east Donegal area, where it overlies the Clady Limestone Member with a relatively sharp (over several metres) contact. A significant alteration in the depositional regime from a predominantly marine to an apparently non-marine sequence is envisaged. A lowering of sea level by several metres would probably be enough to allow a change in sedimentation (refer to Figure 69 for an overall view on sea level estimation for the Donegal Basin during the Dinantian). The fact that the formation is not laterally extensive within the basin would suggest that localised tectonism may have been the cause. However, there exists the possibility of a link between the Banagher Sandstone Formation and the St. John's Point Sandy Limestone Formation and the Muckros Sandstone Formation towards the west. All three clastic units overlie a carbonate sequence comprising a normal open-marine fauna. This may indicate a more widespread regression and lowering of sea level, which was eventually inundated, with the deltaic muds of the Bundoran Shale Formation. This would imply either that the tectonic causes operated on a wider scale or that this change is controlled by eustatic sea level fall.

- BUNDORAN SHALE FORMATION

The Bundoran Shale Formation is not exposed within the Shalwy Syncline. It overlies the Rinn Point Limestone Formation in west Donegal, and the Donegal Limestone Member and the Banagher Sandstone Formation in east Donegal. The contact with the clastics of the Banagher Sandstone Formation is sharp, implying a flooding event. The basal sections of the Bundoran Shale Formation in the Donegal Basin correspond to the first appearance of the foraminiferal archaediscid fauna. The Bundoran Shale Formation contains two clastic members. The Killin Sandstone Member is exposed at Killin Hill,

where it is seen interbedded with the Bundoran Shale Formation. The Ramp Hole Sandstone Member is exposed (as an approximately ten metres thick channel fill) within the Bundoran Shale Formation in the Doorin Peninsula. These sand-bodies are most likely to be interfingers of clastic material prograding southwards onto the deltaic shales. It is unclear how the large volume of mud within the Bundoran Shale Formation was sourced, as the sandstone part of the system has not been identified. It is clear, however, that the Killin-type feeders (of the Killin Sandstone Member) could not have provided this influx.

- MULLAGHMORE SANDSTONE FORMATION

The Mullaghmore Sandstone Formation is the youngest formation within the Donegal Basin. It is situated towards the core of the Donegal syncline (Mountcharles area), where it conformably overlies the Bundoran Shale Formation. Although the basal part of the Mullaghmore Sandstone Formation within the Donegal Basin displays a sharp contact with the Bundoran Shale Formation, erosive basal contacts are not observed. It is envisaged that the Mullaghmore Sandstone Formation in Donegal represents a fluvially influenced, shallow marine environment. Thus, within Donegal it represents a conformable correlative to the Type 1 sequence boundary, recognised at the base of the Mullaghmore Sandstone Formation in the Mayo area.

CHAPTER 9 STRUCTURE OF THE DONEGAL BASIN

9.1 INTRODUCTION

The Northwest Carboniferous Basin of Ireland (Figure 3) (herein referred to as NW Basin) is bounded to the north, west and east by unconformities and faults separating the Carboniferous sediments from older rocks that generally form higher ground. The boundaries of the NW Basin are not clearly defined, as the Carboniferous continues far to the south and merges with the Carboniferous basins of the central plain of Ireland.

Price and Max (1988) define the southern margin of the NW Basin to be the northern margin of the Curlew Mountains (i.e. Curlew Mountain Fault – refer to Figure 4). The surface faults in the Carboniferous are directly related to regional faults on older subjacent basement. The regional NE/SW trending faults have controlled the tectonics of the NW Basin since the late Precambrian, comprising long, often anatomising through-going structures. Dips within the basins rarely exceed 20^0 except in the fault zones (Millar 1990). Price and Max (1988) outlined that 'major structures within the North-west Carboniferous Basin, as seen on seismic profiles, are characterised by basement involvement with faults penetrating cover and are either a direct result of fault motion or are spatially confined by faulting'. These authors related basement terminology to crystalline rocks underlying all sedimentary rocks, regardless of the age of either. Depth to basement on the northwest side of the NW Basin (i.e. adjacent to the Donegal Carboniferous Basin) is relatively shallow (1200 to 1800 metres thickness). This contrasts with the central portion of the NW Basin at about 4,500 metres and possibly deeper, implying that the Carboniferous sediments on the northwestern side of the basin thicken radically as they pass southeastwards towards the main portion of the basin.

The Caledonian history of terrane assembly within the present basement beneath and adjacent to the NW Basin was most important for configuring basement blocks and major structural alignments. Dalradian and older rocks were deformed (folded, cleaved and metamorphosed up to greenschist facies) during the latest Silurian and possibly early Devonian. The dominant trend of both axes and faults established during this time is NE/SW (Price and Max 1988). Pitcher and Berger (1972) predicted that the Leannan Fault in Donegal had up to 40 km of sinistral displacement during Caledonian time.

During this deformation, a major set of NW/SW fault blocks (probably reflecting the position of older fault blocks) developed.

The major period of deformation, which affected the Carboniferous rocks of the NW Basin is usually ascribed to the Variscan age (latest Carboniferous – early Permian), although, in the absence of younger rocks, it is difficult to prove this.

The dominant structural element during the Carboniferous sedimentation was the movement of horst-and-graben fault blocks. Vertical and horizontal movement occurred along reactivated Caledonian faults and new faults along secondary Caledonian trends may also have developed. Broad synclinal structures were developed along these NW/SW trending fault controls, and transverse (NW/SE) fault blocks and gentle folds were also developed. The NW Basin can be divided into discrete structurally controlled regions (Price and Max 1988).

The Donegal Carboniferous Basin is one of these structurally controlled basins, comprising a broad downwarp with a southwest plunging axis, which passes close to Donegal Town. Bell and Max (1983) and Price and Max (1988) delineated their 'Donegal Basin' as extending southwards from southern Donegal to offshore in the Donegal Bay and onlapping on-land west of the Ox Mountains. Millar (1990) referred to this area as the Donegal/Sligo Zone. The terms the Donegal Basin as utilized in this study, refers to the Carboniferous sediments within the southern Donegal area only.

The synclinal Donegal Carboniferous Basin is flanked to the NW by the line of the pre-Carboniferous Leannan Fault Zone (Figure 4). The Northern Boundary Fault (NBF - with a downthrow to the south in excess of 200 metres) delineates the northern margin of the basin. The eastern margin comprises an unconformable contact, and is also cut by several NE/SW trending faults. Towards the centre of the structure, dips are generally less than 10^0 but near the margin, steeper dips (up to 30^0) are observed. Near the Northern Boundary Fault, dips of 50^0 have been noted within the Killin Sandstone Member (refer to Figure 2). A major set of NE/SW trending faults cross the Donegal Basin. Most have a downthrow into the basin regardless of their location in the basin (i.e. downthrowing to the N-NW in the southeastern part of the basin and downthrowing to the S-SE in the northwestern part).

9.2 MAJOR FAULTS WITHIN THE DONEGAL BASIN

9.2.1 Northern Boundary Fault

The Barnesmore Granite is traversed by a prominent fracture that results in the deep valley of Barnes River and Barnes Lough. The fracture trends ENE/WSW and displaces the margins of the granite in a dextral sense (Leedal and Walker 1954). Traced westwards, the Barnes Lough Fault appears to splay. A NE/SW fracture extends through Lough Eske (to form the Burn's Mountain Fault- refer to Figure 2) and another splay swings WNW to become the Northern Boundary Fault (NBF). This latter fault delimits the northern margin of the Carboniferous Donegal Basin and cuts through the Belshade/Eglish Fault. The NBF reflects a downthrow of at least 200 metres to the south. In the western part of the Donegal Basin (e.g. at Croagh Lough) the NBF appears to curve into the basin and through the western margin in a series of splays. This fault is not exposed, but on the northeastern side of the lake, steeply dipping (to the SE) clast-supported conglomerates are exposed within tens of metres from highly fractured schists. This trend can be followed northeastwards towards Lough Namanfin.

Leedal and Walker (1954) maintain that the 'Lough Belshade Fault' (extending southwestwards as the Eglish Fault of this study) and the 'Barnes Lough Fault' (Northern Boundary Fault of this study) could not have been produced by the same stress conditions. They suggested that the latter fracture is much later, questionably late- or post-Carboniferous or Tertiary.

9.2.2 Lough Belshade – Eglish Fault

The Belshade Fault is exposed north of the Northern Boundary Fault (NBF) (George & Oswald 1957, Pitcher and Berger 1972). The Belshade Fault sinistrally displaces the early Devonian (about 397 Ma) Barnesmore Granite, north of the Northern Boundary Fault by 3 km (Leedal and Walker 1954). Displacements within the Barnesmore Granite, together with the observation of slickensides suggest downthrow towards the southeast across the sinistral Belshade Fault (Alsop 1992).

Studies of apparent continuation of the Belshade Fault into the Carboniferous basin of southern Donegal (i.e. the Eglish Fault in this study) reveal only a late dip-slip motion,

downthrowing towards the southeast, the important sinistral strike-slip component entirely pre-dating basin formation (Pitcher *et al.* 1964). However, the fault on which the slickensides are observed is post-Dinantian and therefore cannot give evidence on the time of basin formation. The dextral displacement between the Belshade and the Eglish Faults (due to movement on the Northern Boundary Fault) is approximately six hundred metres.

The trend of the Eglish Fault can be picked out in the NE/SW trending Eglish river valley (refer to Figure 2 and Enclosure 5.3). The fault is exposed at the junction where the rivers Sruell and Eglish converge (circa. Locality 238, GR19103 38515); thus, disrupting the calcareous shales and siltstones of the Bundoran Shale Formation. This fault extends southwestwards into the basin towards Mountcharles. A southwest-dipping NW/SE antithetic fault extends from the Eglish Fault and cuts along the northern nose of Banagher Hill (partly observed in Enclosure 5.1). It is exposed in the Eglish River at L244 (GR19427 38707). Clean limestones of the Clady Limestone Member are exposed to the north against thin bedded, pebbly sandstone of the Banagher Sandstone Formation.

9.2.3 Burns Mountain – Mountcharles Fault

The Burns Mountain Fault is believed to comprise a splay from the Barnes Lough Fault. Its trend can be picked out in the low land area southeast of Burns Mountain (refer to Enclosure 5.2). The Clady Limestone Member is dextrally displaced by approximately 100 metres at Friary (to the south of L302, GR19583 38371). It then follows the base of Burns Mountain and is exposed to the south of Burns Mountain and Leagan Hill at L305 (GR19378 38256). Here, a south-dipping fracture juxtaposes the Banagher Sandstone Formation (to the south) against the Bundoran Shale Formation to the north. This fault extends southwestwards towards Mountcharles Village.

9.2.4 Donegal Town Fault

The NE/SW trending Donegal Town Fault (Figure 2) can be picked out along northern part of the estuary at Donegal Town, where highly fractured argillaceous limestone of the Donegal Limestone Member are exposed. In addition, jointed rocks are exposed under the bridge near the castle. Several ENE/WSW trending faults (subparallel to the Donegal Town Fault) have been observed within the Lough Eske River (e.g. at Foxes Hole locality 96-65, GR19576 38109). These trends can be observed on structural maps of the Dalradian (Alsop 1994, his Fig. 6).

9.2.5 Leannan – Killybegs Fault

The Leannan Fault is a sinistral strikes-slip fault system, which juxtaposes Dalradian metasediments of different structural trends and metamorphic grades (Alsop 1992). It is directly in line with the Great Glen Fault in Scotland (refer to Pitcher *et al.* 1964). Pitcher *et al.* (1964) maintained that the main movements on the Leannan Fault occurred between the late Devonian and the Viséan, however there is no clear evidence for this statement. The Leannan Fault extends to the northwestern part of the Donegal Basin and appears to converge with the Northern Boundary Fault at Croagh Lough. The Dinantian cover constrains the major components of sinistral strike-slip motions to the Middle to Upper Devonian and correlates with similar late Caledonian sinistral strike-slip motions observed elsewhere in the British and Irish Caledonides (Alsop 1992, Soper and Hutton 1984).

The Killybegs Fault is believed to be a splay of the Leannan Fault. The pattern of the belt is one of gently curving sub-parallel faults; thus, splaying with the Killybegs Fault. The two areas (Shalwy and Bruckless) can be more or less well matched, albeit the latter area comprises a thicker succession. Thus, some movement on the fault must have existed during deposition of the Largysillagh Sandstone Formation. However, the fault did not form any noticeable topographic expression at the surface, as there are no facies that can be interpreted as deposits of a fault scarp.

9.2.6 Faults exposed in the Bruckless and St. John's Peninsula area

The western margin of the main outcrop of the Donegal Carboniferous Basin comprises a faulted north/south trending unconformable boundary, although the unconformity has not been observed in the field. Several faulted localities have been observed. At L202, (GR17417 37906) in a quarry on the main Donegal Town to Killybegs road, a NE/SW fault is exposed between approximately 15 metres of red conglomerates and grey Dalradian pelites (refer to Plate 61). Further south (Locality 200, GR17451 37811 and L201, GR17457 37815) at Cashelreagh Glebe, a NE/SW fault can be extrapolated between highly fractured metasediments and red conglomerates. At Oily Bridge (Locality 181, GR17467 37694), an E/W fault is exposed in the river within the red conglomerates and sandstones. This fault can be extrapolated eastwards to join up with the fault in the stream north of Darney (Locality 182, GR17546 37698). This fault results in silty limestones (of the Calhame Limestone Member) in the north being juxtaposed against buff sandstones of the Largysillagh Sandstone Formation in the south. This fault trend is not similar to the faults splicing the western margin and matches up more with several E/W faults observed further south in the McSwyne's Bay/St. John's Peninsula area.

The north-dipping NW/SE trending '*Syringopora* Fault' is exposed at Locality 153 (GR17552 37527) at Killaghtee. This fault cuts through a calcareous unit (the '*Syringopora* Bed' – refer to Section 4.5.4.2.1.2, Figure 21) to the north and non-calcareous sandstones (Largysillagh Sandstone Formation) to the south. This fault extends through St. Johns Peninsula and is exposed again at Cavan Point (GR17719 37403), where it juxtaposes the Rinn Point Limestone Formation in the south against a heterogeneous carbonate/clastic unit (the Cavan Sandstone Member) in the north (Plate 81). At Kiln Port, an E/W fault is observed between the Rinn Point Limestone Formation in the north and the Shalwy Formation in the south. This fault also cuts across the peninsula. The St. John's Point area contains a series of fractures (refer to Figure 40).

Three parallel NE/SW faults are exposed at Cassan Sound (GR17228 37087), north (GR17165 37040) and south (GR17162 37001) of Trabane beach, respectively. The fault at Cassan Sound separates the Rinn Point Limestone Formation from the Rabley Limestone Member in the south. This fault is also recognised at Portanvan (GR17131

37068). The faults north (north dipping) and south (south dipping) of Trabane exposes a horst of the Rinn Point Limestone Formation between the Rabley Limestone Member and the Gullhuch Sandy Limestone Member, respectively. A well-exposed NNE/SSW fault at Dough Cove (GR17057 36955 - the Dough Cove Fault, refer to Figure 40) separates the Gullhuch Sandy Limestone Member to the east from the Rabley Limestone Member in the west.

9.3 THE FRACTURE PATTERN OF THE NW CARBONIFEROUS BASIN

The complex fault pattern within the NW Basin is a cumulative record of successive tectonic events. Millar (1990) used the stratigraphic framework of the NW Basin to help model basin development and constrain the timing and the nature of movement along the various fault systems. He recorded a total of 455 faults from the region and established a chronostratigraphic comparison of the fracture patterns. Thus, he achieved a structural pattern of north central Ireland, resulting from the interaction of many different structural episodes and the tectonic sequence. This is summarised as follows:

- Early Dinantian NNW/SSE extension (ENE/WSW fracture set)
- Late Dinantian N/S extension (E/W fracture set)
- A Post Dinantian event represented by N/S trending fractures
- Triassic NE/SW extension (NW/SE fracture set)
- Jurassic N/S extension
- Two Tertiary events: ENE/SWS and NW/SE extension

The ENE/WSW fracture set is confined to the early Dinantian (Courceyan to Asbian) succession. The E/W fracture set is dominant in the pre-Namurian rocks and is also seen in the Triassic/Jurassic rocks. The E/W set is considered to represent both late Dinantian N/S extensional event and a later Jurassic event. The NW/SE fracture set is observed in the Carboniferous and Triassic rocks, but is absent from post-Triassic rocks; thus, interpreted as a Triassic NE/SW extensional event (Millar 1990).

Faults accommodating NW/SE extension are the most abundant in the region (43% of Millar's data are assigned to this pattern). They are particularly numerous in the Donegal Basin, East Tyrone area and along the Clogher Valley Fault. These areas all

have relatively thin sedimentary cover and developed above basement containing major NE/SW faults. They may have been reactivated as strike-slip faults, in accordance with the regional stresses (Millar 1990).

Millar (1990) reported a total of 51 faults from the Chadian/Arundian limestone succession around the peninsula leading out to St John's Point (GR17003690), and in large quarries in Ballintra (SE of Donegal Town - GR19203700, this latter locality is outside the study area). Millar presented a simple fault pattern comprising two sets, NE/SW and ESE/WNW. The faults are steep to shallow dipping and generally exhibit normal to oblique movement with very few pure strike-slip faults. A number of faults show dip-slip motion, but only one with reverse motion is recorded. The presence of both shallow dipping faults displaying horizontal fibres and the generally wide spectrum of motion may reflect considerable fault reactivation. Millar (1990) observed that the majority of fault data in the Donegal Basin are consistent with NW/SE and N/S extension directions. NW/SE extension is accommodated by both normal and strike-slip faults and complies with both normal and wrench systems. N/S extension is accommodated by a set of E/W shallow/subvertical normal faults.

Millar (1990) referred to the complexity of faulting at Pound Point (north of St. John's Point) (GR17103713), where there are sinistral (75/170) and dextral (50/100) faults, in addition to shallow normal faults. Although these are all seen to intersect in one outcrop, it is not possible to establish a chronology. The shallow normal faults accommodate an extension compatible with the NW/SE extension produced in the conjugate strike-slip system. He noted that the predominance of NW/SE extension, (perpendicular to the basement faults) could be explained in several ways. As summarised below in Table 9.1, the majority of recorded faults from the 'Donegal Syncline' accommodate NW/SE extension, compared with very few faults in the 'Sligo Syncline'. The latter area contains a much thicker Carboniferous sequence. Thus, Millar postulated that thickness of cover could have been instrumental in partitioning the deformation between the basement and the cover. 'In the thinner sequence (Donegal) the reactivation of the basement faults are manifest as extension perpendicular to the faults, irrelevant of the orientation of the stress system, whereas the thicker sequence (Sligo) exhibits faults which are dynamically compatible with the separate stress system' .

Fault Pattern	Fault Type	Extension Direction
NE/SW	Normal	NW/SE
NE/SW	Strike-slip	NW/SE
ESE/WNW	Shallow/Subvertical normal	N/S

Table 9.1 Summary of faulting in the Donegal Basin as outlined by Millar (1990).

In summary, the complex fault pattern in the Northwest Carboniferous Basin of Ireland is a cumulative record of successive tectonic events. Four extension directions (N/S, NE/SW, E/W and NW/SE) have been confirmed by Millar (1990). Thrust faulting is extremely rare within the basin.

CHAPTER 10 DEVELOPMENT OF THE DONEGAL BASIN

10.1 INTRODUCTION

The variable facies distributions observed within the Dinantian Donegal Basin have been outlined in previous chapters. These facies are a consequence of several factors, namely drainage basins (their size, erosion material and transport energy), rates of erosion, gradients, syn-sedimentary faulting, position of the coastline and sea level variations. The rocks of the Donegal Basin has been sub-divided into a series of formations that can be correlated across the basin by incorporating information from lithostratigraphy and biostratigraphy.

This chapter discusses this correlation and will aim to match certain units and events in relation to lateral facies changes, time and where possible, sequence stratigraphy. As discussed in Chapter 8, a reviewed biostratigraphy of the basin (through intensive analysis of the carbonate sequences) helps to refine this correlation.

Viséan rocks are widely distributed north of a line from Clew Bay to the western end of the Lower Palaeozoic Longford-Down inlier (Sevastopulo and Wyse Jackson, in press). Within this area, there are major changes in facies and thickness reflecting fault-controlled differential subsidence and relative proximity to the source of siliciclastic sediment (sys-sedimentary faulting influenced the Edergole Formation and may also have been influential in the northwestern part of the Donegal Basin – towards Croagh Lough).

As discussed in Section 1.3, the Northwest Carboniferous Basin of Ireland can be subdivided into at least seven sub-basins (Figure 3), which display an overall similar sequence of events during the Dinantian. However, in closer detail, each basin comprise individual facies assemblages, due to variable influences from sea level changes and tectonism. The northern part of the Northwest Basin (i.e. Donegal Basin and Omagh Syncline) lay close to, or included, the margin of marine deposition from early Viséan times onwards (refer to Cope *et al.* 1992). As a result, very little limestone was ever deposited north of Cookstown, County Tyrone and the Omagh and Donegal synclines. The thickest successions are found in the Lough Allen Basin, between the northeastern

Ox Mountains, which formed part of the Ox Mountains-Ballyshannon High, and an eastern shelf area between Armagh and Cookstown.

The deformation in the succession from the Curlews Fault northwards (refer to Figure 4), is mainly by reactivation of Caledonian faults. Tilting within the fault blocks resulted in the stratal dips being steeper near the faults. This period of faulting has generally been linked to Variscan folding. The Donegal Basin is the most northerly of the sub-basins that formed as a result of movement along these reactivated Caledonian faults (Figure 67). The Donegal Basin is considered to have extended much further north than the current exposure. The present-day northern limit of the basin is the trace of the Northern Boundary Fault, where it downthrows to the south by at least 200 metres. This northern limit of exposure is considered to be relatively recent, possibly Tertiary in age, and it is unclear how far to the north of this fault the initial Dinantian coverage would have extended. The present-day western limit of the main Carboniferous outcrop comprises a boundary (near Bruckless), which appears to be an extensively faulted unconformable contact (the unconformity is inferred, not exposed). The intensive faulting results in a NE/SW splicing of this western margin. As mentioned above, the stratigraphy within the Shalwy Syncline and the Muckros inlier closely match that observed within this western part of the main Donegal Basin (Chapter 4). Thus, it is assumed that the Shalwy Syncline and Muckros area were in direct communication with the western area of the main Donegal Basin during their deposition history. The Largysillagh Sandstone Formation is considerably thicker within the Bruckless area. There is little lateral facies change at this level, thus; a fault would allow the thickness changes to be accommodated. The Leannan Fault, which cuts between Bruckless and Shalwy may have been influential in the thickness variation between the two sequences. 'The thicker successions of the west limb of the Donegal Syncline have been attributed to more rapid subsidence related to active movement on the Killybegs (Leannan) Fault' (Sevastopulo and Wyse Jackson, in press). It is possible that the Leannan Fault was active during deposition, but did not leave any evidence at the surface. It is also possible that it could have reached the surface, but has tapered so little that its effect cannot be detected in the sedimentary record. It is uncertain how the outcrop at Slieve League (Section 4.9) fits into the stratigraphical succession, although it would appear to reflect uplift along another splay of the Leannan Fault.

The western part of the main Donegal outcrop initially formed as a subsiding local basin, aligned along a major crustal fracture zone within the northwestern part of Ireland. Weaknesses within the crust resulted in a reactivation of these Caledonian faults to assume strike-slip geometries; thus, causing subsidence and block faulting (Johnson 1967, Leeder 1976, McKenzie 1978). In the early evolution of the basin, accommodation space in the crust was created by continual subsidence from these syn-sedimentary faults. Leeder (1988), Price and Max (1988) and Millar (1990) outline an overall extensional regime in the northern parts of the British Isles. Local marked variation in subsidence due to movement on the large basement inherited faults, led to tilt block and basin provinces (Leeder 1988). Refer to Figure 68 for a sketch of this basin and block faulting. It is questionable whether the Leannan Fault exerted a significant influence on sedimentation throughout the deposition of the basal units (Roelough Conglomerate Formation, the Oily River Conglomerate Formation, the Largysillagh Sandstone Formation, the Lough Eske Sandstone Formation and the Shalwy Formation of this study) (Pitcher *et al.* 1964). There is no real evidence for topographical related deposition. Nevin (1973) envisaged an embayment from Ballyloughan towards Croagh Lough. Provenance information identifies the Dalradian hinterland (and to a lesser extent, the granite plutons) to the north and west of the Northern Boundary Fault as the main source areas (refer to Chapters 4 and 5) that provided fill for the Donegal Basin. The overall thickness of succession within the basin is inferred as between circa 800 metres (in the west: the Oily River Conglomerate Formation to Mullaghmore Sandstone Formation) to approximately 1000 metres (in the east – including the 400 metres thick Edergole Formation to the top of the Mullaghmore Sandstone Formation). The Mullaghmore Sandstone Formation may have been overlain by later Carboniferous sediments, which have now eroded from the cover; although this is not evident.

The limestones of the Ballyshannon Limestone Formation extend southwards from the area of study in the Donegal Town area and are cut by a series of NE/SW faults. George and Oswald (1957) state that 'only a few yards of schist at present day separate the Donegal syncline from the Sligo syncline'. Towards Ballyshannon, the limestones of the Ballyshannon Limestone Formation rest unconformably on schists, thus the basal clastic section that is preserved in the Donegal Basin is missing from this area.

The original shape of the basin can be deduced by information from the facies assemblage (refer to the palaeogeographic reconstructions in Figure 68). As discussed above, the Northern Boundary Fault is a later event, thus the basin would have extend further north. Provenance and palaeocurrent data imply a northerly source for the earliest clastics, which wraps around the western and eastern limits of the basin i.e. NW/N drainage basins feeding rivers within the western areas and draining from the N/NE within the eastern area.

George and Oswald (1957) describe the syncline within the Donegal Basin as 'composite' - the 'north-eastward closure suggests a major pitching axis of inherited caledonoid trend running from near Edergole towards the Doorin Peninsula.'

10.2 PRE-ARUNDIAN DEVELOPMENT

Refer to Figure 69 for a depiction of sea level variation during the Dinantian.

The Edergole Formation represents the oldest rocks within the Donegal Basin. It unconformably overlies Dalradian metasediments along the eastern margin of the basin. These rocks are Tournaisian in age and represent first-cycle detritus within an alluvial fan during the initial phase of Dinantian extension in the Donegal area (Graham and Clayton 1994).

The Roelough Conglomerate Formation and the Oily River Conglomerate Formation represent the initial deposits in the western area of the Donegal Basin (refer to the palaeogeographic map in Figure 68a). The conglomerates overlie the Dalradian cover and differ slightly in their transport histories. The former does not comprise any schist clasts within its sequence, even though it overlies basement schists. Thus, a source area, probably further north may be inferred. The Oily River Conglomerate Formation does contain schist clasts and a slightly more immature transport history is implied. These clastics are inferred to be Lower Viséan in age and represent bedload transport from relatively small southerly-flowing, drainage basins. A similar history is envisaged for the lower part of the Lough Eske Sandstone Formation within the eastern part of the basin.

The Largysillagh Sandstone Formation is also the product of non-marine, sandy bedload systems from northerly-derived drainage basins. However, palaeocurrent data displays more variability than the basal conglomerates with individual current-to directions varying from SE to SW. The drainage area reflects a terrestrial environment with abundant vegetation. Thus, a non-marine depositional environment comprising relatively small channels with common channel switching, flood plains with exposure and soil forming processes (desiccation cracks, palaeosols etc.) and flood deposits in abandoned channels with abundant plant debris is inferred for the Largysillagh Sandstone Formation.

The Shalwy Formation comprises evidence of the initial transgressive phase within the Shalwy Syncline and western part of main Donegal Basin, by representing deposition within the coastal area during the Lower Viséan. Erosion from the hinterlands provided clastic sediments to the southerly-flowing rivers that reached the coastline. These rivers deposited their load initially within the non-marine parts of the fluvial regime (Largysillagh Sandstone Formation). Eventually, deposition extended towards the tidally-influenced reaches of the rivers, lagoons and areas comprising brackish water, as indicated by the presence of low-salinity gastropod fauna. Meanwhile, as the sea transgressed further north during the Viséan, temporary pulses of marine deposition are reflected by carbonate lenses. The '*Syringopora* Bed' is interpreted as a condensed section that formed by slow accumulation during a base level rise. This lag deposit is much thinner (1.3 metres thick) than its correlative (the Calhame Limestone Member – circa 30 metres thick) one kilometre further north. Deposition also occurred in areas dominated by wave reworking and storm influence within the surf zone. A south-north profile from St. John's Peninsula towards Gilbertstown/Garrafada area (6 to 8 km) displays the lateral facies change by interfingering lenses. Here, the marine bands (transgressive pulses) extend northwards and are interlayered with the variably-grained, non-marine sandstones which are produced by the small-scale fluvial rivers in the north. This interfingering of similar aged facies assemblages is also observed towards the eastern part of the basin in the Lough Eske area, within the upper part of the Lough Eske Sandstone Formation.

The clastics which were deposited within the coastal area were gradually replaced by predominantly muddy carbonate sequences (the Rinn Point Limestone Formation, and also the Donegal Limestone Member of the Ballyshannon Limestone Formation) as the

loci of deposition moved offshore towards open marine platforms. Fauna including brachiopods, corals, crinoids, echinoids are common, indicating normal saline marine conditions. The succession comprises predominantly argillaceous limestones. The Donegal Limestone Member is more argillaceous than the cleaner Ballyshannon Limestone Formation further south. This reflects the proximity of the former sequence to terrestrial influence.

A shallowing of the marine platform occurred towards the latter part of the Lower Viséan with the deposition of the St. John's Point Sandy Limestone Formation, the Muckros Sandstone Formation and the Clady Limestone Member (Ballyshannon Limestone Formation). This sequence is characterised by the presence of oolitic limestones and well-sorted, medium grained sandstones. The limestones are much cleaner, comprising less argillaceous material; thus, reflect more well washed, agitated conditions than the underlying muddy carbonates of the Rinn Point Limestone Formation. Reworking along the shelf during a shoaling event is inferred.

The Banagher Sandstone Formation (within the eastern part of the Donegal Basin) represents a relatively thick (c. 200 metres) but apparently short-lived, influx of poorly sorted clastics. The sequence is relatively localised, immature and appears to be proximal to the source. It is not entirely clear whether the sequence is due simply to regression or is progradational due to locally increased sediment supply. As discussed in Section 5.5.8, the abrupt contact between this coarse clastic unit and the underlying clean shelf carbonates of the Clady Limestone Member has the characteristics of a sequence boundary, indicating a major facies shift. However, this boundary is rather local as it cannot be matched elsewhere in the Donegal Basin, and therefore, is not considered to represent a true sequence boundary. This study infers a progradational event with the renewed period of fluvial clastic deposition over a shallow marine environment. A major river capture is not likely; thus, the clastic influx is attributed to source area rejuvenation (Dalradian rocks to the north of the present day Banagher area), associated with tectonism. During early Banagher times, rivers carrying coarse clastics deposited their load along an approximate NE/SW shoreline.

10.3 POST ARUNDIAN DEVELOPMENT

The Bundoran Shale Formation depicts a major change in events within the Northwest Carboniferous Basin of Ireland. These shales are widespread, extending from the Donegal Basin towards the Sligo area. The sequence is thickest within the Donegal Basin (circa 200 metres) and decreases significantly to 61 metres at Coolmore (7 km southwest from the Doorin Peninsula). These muds are interpreted as the distal parts of a delta system (refer to the palaeogeographic map in Figure 68b). The dimensions of this deltaic sequence are discussed within Section 6.8. Within the Donegal Basin, the Bundoran Shale Formation provides an important datum plane on which to hang the stratigraphy. This study concludes that within the Donegal Basin, the first Arundian Stage foraminiferal fauna appears with the onset of this deltaic sequence. This event appears to have occurred much later in more southern parts of Donegal than in the Sligo area, as the upper part of the Ballyshannon Limestone Formation is dated as Arundian in the Sligo area. This diachroneity would be expected in a southwardly prograding clastic wedge. Locally, the base of the shales represents a flooding event in the Donegal Basin, as they rest directly on non-marine deposits in the east and on deposits within a shoaling environment in the west. The Bundoran Shale Formation does not appear to be a 'non-sequence event' in the Donegal area, as there are no apparent gaps or major erosional events at this level. The relationship between the Bundoran Shale Formation and underlying strata in the Kesh-Omagh Basin is interpreted as one of transgressive onlap (Mitchell and Owens 1990). However, the lower part of the Bundoran Shale Formation is not well-exposed and the flooding event may be represented by a very thin transgressive systems tract. The subsequent change in provenance and indications of a much larger drainage system (as discussed in Section 6.8) may relate to changes in drainage effected during a time of higher sea level represented by the flooding event.

An unresolved question is the drainage basin and source area for this large amount of mud. It is interesting that we do not observe the coarser upstream material associated with this prodeltaic sequence. The Banagher Sandstone Formation and the Killin Sandstone Member have been ruled out due to size and maturity of the systems. Additionally, the loci for the sediment delivery point for this prodeltaic sequence is unknown as it unexposed within the present-day Carboniferous outcrop. We may have to consider the present offshore (offshore Donegal Basin, Slyne-Erris Basin) to the northwest.

Within the Arundian, influxes of coarse clastic material from relatively small drainage basins prograded southwards towards the coast (refer to the palaeogeographic map in Figure 68b). The Killin Sandstone Member is relatively widespread within the northern areas of the basin. The northern limit to this river system is not known as it appears to have extended beyond the Northern Boundary Fault. The relatively immature clastics an interfingering relationship with the Bundoran Shale Formation towards the central part of the present Carboniferous outcrop. The Ramp Hole Sandstone Member reflects where a channel extended further south and reached the coastline, cutting into the deltaic shales of the Bundoran Shale Formation.

The Mullaghmore Sandstone Formation comprises the youngest rocks within the Donegal Basin sequence (Arundian to Holkerian in age). This event represents an influx of deltaic sediment that occurred throughout the Carboniferous basins in the northern part of Ireland (referred to as the Mullaghmore Sandstone Formation, the Aughnacloy Sandstone Member and the Clonelly Sandstone Group within the various sub-basins). The clastics reflect eroded material associated with an increase of tectonic activity or a major sea level fall (refer to Figure 69) entering a slowly subsiding basin. The relative homogeneity of the sequence testifies to the vertical and lateral facies stability within the basin and to the subdued relief of clastic source areas from Middle Arundian times (Mitchell and Owens 1990). No major erosional features or downcutting into the Bundoran Shale Formation were observed within the Donegal area. A conformable, gradual coarsening upward sequence between the two formations is exposed within the Mountcharles/Doorin area. This is in contrast with the major downcutting of the Mullaghmore Sandstone Formation into the equivalent Moyny Limestone noted in the North Mayo area and allocated a Type 1 Sequence Boundary (Graham 1996). This event in North Mayo represents an abrupt change with extensive generally well sorted, coarse- to medium-grained sandstones envisaged to represent the product of a large southerly prograding rivers eroding directly into shallow marine carbonates and shales. The Mullaghmore Sandstone Formation within the Donegal section may be inferred as a correlative conformity to this sequence boundary.

Two hypotheses stand on the origin of the sandstones within the Mullaghmore Sandstone Formation. First, they may represent the terrestrially-influenced, deltaic part of the major delta unit within the Northwest Carboniferous Basin, of which the

Bundoran Shale Formation represents the prodelta part. Secondly, it may comprise a separate entity; thus, not linked to the same drainage basin, which fed into the Bundoran Shale Formation system. The first hypothesis would seem more plausible.

10.4 DISCUSSION

Graham (1996) queried the importance of widespread eustatic events within these basins as suggested by Ramsbottom (1973), rather than relatively local tectonic controls. On a local scale, tectonic influence is significant (as suggested by the Edergole Formation, the initial deposition within the Oily River Conglomerate Formation and probably the Banagher Sandstone Formation in the Donegal Basin).

The early Viséan represents a time of widespread transgression, although gradual and reflected a long-term rise of sea level rather than any rapid, short term change (Sevastopulo 1981a, Graham 1996). Mitchell and Owens (1990) present the Maritime Provinces of eastern Canada as an analogue to the Dinantian succession in the Northwest Carboniferous Basin of Ireland. The former area displays a conformable transition between the late Tournaisian to early Viséan paralic sediments of the Horton Group and the middle Viséan to early Namurian shallow water sediments of the Windsor Group (Bradley 1982). The Canadian regime is influenced by a dextral strike-slip, with significant dip slip component, which existed during deposition of both the Horton and Windsor Groups (Leeder 1976).

The development of a sequence stratigraphic framework for any rock succession relies on identification of a heirarchy of stratal units separated by chronostratigraphic surfaces (Van Wagoner *et al.* 1990). This can be done most successfully in shoreline and nearshore successions, where changes in relative sea level leave their mark most clearly (Posamentier and Vail 1988). It is generally difficult to trace key stratigraphic sequences from nearshore into alluvial successions. The Dinantian Donegal Basin reveals a range of fluvial to relatively shallow marine sequences that display a complexity of lateral facies changes from north to south within the basin (refer to Figures 10 and 52).

Several key surfaces may be recognised within the Donegal Basin. An unconformable Viséan surface boundary has been identified at the base of the Lough Eske Sandstone Formation over the Tournaisian age Edergole Formation.

The initial transgressive event (within the Shalwy Formation) overlying the fluvial, non-marine clastics of the Largysillagh Sandstone Formation is identified in the western part of the basin and within the Shalwy & Muckros areas. As discussed in Section 4.5.4.2.1, a condensed section could be inferred at the base of the '*Syringopora* Bed'. The nature of the transgressive pulse which produced the *Syringopora* Bed'/Calhame Limestone Member is unclear. This part of the section has limited biostratigraphical resolution, hence one can only compare approximate time equivalents and detect whether a significant pulse is obvious at a similar expected level within the Sligo or North Mayo area. At present, no correlative pulses have been observed in these latter areas (Graham 1999, pers. comm.).

The key surface corresponding to the main transgressive event within the Viséan is identifiable at the base of the Rinn Point Limestone Formation in the western areas of the basin. This is the initial, widespread, relatively thick (c.100m), well bedded argillaceous limestones and calcareous shale sequence representing normal marine carbonate deposition during a rise in sea level. To the east of the basin, this surface appears to be diachronous and is represented by the Donegal Limestone Member.

A lowering of sea level is inferred at the top of the Rinn Point Limestone Formation, with the deposition of the St. John's Point Sandy Limestone Formation and the Muckros Sandstone Formation. These latter sequences comprise variable oolitic limestones, sandy limestones and well sorted calcareous sandstones, reflecting deposition within agitated, shallower waters.

One of the most distinctive key surfaces is that at the base of Bundoran Shale Formation, and is recognised throughout the northern part of the Carboniferous Basin of Ireland. This surface (associated with a deltaic flooding event) is represented by a abrupt change from variable clastics and carbonates (Shalwy Formation, St. John's Pt. Sandy Limestone Formation, Banagher Sandstone Formation and Donegal Limestone Member) to a widespread, thick sequence (up to 300 metres) of calcareous shales. Within the Donegal Basin, this surface (the base of the Bundoran Shale Formation)

marks the initial Arundian-aged foraminifers. Thus, it is utilized as a datum plane in correlating various sections within the basin (refer to Figure 66). It is unlikely that the sandstones in the Killin Sandstone Member are shore-connected and formed with its own sea level fall. They may represent linked/stacked sandstones reflecting variation in both loci of deposition and amount of sediment supply through time. Thus, climatic controls may be as influential as base level.

The base of the Mullaghmore Sandstone Formation, (although gradational and conformable over several metres in the Donegal area compared with a Type 1 sequence boundary in the North Mayo area) marks another key identifiable surface within the Donegal Basin. Its basal sequence (comprising well sorted sandstones with some plant-rich intervals) marks the base of a regional regressive/progradational event.

The sequence stratigraphical concept helps in correlation where biostratigraphical work is not able to detect changes and has been used here in linking the Lower Viséan successions where they lack finer biostratigraphical subdivision. Syn-sedimentary tectonism in relation to renewed sediment input into the basin has also been recognised (Edergole Formation, Oily River Conglomerate Formation and Banagher Sandstone Formation) within the Dinantian Donegal Basin.

10.5 CONCLUSIONS

The Dinantian Donegal Basin is situated at the northerly exposed margin of the Northwest Carboniferous Basin of Ireland. Subsidence patterns in the Northwest Carboniferous Basin were strongly controlled by an existing template of major NE-SW trending Caledonian faults. As this area lay close to the Carboniferous coastline throughout much of the Viséan, it is ideal for studying relative changes in base level. This study shows that the Donegal succession indicates an overall transgressive sequence from Tournaisian to Arundian times, followed by a regional regression within the Arundian that also affected large areas of northern Ireland.

It has been demonstrated within this work that these events can be temporally constrained using information from field mapping and foraminiferal biostratigraphy. Within this general scheme, there are shorter-lived relative sea level changes that have

been outlined. Brief transgressive pulses are represented by calcareous, mainly muddy, intercalations with distinctive brackish or open marine faunas into fluvial clastic dominated formations. The main locus of deposition changed during these transgressive pulses. An example is the '*Syringopora* Bed' (circa 1.3 metres thick), developed as a transgressive lag deposit in southern areas which correlates laterally with approximately 30m of muddy carbonates of the Calhame Limestone Member to the north. This latter unit can also be correlated with tidally influenced, bipolar cross-bedded sandstones further north. The base of the normal marine carbonates (Rinn Point Limestone Formation) in the south thins out 5 kms further north to a calcareous siltstone containing a brackish fauna (ostracods and gastropods). Similar sequences are apparent towards the eastern part of the basin. These alterations demonstrate the lateral facies changes that occur from south to north in this area, due to influence of the depositional area's proximity to the shoreline during the Dinantian.

The role of tectonism in the evolution of the Donegal Basin has been outlined. In the eastern part of the basin, an approximately 100 metres thick unit of clastics (Banagher Sandstone Formation), lies abruptly above nearshore carbonates of the Clady Limestone Member. Palaeocurrents within the clastics are generally from the north and there is no evidence of marine influence in the basal sections. In an isolated section (such as a borehole) this would have the appearance of a sequence boundary, indicating a major shift from shallow marine to non-marine facies. A possible correlative 5 km to the west (Sallows) comprises coarse-grained pink clastics dominated by granitic debris. The event producing these changes cannot be correlated effectively elsewhere in the basin and is best explained by local syn-sedimentary fault activity. Graham and Clayton (1994) have also demonstrated the role of tectonism in the deposition of the Tournaisian-age Edergole Formation north of Lough Eske.

The relationships described above have been elucidated through detailed mapping, section logging and recognition of facies and their interpreted environments of deposition. The Rinn Point Limestone Formation and its correlative in the east (the Donegal Limestone Member) and the overlying St. John's Point Limestone Formation have been clarified as Lower Viséan in age. It is now apparent that the Bundoran Shale Formation signals the initial Arundian age sequence with the incoming of archaediscid foraminifers within the Donegal Basin. Despite intensive biostratigraphic investigation

of the Dinantian in the Donegal Basin, the scale of resolution within the Lower Viséan is often insufficient to resolve alternate hypotheses from widely spaced sections.

10.6 RECOMMENDATIONS FOR FURTHER WORK

The evolution of the Carboniferous Donegal Basin that has been presented in this work can now be used as a basis for further research into various aspects of the area. It is recommended that some further work at this level of refinement should be carried out in less well known Carboniferous areas of north and west Ireland. This would lead to a better correlation and understanding of Dinantian stratigraphy, especially the sequence stratigraphic structure of the Northwest Carboniferous Basin of Ireland, than exists at the present.

Within the Donegal itself, it is recommended to follow-up an assessment on the provenance of the clastics to see if it could be tied down better by petrographic means. A detailed investigation of the mineralogy of the sandstones may allow more insight into the source area and transport histories.

As presented in this study, the biostratigraphy (using foraminifers and conodonts) is generally constrained within the Lower Viséan. However, a more detailed investigation of the microfacies of individual carbonate sequences may lead to a clearer understanding of the depositional factors of these shallow-marine to basinal environments.

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