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Facies and sequential organisation of a mudstone-dominated slope and basin floor succession: the Gull Island Formation, Shannon Basin, Western Ireland

Ole J. Martinsen[a,*], Trond Lien[a], Roger G. Walker[b], John D. Collinson[c]

[a]*Norsk Hydro Research Centre, P.O. Box 7190, N-5020 Bergen, Norway*
[b]*Roger Walker Consulting, 83 Scimitar View, Calgary, Alta., Canada*
[c]*Delos, Knowl Wall, Beech, Staffordshire ST4 8SE, UK*

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Abstract

The lower part of the Carboniferous Shannon Basin of Western Ireland contains a deep-water succession which exceeds 1200 m in thickness that comprises five lithologically different units deposited within a confined, relatively narrow basin: (i) a calciclastic debris-flow and turbidite unit formed by resedimentation from nearby carbonate platforms, (ii) a siliciclastic black shale succession with former source potential which onlaps basin margins (Clare Shales), (iii) a sandstone-dominated turbidite formation, controlled by ponded accommodation and deposited axially in the basin (Ross Formation), (iv) a mudstone-rich turbidite-bearing succession, which onlaps basin margins (lower Gull Island Formation), and (v) a mudstone-dominated prograding slope succession (upper Gull Island Formation and lower Tullig Cyclothem), which grades transitionally upwards into deltaic deposits. The top unit records progradation at a time when basin differential subsidence had diminished significantly and local basin topography did not control deposition. The two upper mudstone-dominated units are different in terms of both sandstone content and their genetic significance within the overall basin-fill, and their potential relevance as reservoir analogues.

The lower part of the Gull Island Formation contains three principal facies associations: (a) shallow turbidite channels and sheets representing channel margin and levee deposits, (b) mud-rich slumps, and (c) less than 1 m thick, rare, hemipelagic shales. More than 75% is deformed by soft-sediment deformation, but only to a smaller degree affecting sandstone units. The turbidites record transport to the ENE, along the axis of the basin, while the slumps were derived from an unstable northern slope and transported transversely into the basin towards the southeast. The distribution of turbidite sandstone and slumps is inversely proportional. Sandstones decrease in importance away from the basin axis as slumps increase in number and thickness. The lower part of the Gull Island Formation is interpreted to record progressive fill of a deep basin controlled by local, healed slope accommodation with onlap/sidelap of the basin margins. The instability resulted from a combination of fault-controlled differential subsidence between basin margin and basin axis, and high rates of sedimentation.

The upper part of the Gull Island Formation is entirely dominated by mudstones, which grade upwards into siltstones. It contains rare, up to 15 m thick, isolated channels filled by turbidites, showing transport towards the east. The upper part records easterly progradation of a deep-water slope genetically tied to overlying deltaic deposits, and controlled by regional accommodation.

The contrasts between the lower and upper parts of the Gull Island Formation show that onlapping/sidelapping turbidite successions have reservoir potential near basin axes, but that prograding deep-water slopes are less likely to have reservoir potential of significance. A suggested regional downlap surface between the two parts is a significant break and marker in terms of reservoir potential.
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1. Introduction

Mudstone-dominated turbidite systems provide a challenge to exploration for hydrocarbons because their potential reservoir sandstones are relatively thin, commonly challenging to detect on seismic and their stratigraphic position may be unpredictable. The sedimentology and sequential organization of mud-rich turbidite systems depend on their stratigraphic position in a basin-fill succession. Onlapping turbidite systems, which record progressive, 'base-up' sediment fill of basins, are likely to

* Corresponding author. Tel.: +47-55996937.
E-mail address: ole.martinsen@hydro.com (O.J. Martinsen).

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have higher net sandstone content than downlapping systems. The reason for this is that onlapping systems dominantly record basin floor conditions, while downlapping systems (filling basins 'from the side') record slope settings, through which, turbidity currents are prone to bypass unless topographically constrained. In addition, onlapping deep-water successions may record deposition during falling or low sea level, when clastic feeder systems are nearer or at shelf edges, thus supplying coarser sediments directly to basin floor environments.

Detailed facies variability of sedimentary systems is shown well in outcrops and deep-water depositional systems are no exception. In these systems, outcrop studies may be particularly worthwhile because direct observations of modern deep-water sedimentary systems are challenging. However, few outcrops of mudstone-dominated turbidite systems show the possibility of combining facies studies with the overall stratigraphic context.

One outcrop example where this combination is feasible is the Gull Island Formation in the Shannon Basin, Western Ireland (Fig. 1). The formation shows two distinctly different parts. A lower onlapping system is overlain by an upper prograding system. These two systems have significant differences in terms of facies, areal thickness variability and stratigraphic context. Thus, the Gull Island Formation is a valuable analogue for modern, sea floor and subsurface mudstone-dominated turbidite systems, where lithological details cannot be readily observed.

Previous work has described the basin-fill setting, and abundant soft-sediment deformation of the Gull Island Formation (Collinson, Martinsen, Bakken, & Kloster, 1991; Martinsen, 1989; Martinsen & Bakken, 1990; Martinsen & Collinson, 2002; Martinsen, Walker, & Lien, 2000; Rider, 1974; Wignall & Best, 2000). The detailed facies and stratigraphic relationships within the Gull Island Formation have not been published previously. In the following, we focus on facies observations and interpretations, the spatial and temporal variability in facies and stratigraphic architecture related to slope accommodation, and the general applicability of the relationships within the Gull Island Formation to other subsurface successions.

2. Geological setting

2.1. Basin formation

The Shannon Basin is situated on the west coast of Ireland (Fig. 1), centred on the Shannon Estuary. It has formerly been called the Western Irish Namurian Basin (Collinson et al., 1991), but this name is abandoned here because the basin-fill also encompasses older sedimentary rocks (Matthews, Naylor, & Sevastopulo, 1983; Sevastopulo, 1981; cf. discussion by Martinsen and Collinson, (2002)). The basin formed as one of a series of basins developed in northwestern Europe north of the Hercynian

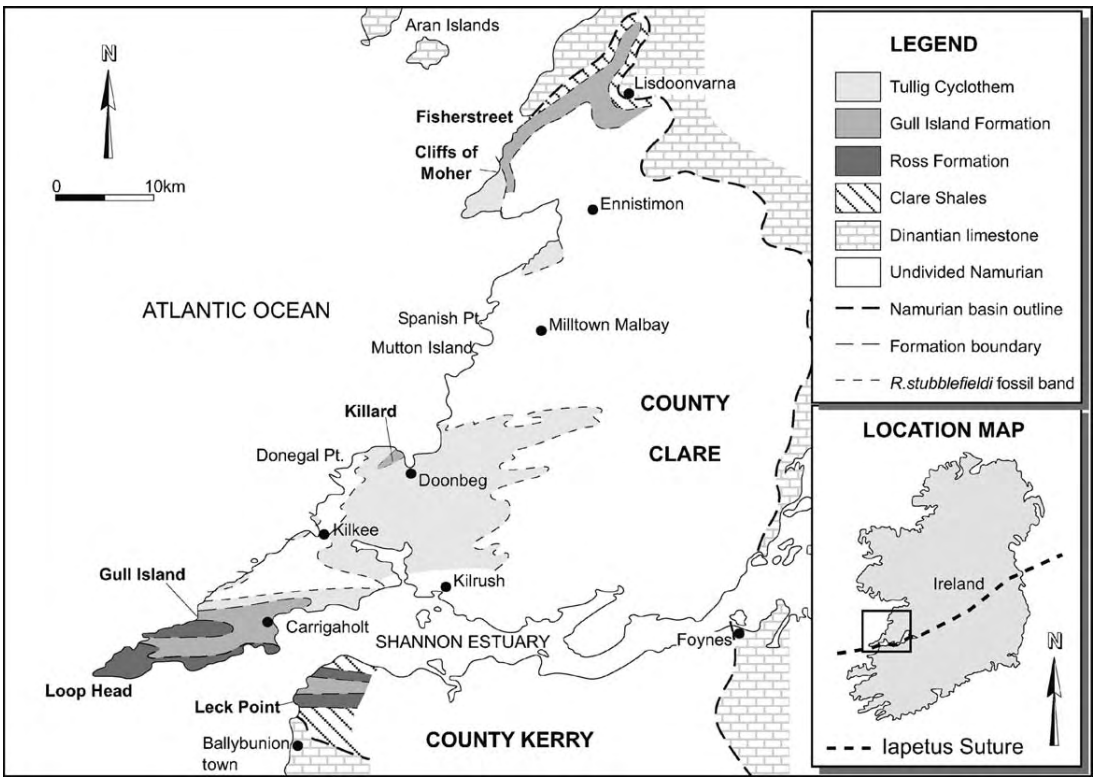

Fig. 1. Geological and location map, Shannon Basin, Western Ireland.

collision zone, as a result of crustal extension in latest Devonian and Dinantian time (Leeder & McMahon, 1988; Martinsen & Collinson, 2002). In several basins in the British Isles, Early Carboniferous bathymetric contrast resulted from deposition of shallow water carbonates on more slowly subsiding fault blocks and crests. Deeper water sediments developed in central basinal areas of more rapid subsidence, where carbonate productivity was not able to keep pace (Collinson, 1988; Strogen, 1988). Such differential bathymetry formed the basinal setting within which turbidite systems accumulated in the Shannon Basin (Collinson et al., 1991).

The distribution of thickness and facies in the Shannon Basin indicates that the basin was confined and elongated along an ENE–WSW line (Fig. 2). This line passes through the present Shannon Estuary and is aligned with the Silvermines-Navan lineament of Central Ireland (Fig. 1; Boyce, Anderton, & Russell, 1983; Collinson et al., 1991; Strogen, 1988). Extending to the northeast, this lineament connects with the Solway Basin/Northumberland Trough in northern England/southern Scotland. The lineament is interpreted to lie above the Iapetus Suture Zone of latest Ordovician to earliest Devonian age (Freeman, Klemperer, & Hobbs, 1988; Klemperer, 1989; McKerrow & Soper, 1989; Phillips, Stillman, & Murphy, 1976; Soper, England, Snyder, & Ryan, 1992). This major lineament controlled the site of maximum subsidence in the Shannon Basin, perhaps related to extensional collapse during regional N–S extension in latest Devonian to early Carboniferous. The ENE–WSW basin elongation is important for the overall understanding of the deep-water basin-fill of the Shannon Basin (Collinson et al., 1991; Martinsen & Collinson, 2002; Martinsen et al., 2000). The confined nature of the Shannon Basin during deep-water deposition suggests that aspects of its basin-fill succession may compare with confined or laterally limited basins elsewhere, such as salt-controlled basins offshore West Africa, rift basins offshore Norway, and even some minibasins in the Gulf of Mexico.

2.2. Stratigraphy

The stratigraphy of the more than 2000 m thick Namurian Shannon Basin succession was formalised by Rider (1974), and can be divided into several formations (Fig. 2). Throughout the stratigraphy, a number of goniatite-bearing, up to 1 m thick black shales or marine bands occur, each with a unique species (Collinson et al., 1991; Hodson & Lewarne, 1961). No such bands have been identified within the Gull Island Formation itself (Fig. 3). However, marine bands below the Gull Island Formation and on top of the overlying Tullig Cyclothem are excellent correlation markers within the basin and envelop the stratigraphy discussed here.

When comparing facies and thickness across the Shannon Basin, the lower part of the Tullig Cyclothem up to the top of the first deltaic sandstone represents a prograding deltaic unit (Pulham, 1989). The top of this stratigraphic level is interpreted to record emergent or close to emergent conditions. This stratigraphic level is roughly parallel to the overlying *R. stubblefieldi* marine band, which

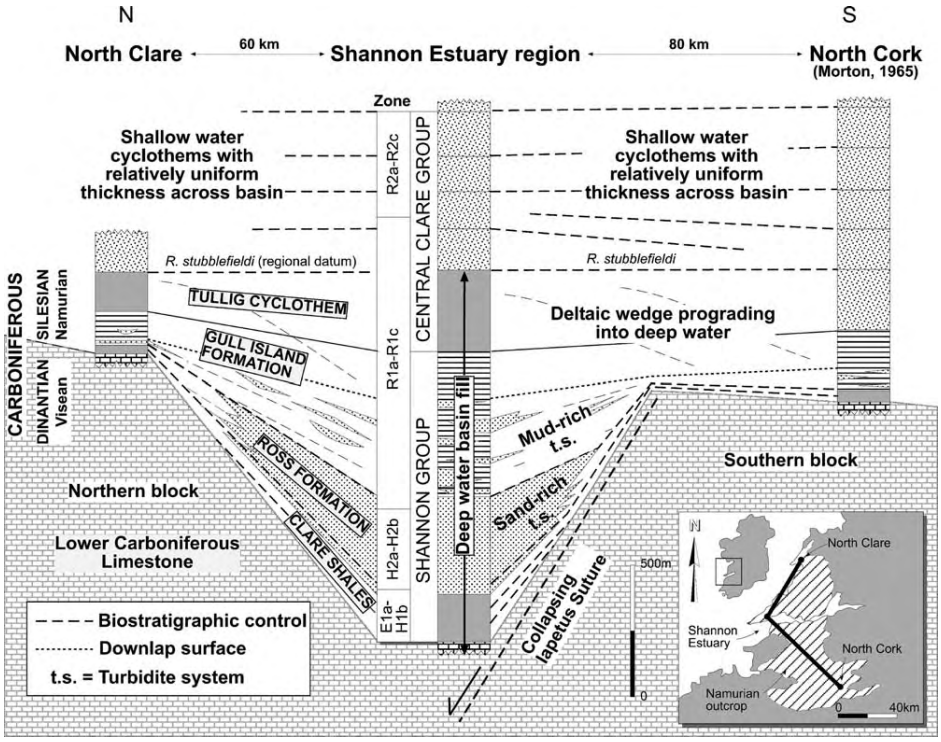

Fig. 2. Stratigraphy of the Shannon Basin.

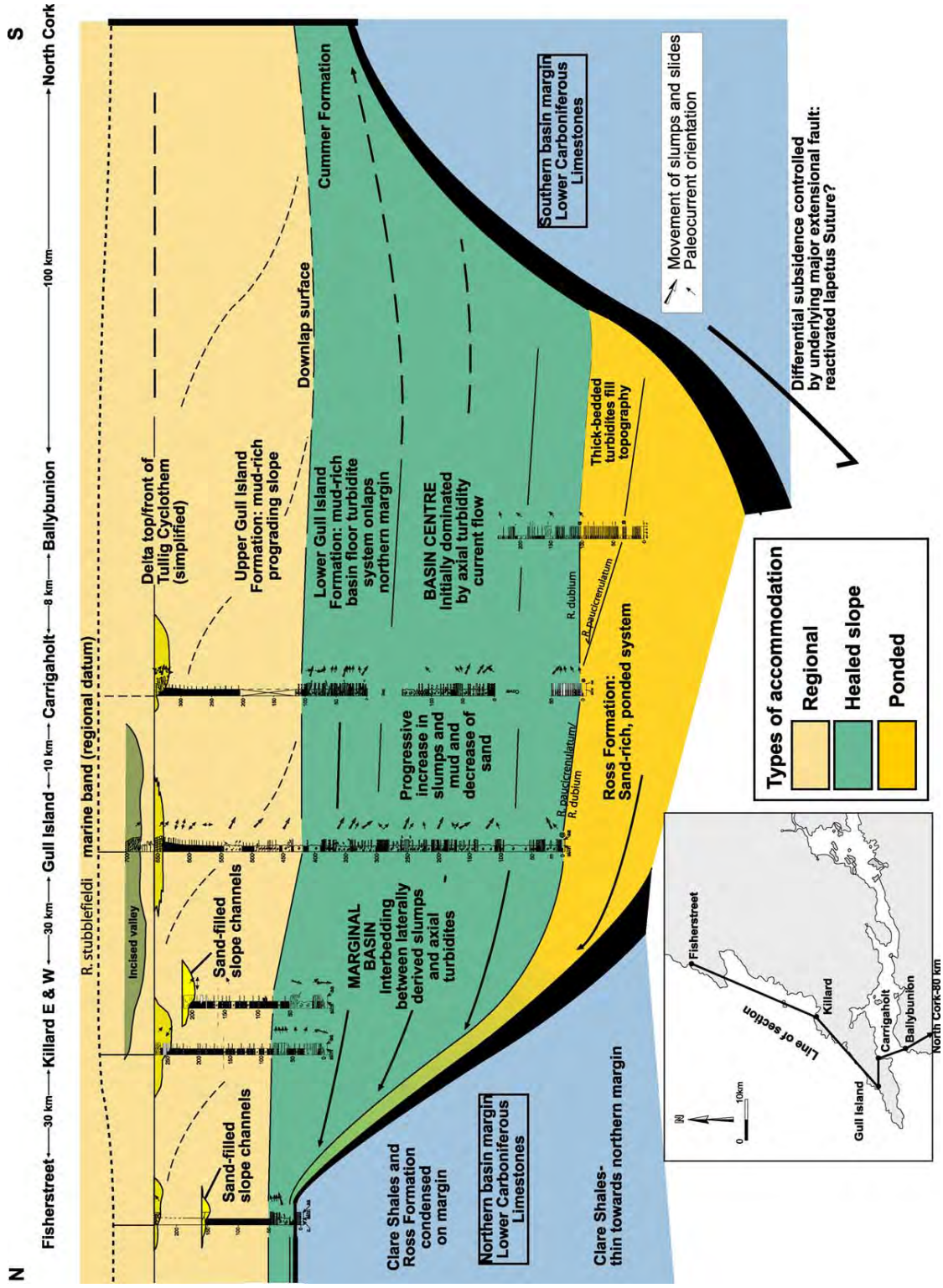

Fig. 3. Correlation of the Gull Island Formation from North Clare through the Shannon Estuary to North Cork. Note the thinning onto both basin margins. The North Cork correlation is based on Morton's (1965) description of the section there. Note the change in thicknesses between the lower and upper part of the Gull Island Formation. The separating surface is defined as a downlap surface. The correlation datum is the *R. stubblefieldi* marine band on top of the Tullig Cyclothem and which is roughly parallel to the top of the lower delta front/shoreline sandstones within the cyclothem.

is used as a regional datum (Fig. 2), although there is an increase in thickness towards the Shannon Estuary region (Pulham, 1989, his Fig. 17; Figs. 2–3). In addition, the thickness of the incised valley-fill of the Tullig Cyclothem, which mainly occurs in the south, adds to the thickness difference. Although probably not entirely time-equivalent across the basin, we use the level on top of the first deltaic sandstone as a pragmatic, proxy datum to hang sections from so that the thickness and facies variability in the underlying Gull Island Formation and the lower part of the Tullig Cyclothem can be analysed (Fig. 3). Pulham (1989) suggested that the Tullig Cyclothem prograded from the W–NW into the basin, i.e. roughly perpendicular to the present shoreline. Therefore, emergence probably took place at grossly the same time in the outcrops studied.

The lower part of the succession reflects a progressive change from quiescent, siliciclastic deep-water conditions represented by the Clare Shales, through a sandstone-dominated basin floor turbidite succession, the Ross Formation (Collinson et al., 1991; Elliott, 2000a,b; Martinsen et al., 2000).

The Ross is overlain by a mudstone-dominated, turbidite-bearing formation, the Gull Island Formation, originally interpreted by Rider (1974) and by Martinsen (1989) to represent the basin slope. Martinsen et al. (2000) reinterpreted the Gull Island Formation to consist of two parts, a lower basin floor part and an upper slope part. We expand on this subject below and document facies and lateral relationships in detail and discuss their relation to slope accommodation. The formation is around 550 m thick around the Shannon Estuary, but decreases to 130 m on the northern basin margin (Fig. 2), some 60 km from the basin axis. A corresponding thinning can be seen towards the south (Fig. 2).

The same pattern of thinning onto basin margins is also seen in the Clare Shales and the Ross Formation: a total thickness of 640 m of these two formations in the basin centre decreases to only 12 m on the northern basin margin (Fig. 2). The trend is clearly demonstrated by the distribution of goniatite-bearing marine bands, which possess unique fauna (Hodson, 1954a,b; Hodson & Lewarne, 1961). The trend is inferred to record onlap onto basin margins (Collinson et al., 1991), a view that has been disputed by Wignall and Best (2000), but defended by Martinsen and Collinson (2002).

The delta cyclothems of the overlying Central Clare Group show a more uniform distribution of thickness and facies (Fig. 2; Pulham, 1989). The exception is the lowermost cyclothem, the Tullig, which is thickest in the vicinity of the Shannon Estuary and thins somewhat towards the north. A corresponding, but less pronounced thinning is also seen towards the south of the equivalent deltaic unit, the Foiladaun Cyclothem (Morton, 1965; Fig. 2). While widespread condensed horizons or marine bands separate overlying cyclothems (Fig. 2), the Tullig Cyclothem has a transitional lower boundary to the Gull Island Formation.

3. Gull Island Formation

3.1. Introduction

The Gull Island Formation is exposed in several areas around the Shannon Estuary. The best exposures are on the Loop Peninsula (Figs. 1 and 3), where more or less complete sections through the formation are seen at Gull Island and at Carrigaholt (Fig. 1). Another complete section occurs at Fisherstreet/northern Cliffs of Moher near the inferred northern basin margin (Figs. 1–3). A key section showing the lower part of the formation occurs north of Ballybunion, on the southern side of the Shannon Estuary (Fig. 3). A pair of key sections of the upper part of the formation occurs near Doonbeg at Killard (Fig. 3). In the following, we divide the Gull Island Formation into two parts, which are lithologically different and which are thought to have different genetic significance within the overall basin-fill.

3.2. Lower part of Gull Island Formation

In the main section at Gull Island (Figs. 1 and 3), the lower part of the Gull Island Formation is 420 m thick. At Fisherstreet on the northern basin margin, the lower Gull Island Formation is only approximately 50 m thick (Fig. 3), but with equivalent facies to the main outcrops around the basin axis in the south. The lower Gull Island Formation is composed of three main lithofacies (Figs. 3–10): (i) rare, thin, undeformed shales, (ii) deformed mudstones, and (iii) tabular and lenticular packages of dominantly fine-grained sandstone beds which also show evidence of soft-sediment deformation.

3.2.1. Shales

Undeformed shales are less than 2 m in thickness and occur in only a few places throughout the formation. The most easily recognised shale bed is at the base of the Gull Island Formation (Fig. 3). This bed contains diagnostic goniatite fauna in two discrete horizons (*R. paucicrenulatum*/*R. dubium*), but it is the upper band (the *R. dubium*) that marks the lower boundary of the Gull Island Formation (Lien, Walker, & Martinsen, 2003). Apart from at Leck Point, Ballybunion, where more than 60 m of sandstones separate them (Fig. 3), the bands are closely spaced in the same shale bed. The closely spaced couplet can be followed around the basin (Collinson et al., 1991), and broadly coincides with the boundary between the underlying Ross Formation and the Gull Island Formation.

Elsewhere within the formation, shales of similar character do not contain diagnostic fauna, although goniatite fragments have been found (T. Elliott, pers. comm., 1998). Thus, they cannot be correlated from section to section.

The shales reflect deposition from suspension of hemipelagic/pelagic material in periods of low sediment supply. The widespread nature of the shale bed at the base of

Fig. 4. Channel sandstone above slump within the lower part of the Gull Island Formation north of Leck Point, Ballybunion. Note the internal low-angle accretion surfaces and multi-storey nature, suggesting multiple phases of cut and fill and some sinuosity to the channel. The cliff is approximately 15 m high. See Fig. 1 for location.

the formation suggests that coarser clastic supply to the basin was shut off for a considerable period of time and possibly reflecting a eustatic highstand (Collinson et al., 1991). The shales higher in the formation probably have a similar origin because of the comparable grain size, but their regional significance cannot be determined given the absence of diagnostic fauna.

3.2.2. Mudstones

Mudstones with high silt content dominate the Gull Island Formation (Figs. 3, 6 and 7). The most pronounced feature is that virtually all mudstone units are deformed by slumping and sliding (Figs. 6–8; Martinsen, 1989; Martinsen & Bakken, 1990). A variety of deformation structures can be observed, but slump folds are most prominent (Fig. 9). They generally take the form of isoclinal sheath folds, but buckling folds are also observed. The slumped units reach more than 50 m in thickness, but some of the thicker units may be composite (Fig. 7).

The mudstones were most likely originally deposited from suspension and formed the background sedimentation in the basin. The pronounced silt character of the mudstones suggests they were supplied by a relatively closely adjacent source or close to a slope. Deformation by slumping could have caused intermixing of lithologies, therefore, sand beds and shales, which were involved in the slumping, might have been thoroughly deformed. However, in many instances, sandstone beds are folded but otherwise their original character is preserved. This suggests that the silty character was a primary character of the mudstones and not caused by intermixing of other lithologies during deformation.

3.2.3. Sandstones

The sandstones within the lower part of the Gull Island Formation are fine-grained and occur in three modes (Figs. 4–10): (i) lenticular, erosive packages, (ii) tabular, thick-bedded packages, and (iii) tabular, thin-bedded packages. The sandstone units vary in thickness between a few metres to up to 50 m, although packages that are less than 10 m are most common (Fig. 3). Individual beds vary between less than 0.05–3.20 m in thickness, but bed thickness between 0.25 and 0.30 m is most common.

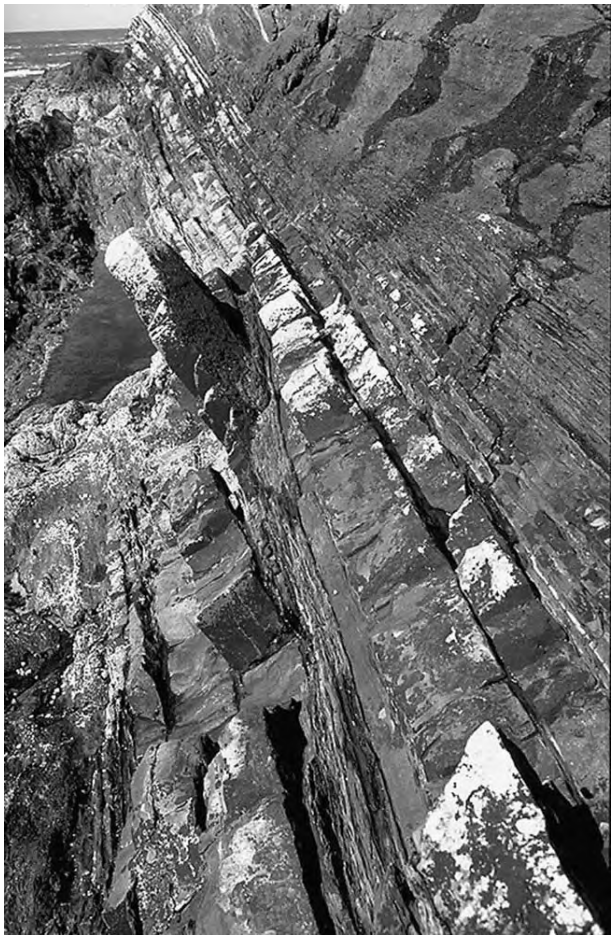

Fig. 5. 1–10 cm thick turbidites in a thin-bedded package in the lower Gull Island Formation at Gull Island. The beds probably represent deposition on channel levees or inter-channel areas.

Fig. 6. Section from the lower part of the Gull Island Formation at Gull Island. Note interbedding between turbidite channel sandstone (lowest part of near cliff) overlain by hemipelagic mudstone, thin-bedded turbidites and a slumped complex. This facies variability characterises this part of the formation. The nearest cliff is 15 m high. See also Fig. 7 for a section through this stratigraphy.

Sharp, sometimes erosive bases and sharp to gradational tops always characterise the individual beds. The thinner beds have more gradational tops than the thicker ones.

Within the thin-bedded tabular packages (Fig. 5), the beds (< 10 cm) are often composed of ripple cross-lamination, and climbing cross-lamination is observed in many beds (Bouma C–E beds). Small-scale convolution and loading of beds is very common. The thin beds are laterally extensive (Fig. 5) and can often be followed over the length of outcrops (i.e. < 100 m). They are also commonly separated by equally thick or thicker mudstone partings. This type of bed is most common away from the Shannon Basin axis in the main Gull Island section (Fig. 1).

The thicker beds, particularly within the lenticular packages (Fig. 4), are often massive and with sole marks (Bouma A–E beds). There may be a thin zone of ripple cross-lamination on the top (Bouma A–C–E beds), but the homogenous nature of the sandstones makes it hard to distinguish structures within the beds, so that horizontally laminated Bouma B-divisions may be under-represented.

The thicker beds are usually separated by very thin partings of mudstones (Fig. 4), and amalgamation of beds is common. In general, the beds are thicker and mudstone partings thinner within the lenticular packages than within the tabular packages.

A noteworthy feature of the thick-bedded tabular packages is thickening-upward trends of the sandstone

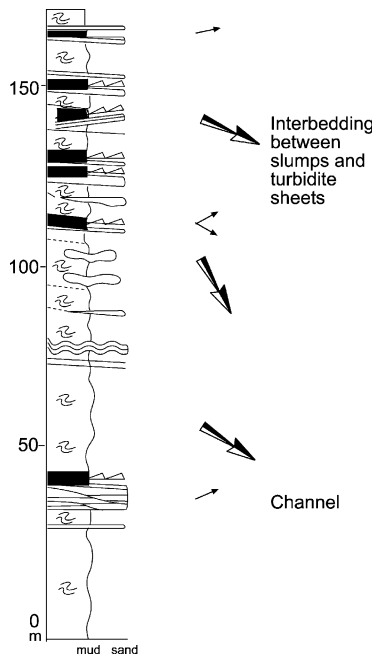

Fig. 7. Log through the 40–210 m level in the lower part of the Gull Island Formation at Gull Island. The logged interval roughly corresponds to the succession shown in Fig. 6, and the channel at the base of the section is the same as the channel at the base of the cliff in Fig. 6. The thick arrows represent paleoslope measurements and the thin arrows paleocurrent measurements.

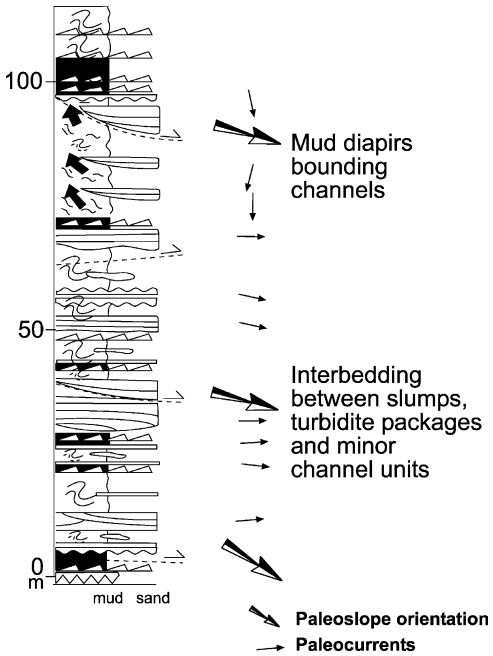

Fig. 8. Section through uppermost part of the lower Gull Island Formation at Carrigaholt (see Fig. 3). Note interbedding between channels, mud diapirs bounding channels and slumps.

beds (Fig. 10). These packages, at the most 3–4 m thick, are repetitive and seem to comprise a thickening-upward sequence above a surface with megaflutes. The trend culminates in several amalgamated beds, whose upper surface is modified locally by megaflutes, which initiate a new package. This packaging trend, which is particularly common in the lower part of the Carrigaholt section, and at Ballybunion (Fig. 3), has been described in detail by Lien et al. (2003) for the Ross Formation, while the megaflutes were described by Elliott (2000b).

Soft-sediment deformation features are rare within the sandstones. This is in marked contrast to the surrounding mudstones that almost without exception are slumped. The thicker sandstone packages show occasional evidence of deformation by sliding.

The lenticular packages are interpreted to represent shallow channels because of their bed types, bed amalgamation, erosive bases and external shapes. The thick-bedded tabular units are interpreted to record deposition in or on margins of channels, or are splays at the front of channels. The interpretation of Lien et al. (2003) for the Ross Formation is followed, in that the thickening-upward packages are inferred to result from progressive splay onto channel margins as nearby channels filled. The specific stratigraphic position, where the thickening-upward packages are recognised within the Gull Island Formation at Carrigaholt and Ballybunion (lowermost part and near basin axis) is significant in a wider stratigraphic context and will be discussed below.

The thin-bedded packages within the Gull Island Formation are interpreted to represent deposition on channel levees or channel margins because of their bedding characteristics and sedimentary structures. The high proportion of cross-lamination, climbing cross-lamination and bed convolution suggest deposition with a higher rate of suspension fall-out, which is common on levees (Walker, 1992).

Because of outcrop limitations laterally, it is difficult to demonstrate the spatial relationships between the thick- and thin-bedded tabular packages or sheets and the interpreted channels. Lien et al. (2003) document such lateral relationships in the Ross Formation, and similar

Fig. 9. Isoclinal slump fold within the lower Gull Island Formation at Fisherstreet on the northern basin margin. The slump is truncated by two overlying tabular packages of turbidites representing interchannel or frontal splays.

Fig. 10. Thickening-upward packages of thin-bedded turbidites in the lower part of the Gull Island Formation north of Leck Point, Ballybunion. Note backpack for scale.

relationships are inferred for the lowermost Gull Island Formation in the outcrops closest to the Shannon Estuary (Fig. 1).

3.2.4. Deformation styles

More than 75% of the lower Gull Island Formation is deformed by soft-sediment deformation, and particularly by slumping and sliding (Fig. 3). The movement distances of the slides involving sandstone packages were probably very small and not exceeding several tens of metres. It is less easy to assess movement distances for mudstone slumps. Many slumped units are thoroughly deformed and have basal décollements in addition to having severe internal deformation (Fig. 9). Thus, most slumps were not 'rooted', with deformation taking place over a fixed base, but probably travelled some distance. Yet, the silt-dominated mudstone lithology in the deformed units is totally dominant, and there is little evidence of mixture between an external lithology transported in with the slumps and a 'normal' background lithology. Therefore, it is assumed that the slumps in most instances travelled some distance (maximum several kilometres), but were not introduced from an area with a different lithology.

There is no significant change in lithology between the different outcrop localities, which are separated by up to several tens of kilometres. This fact lends no support to either short- or long-distance transport of slumps. Slump scars are not observed within the lower part of the Gull Island Formation, suggesting that this depositional setting received products of slope instability, and was not the site of initiation of instabilities.

The abundance of slumping in the mudstones and lack of significant soft-sediment deformation within the sandstones is peculiar. One would also expect the sandstones to be consistently deformed if deposition took place on a slope as originally suggested by Martinsen (1989).

3.3. Upper part of Gull Island Formation

The upper part of the Gull Island Formation is lithologically different from the lower part, and compares with the lower part of the overlying Tullig Cyclothem. The boundary between these two units is gradational and hard to define. Most likely, there is a genetic link between them. The Tullig Cyclothem is deltaic in origin and contains several shallow-water and delta front sandstones towards its top (Pulham, 1989; Fig. 3).

The upper part of the Gull Island Formation and the lower part of the Tullig Cyclothem are together approximately 200 m thick in the main section at Gull Island, while

the equivalent section at Fisherstreet/Cliffs of Moher on the basin margin is almost equally thick (Fig. 3). At Carrigaholt, closer to the basin axis than Gull Island, the estimated thickness of the lower Tullig-upper Gull Island unit is around 220 m (Fig. 3).

Two different facies are identified within the upper part of the Gull Island Formation: (i) mudstones with increasing silt content upwards, and (ii) isolated, rare sandstones.

3.3.1. Mudstones

These mudstones are comparable to those in the lower part of the Gull Island Formation. However, very close to the base, distinctive silty laminae appear, and the mudstones grade upwards into siltstones with progressively coarser laminae. In all investigated sections, the same coarsening-upward trend of the silty mudstones is obvious (Fig. 3). At around 130 m of section below the first deltaic sandstone in the Gull Island section (Fig. 3), wave ripples occur on bedding planes. From this point upward, the siltstones become cleaner and grade upwards into thicker sandstones that in places show evidence of storm influence such as hummocky and swaley cross-stratification. Spectacular examples of sliding occur within this part of the section (Martinsen & Bakken, 1990).

The silty mudstones were deposited from suspension. The coarsening-upward character indicates increasing proximity to the source, and thus progradation. The cleaner laminae below the level, where wave ripples are first observed, suggest periods of higher sediment input, perhaps related to floods. An alternative interpretation is slight agitation of the sea bottom by waves, but too deep to create ripples.

3.3.2. Sandstones

In contrast to the lower part of the Gull Island Formation, sandstones are generally absent between the top of the lower Gull Island Formation and the base of the first deltaic sandstones within the Tullig Cyclothem (Fig. 3). Rare isolated thin beds and lenticles of sandstone occur in places within deformed units. However, at Cliffs of Moher in the north, and at Killard, in an intermediate locality between the basin axis and the northern basin margin (Figs. 3 and 11), two 10–15 m thick lenticular sandstones occur with erosional bases. Lithostratigraphically, these sandstones are within the lowermost part of the Tullig Cyclothem, but occur within the overall coarsening-upward succession and are cut into silty mudstones.

The example at Cliffs of Moher (Fig. 11) is best exposed and shows a 15 m thick and more than 200 m wide, winged lenticular sandstone. Internally this sandstone contains stacked, partly amalgamated beds of massive to laminated (Bouma A–B) turbidites, which thin and lap on to channel margins. The uppermost sandstones extend out across the main sandstone body margins.

The stacked sandstones are interpreted to represent deposition of turbidites within isolated channels. The winged appearance of the channel at Cliffs of Moher suggest progressive fill of a pre-cut erosional topography.

3.3.3. Deformation styles

Soft-sediment deformation is present at several stratigraphic levels, both within the Gull Island Formation and the Tullig Cyclothem. There is much less evidence of deformation in the upper part of the Gull Island Formation than in the lower. Only 10–25% of the upper Gull Island Formation is deformed by sliding and slumping (in contrast to 75% in the lower part). Deformation is most common in the south, in the Gull Island section (Fig. 3). In the north, at Fisherstreet/Cliffs of Moher, very little deformation is observed (Figs. 3 and 11).

Soft-sediment deformation style also differs considerably between the lower and upper Gull Island Formation. Several slump scars occur in the upper part, and large extensional faults are also observed (Martinsen & Bakken, 1990).

3.4. Paleoflow and paleoslope data

Paleoslope data, such as the orientation of fold axes and axial planes, thrust faults, backthrusts and normal faults within slumps and slides, were measured continuously through the Gull Island Formation (Fig. 12). Because the deformation style was dominated by simple shear, sheath folds are the dominant deformation structures (Fig. 9). These directional fold structures are individually very variable in orientation along their axes, so a large number needs to be measured to achieve a trustworthy regional trend. A large number of measurements are also necessary for thrust and normal faults, because these are commonly curved in plan view. A single two-dimensional outcrop can thus easily leave a false view of the true orientation of the structures.

The different structures consistently suggest that principal stresses were oriented WNW–ESE (Fig. 12). This suggests that there was a paleoslope facing to the ESE–SE. The measurements were taken from both the upper and lower parts of the Gull Island Formation and apparently show no significant variation between the two parts.

Paleocurrent data show another trend. Measurements of ripple cross-lamination in the lower part of the Gull Island Formation show transport of turbidity currents towards the northeast (Fig. 13-1 and 13-2), similar to the underlying Ross Formation (Lien et al., 2003). Note that the upper 200 m of the lower Gull Island Formation shows a bimodal paleocurrent trend, with a subordinate direction towards the east–southeast (Fig. 13-2). The east–southeast trend is dominant in the measurements of ripple cross-lamination in the upper part of the Gull Island Formation (Fig. 13-3). Sole marks from the lower part of the Gull Island Formation are consistent with the ripple cross-lamination and show a SW–NE trend (Fig. 13-4). Bimodal grooves and unimodal flutes and tool marks were grouped into the same rose diagram to illustrate the full trend of sole marks. Sole marks from

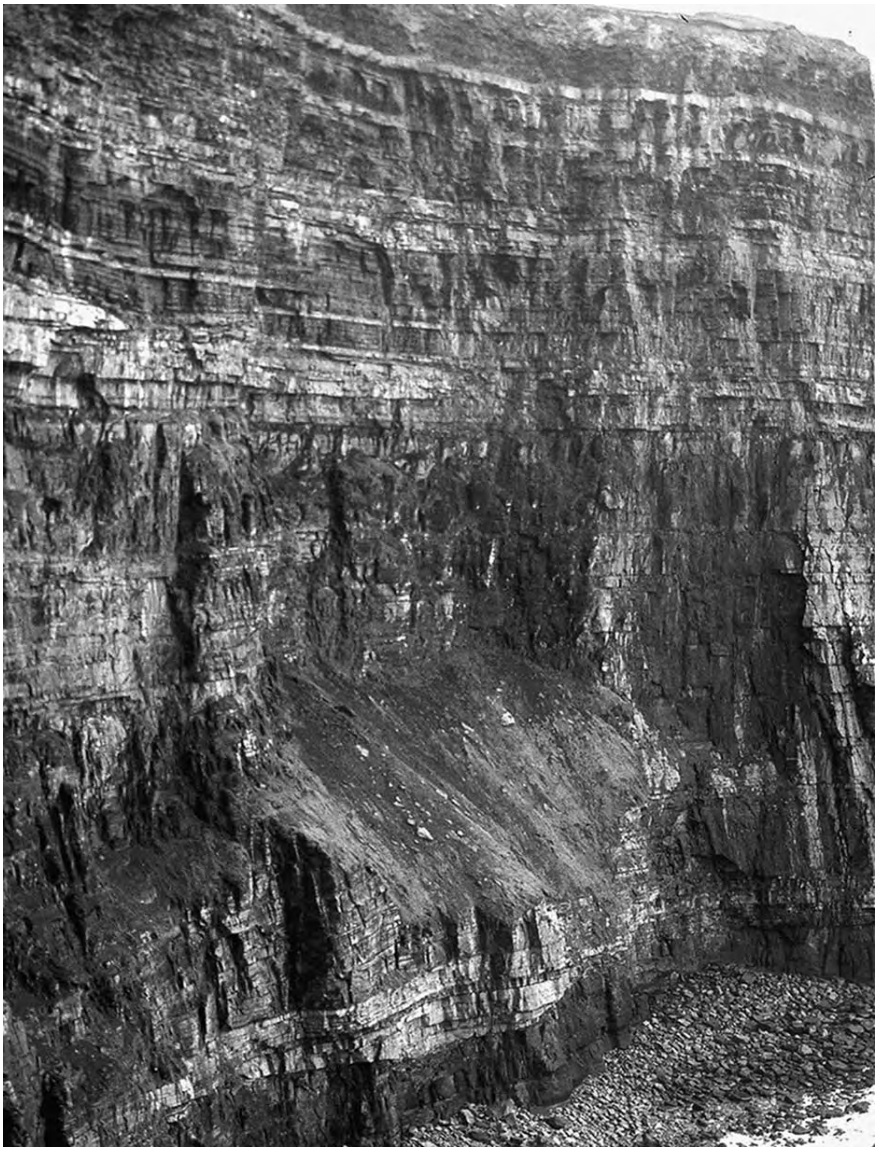

Fig. 11. A turbidite-filled erosive channel occurs at the base of the Cliffs of Moher within the transitional strata between the upper Gull Island Formation and the Tullig Cyclothem. The channel is seen at the base of the cliff. The cliff is more than 200 m high and records the upward progradation into delta top sediments within the Tullig Cyclothem.

the upper part of the Gull Island Formation were not possible to collect given the sparse and thin sandstone beds with few sole marks developed.

Pulham (1989, his Fig. 19) interpreted the Tullig Cyclothem to record progradation to the E–SE, although significant local variability occurred, as anticipated in a largely fluvial-dominated delta. In fact, Pulham's (1989) model roughly depicts a lobate system with overall more SE-directions in the south and more NE-directions in North Clare, in a more lateral setting. Such a model accords with the inferred lobate shape of the upper Gull Island slope (Martinsen, 1989). Some of the more local variability shown by Pulham (1989) is that several mouth bar sandstones of the Tullig Cyclothem prograded towards the E–NE. The overlying fluvial sandstones show paleoflow to the NE. These sandstones were initially interpreted by Pulham (1989) as distributary channel sandstones, but have later been reinterpreted as incised valley-fill sandstone, unrelated to the mouth bar sandstones (Elliott & Pulham, 1990).

Throughout deltaic deposition in the basin, wave ripples suggest wave approach from the SE, supporting a NE–SW oriented coastline (Pulham, 1989). This interpretation is clearly contradicting an E–W oriented regressive coastline within a northerly prograding deltaic system of Wignall and Best (2000). The latter authors showed very little paleocurrent data to support their model, and based their

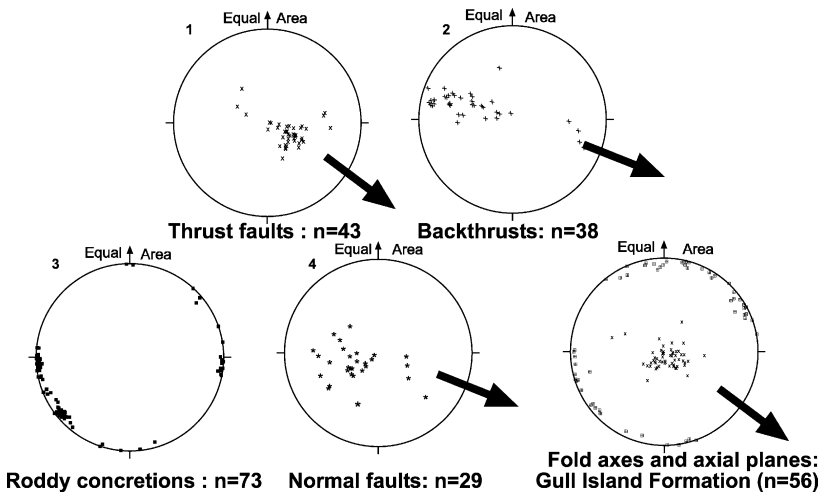

Fig. 12. Paleoslope data from the Gull Island Formation. Note the consistency of the data in defining a paleoslope, which faced towards the SE.

interpretation on observations of single locality examples, rather than a series of statistically reliable measurements throughout the Gull Island Formation and the Tullig Cyclothem.

The Kilkee and Doonlicky Cyclothems, which overlie the Tullig, show progradation directions towards the SE (Pulham, 1989, his Fig. 14). Thus, over time, the preferred progradation direction of deltaic deposits seems to have been similar to that of the slope of the Gull Island Formation. Variability exists, particularly within the Tullig Cyclothem, but it is believed that over time easterly and southeasterly directions of progradation of the slope and deltaic systems prevailed. The northeasterly directions observed within the Tullig Cyclothem may be local variability, perhaps laterally on an overall easterly to southeasterly prograding deltaic system. The axis of this system may have been located, where the Shannon Estuary is and where subsidence was highest, based on thickness data (Pulham, 1989; Figs. 2 and 3).

3.5. Temporal and spatial variability of facies

3.5.1. Thickness variations

The only two sections with a complete exposure of the Gull Island Formation are at Gull Island and at Fisherstreet (Fig. 3). However, based on structural restoration, the section at Carrigaholt is estimated to be approximately as thick or slightly thicker than the Gull Island section (Fig. 3). The position of the diagnostic faunal band couplet, *R. paucicrenulatum*/*R. dubium*, at the base of the formation, and the top level of the first deltaic sandstone within the overlying Tullig Cyclothem (roughly parallel to biostratigraphically constrained datum of *R. stubblefieldi*; Fig. 3), place the other sections of the Gull Island Formation in a regional framework, where lateral comparisons are possible (Fig. 3).

The boundary between the lower and upper parts of the Gull Island Formation is based on two significant criteria. (i) The boundary forms the base of the coarsening-upward profile culminating in the delta front and top deposits of the Tullig Cyclothem. (ii) Thick-bedded turbidite sandstones are absent above this line apart from isolated channel sandstones.

Regional correlation suggests that the lower part of the Gull Island Formation fills in a major depression centred on the Shannon Estuary (Fig. 3). Despite the thickness variations, the facies are consistent between sections. The upper part of the Gull Island Formation and the lower part of the Tullig Cyclothem have a much more uniform thickness distribution (Fig. 3), with an increase towards the south. The boundary between the two parts of the Gull Island Formation is gently inclined towards the south, and would be more inclined if the top marine band, the *R. stubblefieldi*, had been used as a datum (Fig. 3).

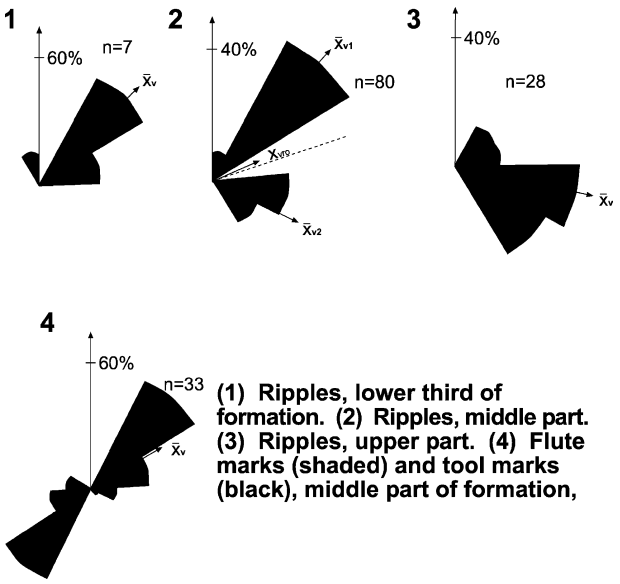

Fig. 13. Paleocurrent data from the Gull Island Formation.

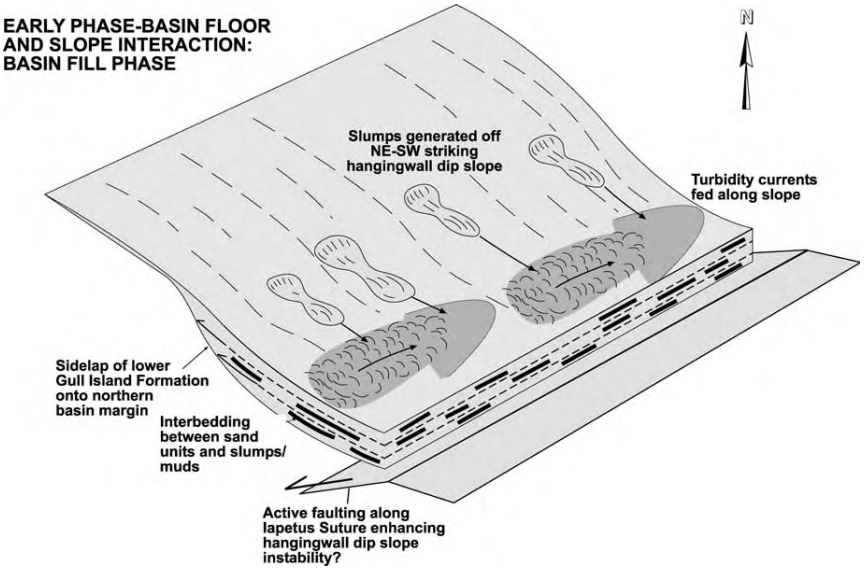

Fig. 14. Depositional model for the lower part of the Gull Island Formation.

3.5.2. Variability in sandstone proportion and slump thickness

Very detailed measurements of bed thickness within all sections apart from at Ballybunion (where many beds are inaccessible) have allowed for a close comparison of sandstone proportions within the lower part of the Gull Island Formation (Table 1). In addition, slump thicknesses are compared with the data from the sandstone beds.

The sandiest parts of the formation occur at Ballybunion and Carrigaholt, where there is, respectively, 25% (estimated due to inaccessibility) and 22% sandstone. At Gull Island, Killard and Fisherstreet, the sandstone proportion is lower (11, 14 and 13%, respectively). The same trend is also shown in the mean bed thickness, where the highest values occur at Ballybunion and Carrigaholt (Table 1). At Gull Island, the average bed thickness is 22 cm, while it is 47 cm at Killard and 18 cm at Fisherstreet. The anomalously high value at Killard is explained by the fact that this section penetrates two channel complexes with very thick beds (Fig. 3). The overall sandstone proportion in this location is very low (Table 1). The highest proportion of sandstone occurs in the lowermost part of the Carrigaholt section, where 56% of the section is sandstone. A similar value is estimated for the equivalent interval at Ballybunion (Table 1).

Interestingly, the thicknesses of slumps are inversely proportional to the sandstone content (Table 1). In the two sections, where a high enough number of slumps were measured to be statistically significant (Gull Island and Carrigaholt), the average slump thickness is 7 and 3 m, respectively. Thus, the highest proportion of sandstone occurs in the lowermost part of the formation and in the axial positions of the basin close to the Shannon Estuary. The thickest slumps seem to occur some distance away from the actual basin axis. The sections furthest away from the basin axis, such as Killard and Fisherstreet, have less slump units and low sandstone proportion in relation to the basin axis localities (Table 1). Therefore, it is the proportions of facies and not the types that vary between localities from basin axis to basin margin.

Table 1
Sandstone parameters measured within the lower part of the Gull Island Formation

Area	Ballybunion	Carrigaholt	Gull Island	Killard W	Fisherstreet
Section thickness (m)	125	300	420	160	130
Number of beds		245	203	49	36
Maximum bed thickness (cm)		320	160	280	60
Mean bed thickness (cm)	30*	27	22	47	18
Sandstone proportion (N/G)	25*	22	11	14	13
Mean slump thickness (m)		3	7		

* signifies estimated values.

4. Stratigraphic and depositional model

4.1. Contrasts between the lower and upper parts of the Gull Island Formation: onlap vs. downlap

The lower part of the Gull Island Formation decreases significantly in thickness from basin centre to basin margin (Fig. 3), has turbidite sandstones of different types, shows numerous slumps and the sandstone proportion and mean bed thicknesses decrease from basin centre to basin margin at the expense of an increase in slump thickness (Table 1). In contrast, the upper part of the formation coarsens up, has only isolated turbidite channel sandstones, and is more or less equally thick from basin centre to basin margin. These contrasts are interpreted to represent two different types of deep-water sedimentary systems, which are outlined in more detail below.

4.1.1. Lower part: onlapping, basin floor system

The lower part of the Gull Island Formation is best explained as an onlapping/sidelapping, basin floor system (Figs. 3 and 14). Martinsen (1989) and Collinson et al. (1991) suggested that the entire formation was linked and represented an advancing slope succession.

Paleocurrent measurements suggest that turbidity currents flowed along the basin axis towards the NE–ENE (Fig. 13). These deposits become less frequent and thinner towards the north (Table 1), suggesting gradual encroachment onto a basin margin. The paleoslope data show that slumps were derived from the NW and transported to the SE (Fig. 12), perpendicular to the turbidity current flow. At Fisherstreet in the north, the paleoslope data from one slump show transport towards the NE, suggested by Martinsen (1989) to indicate a lobate shape of the paleoslope. In addition, this location probably was not an active depositional site until the southern low area around the Shannon had been filled. At this time, the topographic control was less, if existent, and sediment supply could spread more widely.

The abundance of slumps shows that the slope from which they were derived was highly unstable. Most likely, the turbidites were not deposited on this lateral slope but very close to its base (Fig. 14). The high sandstone proportions at Ballybunion and at Carrigaholt strongly suggest that these locations were close to the basin axis, whilst the lower sandstone proportion and increasing number and thickness of slumps at Gull Island suggest that this location was closer to the unstable lateral slope (Fig. 3), and perhaps even in the transitional zone. Given that continued differential subsidence took place, the margins of the onlapping, basin floor system probably became gently inclined in a progressive manner. This process would have enhanced further slumping from the margins, and can also explain the rare presence of deformation within the sandstone units.

The abundance of slumping in mudstones in the lower part of the Gull Island Formation is apparently difficult to reconcile with a basin floor interpretation. The abundant slumping led Martinsen (1989) to interpret the entire Gull Island Formation as a slope system. The largely undeformed, tabular sandstone packages or sheets that dominate the lower part of the Gull Island, are more likely to have been deposited on a basin floor than on a slope. In contrast, the muddy slumps probably originated on the nearby slope (also indicated by their lithology) and travelled to near the foot of the slope or on to the adjacent basin floor. This seems to be the only likely alternative for why undeformed, tabular turbidite packages are interbedded with thoroughly deformed slumps.

The simplest interpretation is that the decreased sandstone thickness towards the north shown by the contrast between the Shannon Estuary outcrops and Fisherstreet, and the contrasts in paleocurrent and paleoslope data, result from onlap/sidelap of a mud-rich turbidite system, supported by the regional correlation (Fig. 3). Another argument is the overall stratigraphic pattern from the Clare Shales through the Ross Formation, the Gull Island Formation and the Tullig Cyclothem. Biostratigraphy and thickness differences, which decrease with time between the Shannon Estuary region and the basin margins to the north and the south (Fig. 2), strongly indicate the existence of a central basin trough that was progressively filled, and where differential subsidence decreased with time (Collinson et al., 1991; Martinsen & Collinson, 2002). Such ongoing differential subsidence may have contributed to the continued instability of rapidly deposited sediments, causing gliding of slumps and slides back towards the basin axis.

Gradual encroachment by the onlapping lower Gull Island Formation onto the basin margin culminated with turbidites reaching the northern margin at Fisherstreet (Fig. 3). This locality probably represented a basin high that suffered condensation through most of the early Namurian history of the Shannon Basin (Collinson et al., 1991; Martinsen & Collinson, 2002). It could only have received turbiditic sediments once the central depression of the basin had been filled and margins onlapped. Other stratigraphic scenarios are unlikely (e.g. downlap suggested by Wignall and Best (2000)) because of the facies and thickness distribution, and regional correlation (Figs. 2 and 3; Martinsen & Collinson, 2002; Pulham, 1989).

4.1.2. Upper part: prograding delta slope system

The coarsening-upward profile, similar thicknesses and gross decrease of turbidite sedimentation (Fig. 3) suggest that the basin physiography and bathymetry started changing during deposition of the upper part of the Gull Island Formation. We interpret these characteristics to represent the early progradation of the Tullig delta system slope (Figs. 3 and 15). The absence of turbidites and presence of slump scars are explained by an increase in depositional gradient so that turbidity currents bypassed the slope in isolated channels. The channels were filled during abandonment. The coarsening-upward trend records increasing

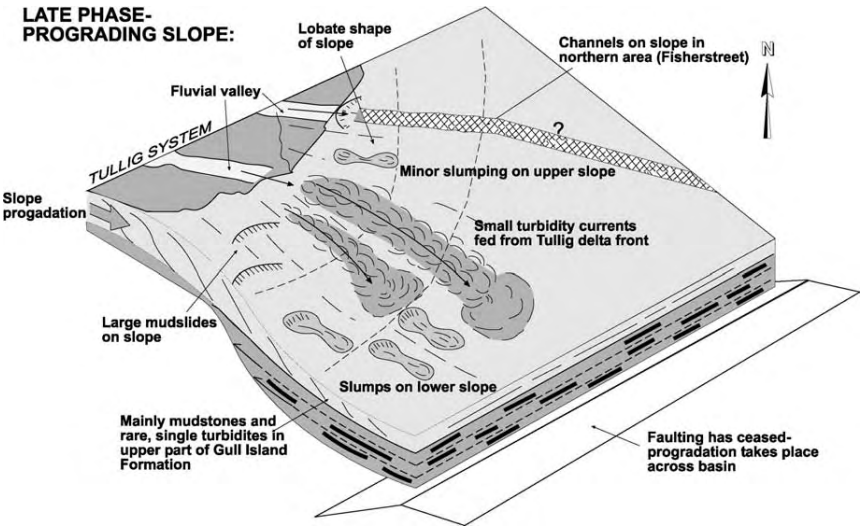

Fig. 15. Depositional model for the upper part of the Gull Island Formation.

proximity to the delta front. An obvious inherent part of prograding systems is that they downlap down onto underlying stratigraphy (Figs. 3 and 15). Therefore, a consequence of the facies interpretation is that the boundary between the lower and upper Gull Island Formation is a downlap surface (Fig. 3). The direction of progradation was initially to the southeast, based on paleoslope data (Fig. 12), and supported by the directional data and depositional model of the Tullig Cyclothem (Pulham, 1989).

Lenticular channel sandstones are the only coarser lithology below the delta top sandstones within the overall coarsening-upward, progradational succession. These sandstones are only observed in two sections (Fisherstreet and Killard east section; Fig. 3), but their limited lateral extent suggests that similar lenticular sandstones could be present between the widely separated outcrop sections

4.2. Sequential organization and relation to basin tectonics

4.2.1. Tectonic control on basin topography

It is possible that the abundant slumping and differential subsidence during deposition of the lower Gull Island Formation were driven by reactivation of a master fault along the Shannon Estuary axis, parallel to the Iapetus Suture zone (Fig. 14). There is no data to show whether the detailed distribution of thickness in the basin was symmetric or asymmetric. However, faulting more easily drives differential subsidence, and a perfectly symmetric distribution of thickness is difficult to explain by simple sag, particularly in an apparently narrow basin (Fig. 2). Therefore, the preferred interpretation is that the Ross and Gull Island Formations filled a reactivated half-graben with a master fault along its southern margin (Figs. 3 and 14; Lien et al., 2003). Slumping, therefore, may have taken place down the continuously downwarped hangingwall dip slope of the reactivated half-graben (Fig. 14), but whether the proposed fault broke surface anywhere is unknown.

It is likely that inferred movement along a Shannon fault, as implied in Fig. 14, had ceased during the deposition of the upper part of the Gull Island Formation (Fig. 15), to allow for the progradation of the deltaic slope into the basin. Therefore, fault movement along a reactivated basement fault may have driven changes of accommodation within the deep water Shannon Basin.

4.2.2. Sequence stratigraphy and slope accommodation

It is tempting to interpret the stratigraphic superposition of a downlapping system above an onlapping system in a traditional sequence stratigraphic fashion, whereby the latter was deposited during falling and low sea level as a lowstand systems tract, and the former during high sea level as a highstand systems tract. The boundary between the two systems would then be a maximum transgressive surface and a regional downlap surface (Fig. 3). Such reasoning may be applicable, but several other factors must be considered. The lower part of the Gull Island Formation overlies a very sand-rich onlapping turbidite system, the Ross Formation (Lien et al., 2003; Martinsen et al., 2000). The sand-rich nature of this system may suggest that this was the falling stage during basin-fill when clastic supply systems were very close to the basin shelf edge and supplied large quantities of sand to the deep water areas. Thus, the lower part of the Gull Island Formation could record late lowstand conditions followed by highstand conditions during the deposition of the upper part. Such a scenario can explain the lithological variations in a traditional sequence stratigraphic scheme.

A more appropriate way of considering this succession is by relation of facies and thicknesses to accommodation generated by local, basin-scale differential subsidence (see above). If differential subsidence was initially very high

during deposition of the Ross Formation, supplied sandstones were largely trapped and ponded within the Shannon Basin because of basin topography. The change to a mudstone-dominated setting within the lower part of the Gull Island Formation might suggest that differential subsidence and accommodation generation decreased, causing topographic in-filling and allowing bypass of sand to an equivalent basin down slope. In effect, the transition might have been augmented by a change from ponded to healed slope accommodation on the lower slope. In such settings, sands tend to accumulate at the base of slope (Prather, 2003) as interpreted for the Gull Island Formation. Whether an outboard ridge controlled a graded slope profile, comparable with the Sigsbee escarpment in the Gulf of Mexico case (Prather, Booth, Steffens, & Craig, 1998) is unknown.

Broadly, time-equivalent strata in northern England, in a similar basin context, show a similar development, where deep basins were progressively filled from north to south, and where mudstone-dominated slope successions succeeded sand-rich basin floor turbidite systems. There, turbidite deposition spilled to the next basin when an updip basin had been filled (Collinson, 1988). However, in these examples, there is less evidence for a mud-dominated basin floor between the sand-rich turbidites and the prograding slope. Because of later uplift and erosion, there is no evidence for a cascading basin regime in Western Ireland, but the comparable extensional tectonic context suggests that it is possible.

In summary, two explanations are possible for the change in dominant lithology from sandstones in the Ross Formation to mudstones in the Gull Island: (i) regional sea level with falling-early lowstand stage during Ross time and late lowstand during early Gull Island time, and (ii) local basin accommodation controlled by subsidence, with initial ponding (Ross), later bypass with response to a healed slope accommodation (lower Gull Island) and final response to a graded slope profile (upper Gull Island and lower Tullig Cyclothem; see below). Model (ii) is preferred, as it better explains the abundant slumping. It was not until late lower Gull Island time that turbidites reached the basin margin position at Fisherstreet, and by this time, bypass must have occurred when lateral margins were overtopped. However, a sill at the distal, northeastern end of the basin might have been lower than the lateral northern and southern basin margins, so bypass could have occurred significantly earlier, supporting the interpretation of the lithological change from the Ross to the Gull Island.

The interpreted progradation of the upper Gull Island Formation–Tullig Cyclothem succession did not take place until the local topographic accommodation space within the Shannon Basin had been filled (Fig. 3). It is likely that this system reacted to regional, graded slope accommodation controlled by sea level and regional tectonics and not to local bathymetry. The ratio of accommodation generation to sediment supply probably diminished in response to decaying differential subsidence, allowing for progradation across the basin (Collinson et al., 1991).

4.2.3. Smaller-scale sequence organization

As with fluvial and nearshore marine sedimentary systems, it is tempting to try to resolve the stratigraphic organization of deep-water facies successions at higher-resolution than at basin-scale. The three dominant facies, slumps, turbidite deposits and hemipelagic mudstones are available for such analysis. They are potentially similar to cyclic mass-transport complexes, turbidite sheets and channels, and draping condensed deposits, for example, observed on modern submarine fans (Walker, 1992 for a summary discussion). However, a few limiting factors are worth noting. To believe in a higher-frequency cyclic control, the different facies must be temporally separate and they must be derived from more or less the same source. In addition, the cyclic pattern must be repetitive and laterally traceable, i.e. it cannot occur in one section and not in the others.

In the present case, the only traceable condensed horizons are the goniatite-bearing marine bands at the top and within the Ross Formation (Figs. 2 and 3). Such bands are not recognised within the Gull Island Formation, although a few candidate horizons occur, but without diagnostic goniatites. Moreover, these horizons cannot be traced between sections (Fig. 3).

Furthermore, the slumps were probably derived from a lateral slope and not from the same source as the turbidites. Thus, it is likely that turbidite sedimentation occurred at the same time as slumping so that these events were not temporally but rather spatially separate. Slumps and turbidite units cannot be correlated from section to section.

5. Discussion

Onlapping/sidelapping turbidite systems in confined basins are probably controlled by local, fault-driven topographic accommodation, while prograding, delta/shoreline-fed slope systems with turbidites are in this and many other instances controlled by regional accommodation associated with relative sea-level changes. The nature and rate of sediment supply is vital in controlling the way in which these two different systems develop.

Turbidite systems that onlap/sidelap margins of confined, elongate basins are commonly axially fed (Macdonald, 1986; McCaffrey & Kneller, 2001), such as implied for the lower part of the Gull Island Formation. Accommodation in such basins is controlled by local deep-water topography (a function of local tectonics) and not by sea level (Prather et al., 1998). Whether this local accommodation gets filled depends on sediment supply and local tectonics. Furthermore, basins which experience periods of very high subsidence have their clastic supply shut off temporarily because drainage systems are reorganised (Biddle &

Christie-Blick, 1985 and references therein). Black shale successions with source potential dominate the lowermost Namurian successions in northwestern Europe (Besly & Kelling, 1988 and references therein). These fine-grained rocks were deposited immediately following maximum extension and subsidence (Gawthorpe, 1987), and this model also applies to the Clare Shales in the Shannon Basin.

If several confined basins line up from the sediment source and basinwards, inboard basins must be filled before outboard basins can receive sediments. This scenario is important in the Gulf of Mexico minibasin region (Badalini, Kneller, & Winker, 2000; Prather et al., 1998), and in the California borderland. For the Shannon Basin and surroundings, we do not have sufficient data to show whether this was the case. However, similar basins in northern England show this style of basin filling (Collinson, 1988). Because the tectonic situation compares, it is not unreasonable to suggest that other extensional basins or half-grabens may have existed to the north or south of the Shannon Basin.

A final, relevant point is the change of sediment supply from calciclastic to siliciclastic, which characterises the end-Dinantian of many British Carboniferous basins. Such a change demands time to be effective since siliciclastic sediments are derived from extrabasinal sources and new drainage routes must be set up or invigorated. In the case of the Shannon Basin, a prolonged lag time from the carbonate-dominated setting, which prevailed until late Dinantian, to the siliciclastic setting in the middle Namurian would have provided time in which enhanced differential subsidence occurred with little sediment supply to fill the growing local accommodation. With onset of sand supply, onlapping basin floor and slope systems, rather than progradational systems controlled by regional sea level and high sediment supply, prevailed until local topography was eliminated.

Prograding, shoreline/delta-fed slopes and fans with turbidites are frequently mud-dominated (we exclude coarse-grained deltas and fan deltas in this discussion: Colella & Prior, 1990; Nemec & Steel, 1988), and the upper part of the Gull Island Formation and the Tullig Cyclothem is an example of this. Large rivers with a high proportion of suspended sediment load feed many such systems and they develop during highstand of sea level. A notable exception is the Eocene Tyee Formation in Oregon, which is very sand-rich (Heller & Dickinson, 1985). Development of turbidites in such systems is dependent on other factors on the width of the shelf (e.g. Droz et al., 1996) and sea-level stand (Weimer, 1990). Prograding systems do not necessarily develop downslope turbidite systems, particularly if the regional available accommodation is high, thus preventing sand transport to the shelf edge. There is inadequate regional data to show whether the upper Gull Island–Tullig system had turbidites at the base of its slope, but it is not a necessary consequence of the model. This slope system is separated in time from the underlying confined basin turbidite systems, which were controlled by local accommodation. In addition, the stratigraphically equivalent units in North County Cork, in the direction of which some of the progradation took place, do not show base-of-slope turbidites (Fig. 3; Morton, 1965). Most likely, therefore, the turbidites within upper Gull Island–Tullig slope system were limited to relatively small channels fed from delta front areas (Figs. 11 and 15).

6. Conclusions

Outcrop successions, where detailed facies and lithology information can be combined with regional stratigraphy and basin-fill patterns, are very useful for application to subsurface situations. In the subsurface, lithological and detailed architectural information are not usually retrievable because of seismic resolution. High-resolution 3D seismic allows for invaluable plan view images of turbidite systems (Weimer et al., 2000 and references therein). Therefore, linking outcrop information with seismic images is very important for assessing turbidite systems. With present technology, this is not a straightforward procedure given the scale and resolution difference between most outcrops and seismic surveys.

The Shannon Basin outcrops are still valuable as analogues for subsurface studies. We summarise some of the main points below (compare with Fig. 3 and Table 1):

(1) The Gull Island Formation in the Shannon Basin in Western Ireland is part of a more than 1200 m thick deep-water basin-fill succession. The mud-rich formation can be divided into two parts: (i) a lower onlapping turbidite system with axially fed shallow channels, channel margin sheets and levee deposits and strongly influenced by slumping; and (ii) an upper progradational system connected to overlying deltaic deposits with isolated turbidite-filled channels and fewer, but larger deformation structures signifying its slope origin.
(2) The lower part of the Gull Island Formation shows reservoir-type sandstones in a mud-rich turbidite system interpreted as healed slope accommodation developed above ponded accommodation (Ross Formation). Sheet and channel sandstones with the highest net/gross values (Table 1) are thickest and best developed in the lowermost part of the formation and near the basin centre, at the foot of the slope.
(3) Potentially prospective sandstones also occur away from the basin axis at several intervals within the onlapping succession of the lower Gull Island Formation. The best sandstones in these locations are limited to channels, are thinner, and would be multi-pay, stacked intervals in the subsurface.
(4) The potential reservoir intervals are bounded by thick, slumped silty mudstone intervals. The lateral extent of these potential barriers exceeds the scale of outcrops

(>300 m). Thin, hemipelagic shales are rare, but are potentially basin wide (>15 km) in extent and represent condensed horizons of probable eustatic origin.

(5) With time, and when the local, ponded and healed slope basin accommodation was close to being filled, potential reservoir sandstones also occur on basin margins, shown by the turbidite packages at Fisherstreet, on the northern Shannon Basin margin. Therefore, potential reservoir sandstones are considered to be laterally more extensive during late stages of fill than in the early phases. Nevertheless, assuming that sand supply stayed constant, overall reservoir potential decreases because sandstones became more spread out and not concentrated along the basin axis as seen in the lower part of the Gull Island Formation.

(6) The upper part of the Gull Island Formation and the overlying deltaic deposits were controlled by regional accommodation probably related to sea level or regional tectonics. Potential reservoir sandstones within this prograding, mud-rich delta-fed slope were limited to isolated channel sandstones. This slope probably developed to grade as a response to decayed or ceased differential subsidence in the basin, increased sediment supply and regional sea level.

(7) Both the two parts of the Gull Island Formation can be compared with subsurface turbidite successions. The lower part, together with the underlying Ross Formation, shows close comparisons with deep-water stratigraphy in confined basins, where local tectonics play a major role. The upper part compares with progradational deltaic shelf margins, many of which are mud-prone and where reservoir potential is limited.

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