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The genesis of exceptionally thick shallow marine sequences exposed within the South Munster Basin of southern Ireland.

Jamie G. Quin

Thesis submitted to the University of Dublin (Trinity College) for the degree of Doctor of Philosophy.

October 2001

Declaration

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Abstract

The South Munster Basin (southern Ireland) is an E-W trending fossil rift system that was active during the Late Devonian and Early Carboniferous. Subsidence during this period was rapid and led, despite a high sediment flux, to transgressive replacement of continental by shallow then deeper marine settings. One of the most striking features about the resultant succession is that it includes unusually thick paralic and shallow marine sequences (often > 1km) and these in turn contain exceptionally thick sandstone rich packages (often > 300m). Although these superficially resemble prolonged episodes of continuous sedimentation, detailed logging of 19 coastal sections (~ 5.2 km vertical section) indicates that these packages are actually composed of numerous small-scale sequences each separated by a sequence boundary. What is unusual about this sequence therefore, is that individual sequences are stacked in space over many cycles of relative sea-level change and are not, as is more commonly found, widely distributed. The main control upon this stacking pattern is thought to have been the juxtaposition of a rapidly subsiding basinal area with an isostatically stable basin margin region as this pinned the maximum landward extent of the coastline during successive cycles of relative sea-level change. Other factors that may have contributed to this style of accumulation include minimal basin margin uplift, a large and mature sediment flux, transverse sediment delivery, low shelf gradients and the change in orientation of the basin margin in this region.

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Chapter 1

Introduction

1.1 Project aims

Despite the sensitivity of coastlines to factors such as relative sea-level and sediment supply paralic and shallow marine facies do sometimes accumulate to form thick vertical successions. A good example of this occurs within the late Devonian to early Carboniferous South Munster Basin of southern Ireland. In this succession, stacked shallow marine facies sometimes exceed 1km in thickness and include sandstone packages that are over 300m thick.

The principal objective of this study is to investigate the depositional setting of this sequence and to use this to determine the factors that may have been influential to the genesis of thick shallow marine deposits, particularly those dominated by sandstone.

1.2 General setting

During the late Devonian to Early Carboniferous period Ireland was subject to a seasonal climate (Witzke and Heckel 1988; Graham 2001) and was situated on the south side of a large continental landmass that has sometimes been termed the Old Red Continent (House 1968). This landmass consisted of an amalgam of smaller continental units (figure 1.1 and 1.2) including Laurentia, Avalonia and Baltica that had come together following closure of the Iapetus Ocean during the Caledonian Orogeny (McKerrow *et al.* 2000). In the British Isles region this event was dominated by strike-slip movement and this style of displacement continued until mid-Devonian times when it was replaced by a fairly long-lived extensional phase.

In southern Ireland this change in tectonic style coincided with a break in the sedimentary record (Naylor *et al.* 1989) between the late Silurian or early Devonian Dingle Group and Middle Devonian (Williams *et al.* 1997, 2000a) Old Red Sandstones. When sedimentation recommenced during the Middle Devonian deposition was dominated by fluvial strata derived from the north and west (Graham 1983; MacCarthy 1990; Graham *et al.* 1992; Kelly and Olsen 1993; Kelly and Sadler

1995; Sadler and Kelly 1993; James and Graham 1995) which accumulated over a relatively wide area of extensional known as the Munster Basin (Capewell 1965; Clayton *et al.* 1980; Naylor *et al.* 1980; Matthews *et al.* 1983; Sanderson 1984). Although this basin is often described as an extensional half-graben (bound to the north by the Dingle Bay fault) the identification of individual fault planes within this thick fine-grained succession is difficult. It is therefore possible, especially considering the pre-Variscan width of the basin (~180km), that basin structure was rather more complex (Williams *et al.* 2000b).

Subsidence associated with the Munster Basin persisted until late Upper Devonian times when a readjustment of extensional architecture terminated subsidence in the north of the basin leaving a narrower and perhaps more discrete depocentre in the south (figures 1.3 and 1.4). It is unclear whether this new focus of subsidence, termed the South Munster Basin (George *et al.* 1976), reflects the development of an entirely new structural framework or continued utilisation of faults previously active during the development the Munster Basin. In a regional context both the Munster and South Munster Basins formed within the western part of a roughly east-west trending extensional regime that was active between Silurian and Viséan times (Franke 1989). However, estimates of crustal stretching within the South Munster Basin of around ß=2 (Sanderson 1984) together with the limited presence of volcanic rocks (Graham *et al.* 1995), suggest that the magnitude of extension in Ireland was somewhat smaller than that further east (Friend *et al.* 2000).

The sequence within the South Munster Basin commenced with an Old Red Sandstone package of mainly fluvial origin and of Givetian or Frasnian to Strunian age overlain by an exceptionally thick but poorly understood coastal/marine siliclastic sequence of Strunian to Tournaisian age (figures 1.2 and 1.5). This shallow marine sequence, which contains the thickest Strunian package recorded in Europe (Graham 2001), was then terminated during the Tournaisian period following drowning of the northern basin margin (North Munster Platform - see figure 1.4). This event was associated with migration of the coastline northwards and development of a widespread shelf carbonate sequence upon the North Munster Platform whilst deep marine facies accumulation in the basin. This pattern persisted until the Namurian period when an influx of southerly derived turbiditic sandstones

into basinal areas (Naylor *et al.* 1987) probably herald the onset of direct Variscan influence in this area.

Eventually (during late Carboniferous or early Permian) the sequences of both the Munster and South Munster Basins were themselves deformed by the northerly migrating Variscan deformational event (Graham 2001). This led to shortening of the entire sequence by 33-52% (Cooper *et al.* 1984, 1986; Ford 1987; Meere 1995) together with considerable dextral displacement (Sanderson 1984). Although it is uncertain whether this deformation was thick-skinned (Sanderson 1984; Phillips 1985) or thin-skinned (Cooper *et al.* 1984, 1986) it is clear that most of the shortening was accommodated within large-scale folds, at least at the present-day erosion level. The hinge lines of these generally plunge gently to the east and trend roughly E-W in eastern parts of the basin but trend ENE-WSW and plunge gently to the west in western areas (figure 1.4). However steeper fold plunges may also be encountered and in some cases may be associated with extensional geometry (Graham and Reilly 1976; Bamford and Ford 1990; Ford 1990). Shortening also resulted in the development of a prominent axial planar cleavage which is usually penetrative in finer grained lithologies but spaced in coarser grained units (Capewell 1957; Walsh 1968; Reilly and Graham 1972, 1976; Graham and Reilly 1976; Naylor 1978; Cooper *et al.* 1984, 1986; Phillips 1985; Ford 1990; Bresser 1996). The VARNET seismic profiles shown in figure 1.3 (Vermeulen *et al.* 2000) provide an interesting insight to the sub-surface geology of this region today although it is difficult to distinguish the influences of extension and subsequent compression in these interpreted sections.

Although post-Variscan strata is rare in southern Ireland a number of outcrops dating to this period have been documented and provide interesting clues as to the geological history of this time. Perhaps most importantly, the preservation of Jurassic, Cretaceous and Tertiary sediments at low altitudes within collapse structures on the present day Carboniferous surface suggests that the land surface of southern Ireland as a whole has not been subject to much regional uplift and erosion during Mesozoic and Tertiary time (Naylor 1992). Despite this however, active extensional tectonics clearly progressed throughout much of this period in the basins surrounding Ireland and it is possible that some of the higher topography of the

present day results from localised uplift associated with this. The glaciated landscape so typical of the present day is largely attributed to the Munsterian and Midlandian periods (McCabe 1985).

1.3 The South Munster Basin

1.3.1 Basin Structure

The northern margin of the South Munster Basin is often known as the Cork-Kenmare line and has been identified from major thickness variations in Devonian / Carboniferous marine strata in both the Cork Harbour / Crookstown region (Naylor 1969, MacCarthy *et al.* 1978; MacCarthy 1987; Sleeman *et al.* 1978) and in the vicinity of Kenmare (Wingfield 1968; Naylor and Sevastopulo 1979). However, because the intervening region lacks strata dating to this period (Sevastopulo 2001) its location across much of southern Ireland is uncertain (figure 1.4). Despite this there is good reason to speculate that this margin consisted of a series of en echelon fault segments (Naylor *et al.* 1989, 1996; Williams *et al.* 1989). The main arguments in favour of this are that in both areas where the basin margin is reasonably constrained strata exhibit an along strike transition from basinal to basin margin facies (in a west to east direction). Furthermore, these areas themselves lie out of Variscan strike (figure 1.4).

Unfortunately there is less agreement on the location of the southern basin margin. Although MacCarthy and Gardiner (1987) suggest that the rather poorly constrained zone of reduced subsidence in south Cork (Graham 1972, 1975b) termed the Glandore High (Naylor *et al.* 1974) reflects the southern margin of the basin, Naylor *et al.* (1989) argue that this is simply an intra-basinal feature. Perhaps associated with this structure is an ENE-WSW trending but poorly constrained fault previously referred to as the Dunmanus-Castletown fault (Williams *et al.* 1989, 2000). It is possible that this has been imaged on the VARNET B seismic profile (figure 1.3 and 1.4), albeit on the south rather than the north side of Dunmanus Bay, by Vermeulen *et al.* (2000). This section indicates a down to the north displacement on this structure which may represent the northern margin of the Glandore High (figure 1.3).

Another area of (slightly) reduced subsidence located in the Sheeps Head area (Naylor *et al.* 1983) has been explained in terms of fault rotation on the so-called Dunmanus-Castletown fault (Williams *et al.* 1989; McAfee 1992). However because the VARNET B line indicates a northerly dipping fault-plane with down to the north displacement this interpretation seems unlikely (figure 1.4).

The only relevant stratigraphical information from offshore comes from two wells. Esso-Marathon 48/30-1 (figure 1.4) intersected a shale rich succession of Courceyan age (Higgs 1983; Naylor *et al.* 1989) and the Cities Services 63/4-1 well (drilled in the Fastnet Basin) intersected Courceyan shelf carbonates (Naylor and Shannon 1982). The thickness of the shale rich succession in Esso-Marathon 48/30-1 located south of the Irish coast has been used to argue for a basinal rather than basin margin setting in this area (Naylor *et al.* 1989).

1.3.2 Dating

Owing to the poor preservation of macrofauna within the clastic sequence exposed in the South Munster Basin, dating is based primarily upon the miospores zonation (figures 1.2 and 1.5) introduced by Neves *et al.* (1972) and later refined by Higgs *et al.* 1988 and O'Liatháin 1992. However, it should be noted that the division of the HD biozone as advocated by O'Liatháin (1992) does not seem to have been widely adopted. The greatest problem with this scheme is that because the successions of southern Ireland are so much thicker than elsewhere in Europe individual miospore zones with this sequence are extremely thick (up to 800m). This is obviously makes correlation between individual sections difficult.

1.3.3 Stratigraphy

Marine conditions first appeared in the eastern part of the basin during the LL biozone (figure 1.5). It appears that the coastline then migrated northwards and westward reaching Seven Heads and Toe Head at the start of the LE biozone, South Dunmanus during the late LE biozone and the Bantry Bay area at the beginning of the LN biozone (Clayton and Higgs 1979; Clayton *et al.* 1986; Higgs *et al.* 1988; O'Liatháin 1992). Marine strata deposited during this period (late Devonian) generally exhibit only gradual changes in facies type (Naylor 1966; Kuijpers 1972)

but an upwards replacement of tide by wave influence is often reported (Kuijpers 1971, 1972; De Raaf and Boersma 1971; Van Gelder 1974; Graham 1975b; Bamford 1988) and was probably followed by increasing storm influence (Bamford 1988; Williams *et al.* 1989). At the start of the Carboniferous period (VI biozone) a further rise in relative sea-level led to landwards migration of the coastline and development of a widespread mudstone unit within the basin (Castle Slate Formation). This was followed during the HD (lower) biozone (O'Liatháin 1992) by a phase of variable sea-level and attendant coastal migration (Narrow Cove Formation). Deposition at this stage was mainly storm influenced in the east of the basin (de Raaf *et al.* 1977) but tide and wave influenced in the Beara Peninsula / Bantry Bay region in the west. This shallow marine sequence was followed at the start of the HD (upper) biozone (O'Liatháin 1992) by a phase of deepening and migration of the coastline northwards.

1.3.4 Stratigraphic revision

Unfortunately the stratigraphic terminology employed for the late Devonian to early Carboniferous marine sequence varies markedly between authors and is in some cases difficult to reconcile with the recorded successions, particularly in light of recent palynological correlation (Higgs *et al.* 1988; O'Liatháin 1992). The benefits of the revised stratigraphic framework shown in figure 1.5 are that this system may be applied on a basin-wide basis and formation boundaries coincide with both biozone boundaries and major facies changes. The reader is referred to Naylor *et al.* (1983), MacCarthy and Gardiner (1987) and Pracht (1994) for extensive reference to earlier work.

Devonian

The base of the late Devonian marine sequence is clearly diachronous and stretches between LL, LE and LN biozones whilst the top coincides with the boundary between the LN and VI biozones (Higgs *et al.* 1988; O'Liatháin 1992). In most recent literature this part of the sequence is referred to either as the Old Head Formation (McAfee 1992) or the Old Head Sandstone Formation (Bamford 1988; Williams *et al.* 1989; Sadler 1993; Pracht 1994; Naylor *et al.* 1989). However in western parts of the basin this part of the stratigraphy has also been grouped with the basal part of the Carboniferous sequence to form a unit known as the Ardaturrish Formation (Naylor *et al.* 1969, 1974, 1996; Jones 1974). Although this term applies

to a portion of the stratigraphy that is indeed lithologically similar, recent identification of the Castle Slate Formation within this package together with new palynological constraint (Higgs *et al.* 1988; O'Liatháin 1992) allow application of the term Old Head Formation (McAfee 1992) on a basin-wide basis. This term is preferred to the more widely applied Old Head Sandstone Formation because of the wide variation in sandstone and mudstone content displayed in sections across the basin (figure 1.5).

Division of the Old Head Formation into members is complicated by the variability of stratigraphic terms applied in different sections. In this study, where only the upper part of the Old Head Formation has been analysed (LN palynozone), two members are tentatively recognised. The lowermost of these is the relatively sandstone rich Daunt Member and this is overlain by the more mudstone rich Tower Member. Although both of these units have been identified in sections across the basin the transition between them is often subtle and sections intersecting the Tower Member in the south coast region between Toe Head and the Old Head of Kinsale may include thick sandstone packages.

Carboniferous

Usage of the term Kinsale Formation (e.g. Gardiner and Horne 1972; Graham 1975; Naylor *et al.* 1979; MacCarthy 1979; Naylor and Reilly 1981; Naylor *et al.* 1996) is abandoned in this study whilst three of the constituent members (the Castle Slate, Narrow Cove and Pigs Cove Members) are upgraded to formational status (e.g. Naylor 1966, Williams *et al.* 1989).

The Castle Slate Formation at the base of the Carboniferous consists of dark grey mudstone and is found throughout the basin. The base of this unit often marks a pronounced change in facies and coincides with the boundary between the LN and VI biozones (Higgs *et al.* 1988; O'Liatháin 1992) and possibly also with the Devonian / Carboniferous boundary. The top is marked by the first occurrence of sandstone laminae and lies close to the boundary between the VI and HD biozones (Higgs *et al.* 1988; O'Liatháin 1992). This facies boundary may be diachronous becoming younger to the south away from the palaeo-shoreline.

The overlying sequence stretching from near the VI / HD boundary to the HD (lower) / HD (upper) boundary consists of both sandstone and mudstone rich packages and is referred to as the Narrow Cove Formation in this study. Although this term has been traditionally restricted in application to eastern parts of the basin (e.g. Jones 1974; Naylor *et al.* 1983; McAfee 1992; Williams *et al.* 1989; Pracht 1994) this study extends its usage to encompass western areas. Consequently the mixed mudstone and sandstone rich Ardaturrish Formation and the sandstone rich Reenagough Formation are reduced to member status although this study indicates that the lithological divisions used to differentiate these units are repeated elsewhere in the basin thus encouraging basin-wide application of these terms. This study also lowers the top of the Reenagough Member and substitutes a new member into the upper part of the Narrow Cove Formation. This unit, termed the Black Ball Member in this study, reflects a dramatic increase in mudstone content overlying the Reenagough Member (although the top may be sandstone rich) and is equivalent to McAfee's (1992) member 2 (figure 1.5).

Finally, following recent palynological constraint (O'Liatháin 1992) this study extends usage of the term Pigs Cove Formation to western parts of the basin thus abandoning the term Ardamanagh Formation (figure 1.5). The base of this unit which is usually marked by a rapid increase in mudstone rich facies, lies close to the boundary between the HD (lower) and HD (upper) biozones in all parts of the basin (O'Liatháin 1992).

1.4 Methodology

1.4.1 Logging

This study is based on 10 months field based logging of coastal sections. Analysis has concentrated on the early Carboniferous sequence exposed in western parts of the basin but also includes analysis of the late Devonian and early Carboniferous marine sequence across the basin. The sections are described in four separate chapters dependent on geographical location. The geographic and stratigraphic location of the measured sections is illustrated in figures 1.4 and 1.7 respectively.

Section analysis involved compilation of a local geological map followed by detailed base to top analysis and measurement of the section. Logging measurements (e.g. grain-size, the nature of bedding contacts and lateral variation) were noted in field notebooks rather than on pre-drafted logging sheets and in general, generic description of individual lithological units was made before facies or environmental interpretation.

Logs were compiled using Adobe Illustrator and are shown later in the text (chapters 3-6), the reader is referred to the log legend provided in figure 1.6 as a guide to interpretation.

1.4.2 Restoration of palaeo-current orientation

Where bedding dip exceeded 30° it was necessary to remove the effects of this tilting before accurate measurement of bedform orientation could be ascertained (Ramsay, 1961). In this study, all measurements were first 'untilted' using a computer program but a selection of these were also restored manually using a Wulff Stereonet (Ramsay 1961; Graham 1988; Leyshon and Lisle 1996) to corroborate results. The theory behind this procedure is outlined below.

If a fold axis is horizontal then removal of tilt can be accomplished simply by rotating bedding about an axis parallel to its strike until it comes to a horizontal position. Lines (for instance poles to cross-sets) which are marked by points on the net, move around small circles by an amount governed by the angle required to restore bedding to horizontal. However, when the fold axis is dipping the process of restoration is more complex because the strike of the bed can never be parallel to the fold axis. Firstly, bedding should be rotated about a horizontal axis perpendicular to the trend of the fold axis until the fold axis becomes horizontal (untilting). All lines on the net move around small circles by this amount. The beds may then be restored to their original orientation by rotation around a second horizontal axis this time parallel to strike. Again, each rotated line on the net moves around a small circle by an amount governed by the angle required to restore bedding to horizontal.

Although this restoration process does not take account of the deformational shape changes undergone by bedforms, it is rare to find sufficient information in natural settings to allow for correction of this (Ramsay 1961). Consequently, as in most studies, these effects are ignored. However, the graphical depictions of shape change shown in Ramsay (1961) suggest that failure to account for these changes will not significantly affect the measurements made in this study.

1.4.3 Calculation of wave period and wave fetch

Wave period was kindly calculated by Prof. Philip Allen using a computer program. These calculations are based on the equation

$T = \pi d_0 / U_{max}$

(Le Mehaute *et al.* 1969)

Where T = wave period, d_0 = orbital diameter, U_{max} = maximum orbital velocity

Obviously before calculating wave period it is first necessary to calculate both the near-bed orbital diameter of water particles overlying the ripple (d_0) and to determine the orbital velocity of this flow (U_{max}). The relationship between near-bed orbital diameters and ripple spacing is summarised by Miller and Komar (1980) whilst the easiest means of calculating the maximum near-bed velocity (U_{max}) is by using the graph of Allen (1979, p 675). This type of analysis should be reserved to symmetrical or near symmetrical wave generated ripples developed in clean quartz sands. Furthermore it should be restricted to wave ripples that display VFI's (Bucher 1919) of less than 7.5 and certainly less than 10 because these ripples (vortex ripples) exhibit the least ambiguous relationship between orbital diameter and ripple spacing (Allen 1981).

The rationale behind calculating wave period is that wave period is determined by wind strength, duration and fetch. Placing reasonable limits on wind speed and duration it is possible to use wave forecasting methods to derive fetch limits for calculated wave periods. In fetch limited seas the analysis of Neumann (1953) is particularly useful (Allen 1984).

1.4.4 Calculation of maximum water depth

With knowledge of orbital diameter and wave period (see previous section) it is possible to constrain the maximum depth at which symmetrical ripples were generated (Allen 1984). To do this a number of steps should be followed.

Step 1

Firstly, it is necessary to calculate the deep-water wavelength using the equation:

$L_d = gT^2/2\pi$

Where L_d = deep-water wavelength and T = wave period.

Step 2

We must then study the transformations that take place in a wave of known period T as it moves into shallower water. This may be done by using graphs for Airy wave transformation provided by Wiegel (1964). These plot the ratio h/L_d against L_s/L_d (where L_s = shallow water wavelength) and thus allow determination of shallow water wavelength (L_s) for a particular water depth.

Step 3

The wave height at this water depth may then be calculated using:

$H = d_0(\sinh(2\pi h/L_s))$

Where H = wave height and d_0 = orbital diameter of water particles immediately overlying the sediment surface.

Step 4

Finally, it is necessary to determine whether the reconstructed wave parameters for specified water depths are stable. To check this the wave parameters should satisfy both the shallow water criterion (Miche 1944) and the limiting steepness criterion (McCowan 1894). These are:

Shallow water breaking criterion (ignoring the effects of sea-bed slope)

$(H/h)_{\text{limit}} = 0.78$

Limiting wave steepness criterion

$(H/L)_{\text{limit}} = 0.14\tanh(2\pi h/L_s)_{\text{limit}}$

If the wave of given period is unstable at the given water depth then the water depth used during step 2 should be reduced and the calculations repeated. In this way it is possible to determine the maximum water depth at which the wave of known period would have been stable.

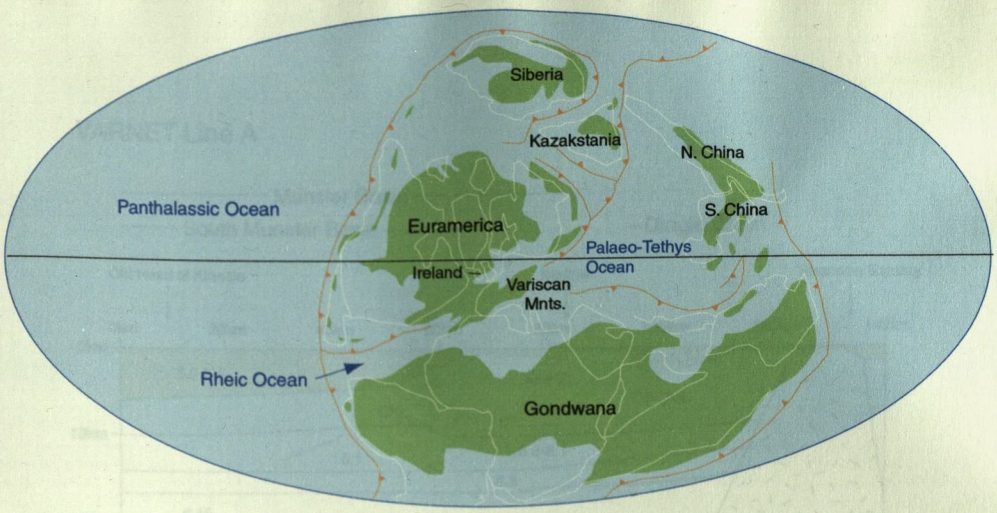


Figure 1.1 - Palaeogeography during the late Devonian (Scotese 2001)

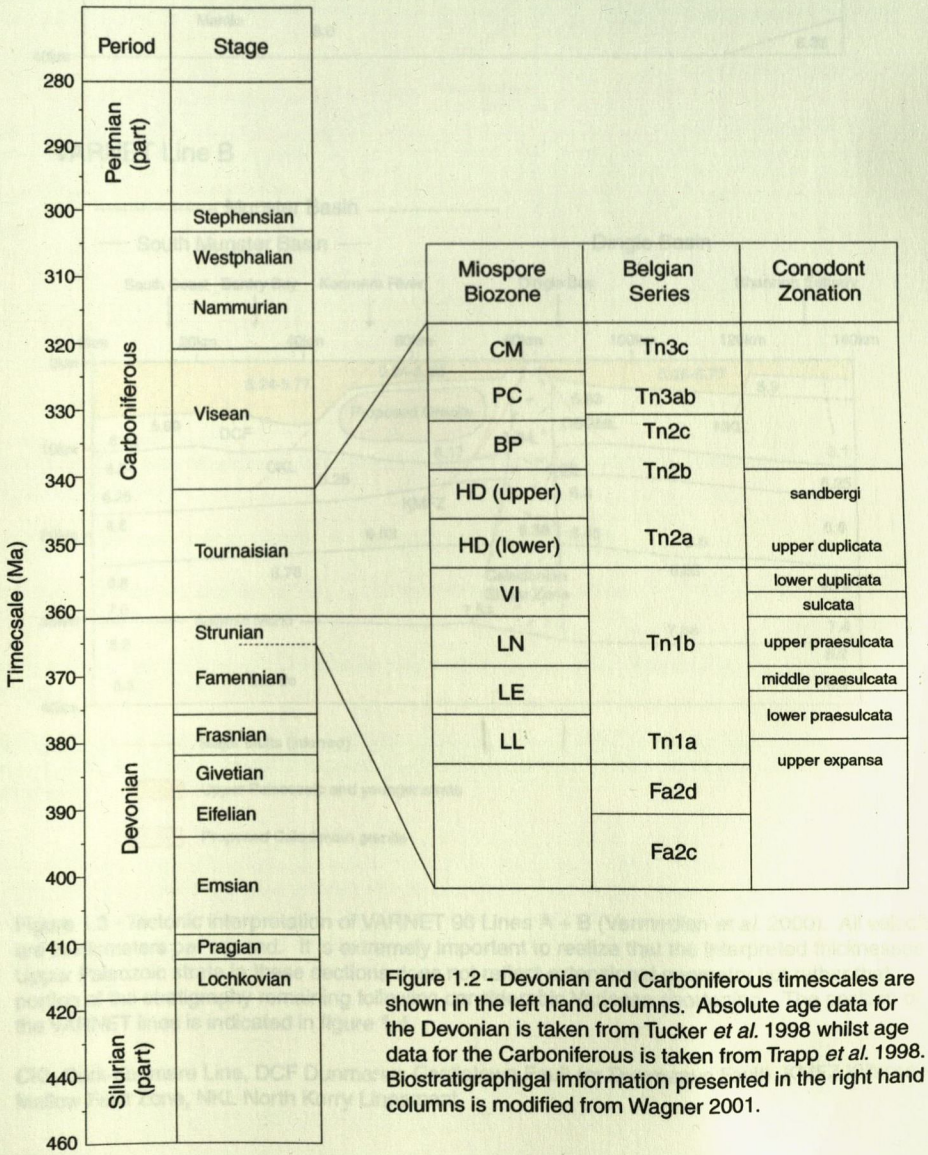


Figure 1.2 - Devonian and Carboniferous timescales are shown in the left hand columns. Absolute age data for the Devonian is taken from Tucker *et al.* 1998 whilst age data for the Carboniferous is taken from Trapp *et al.* 1998. Biostratigraphigal imformation presented in the right hand columns is modified from Wagner 2001.

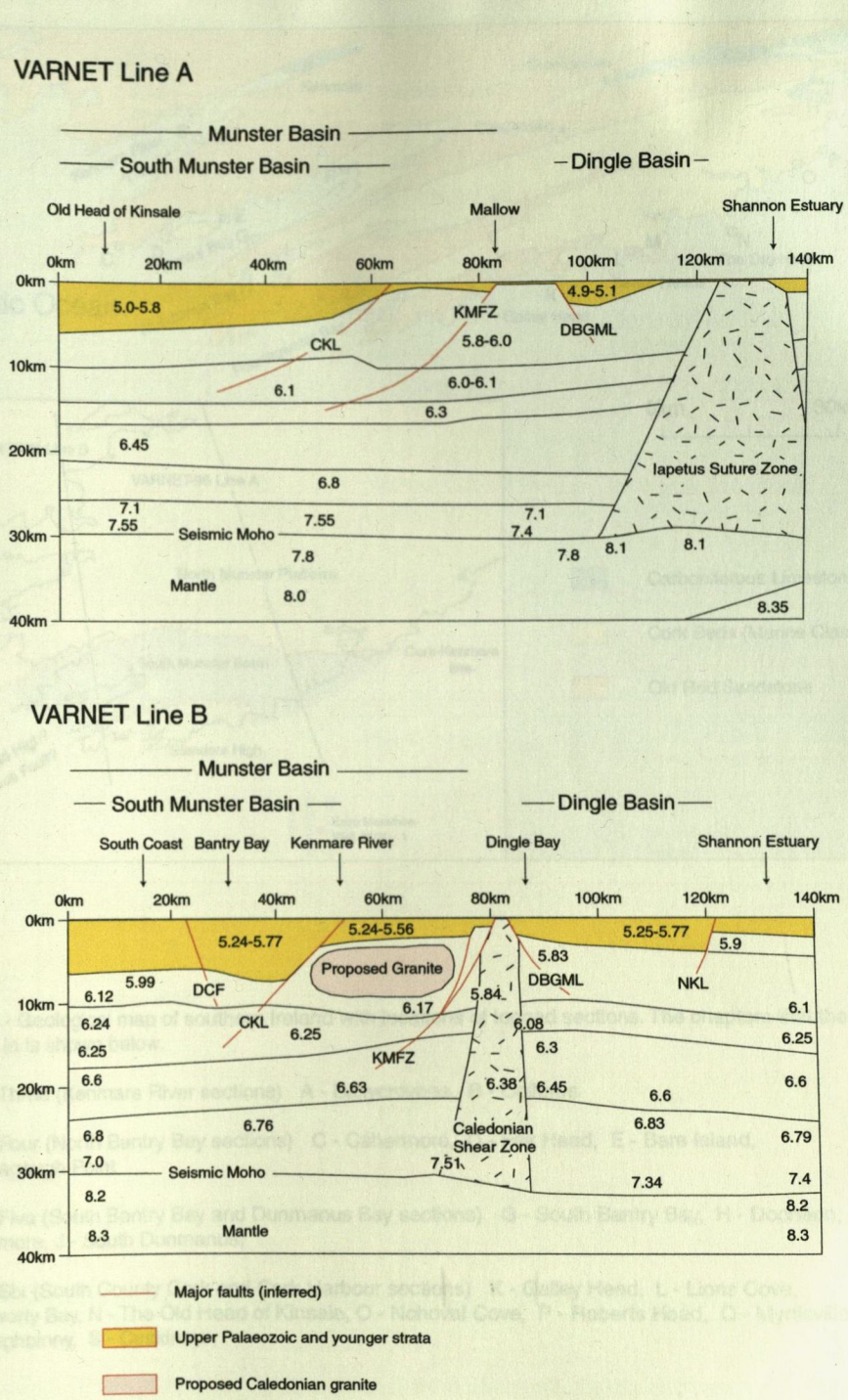


Figure 1.3 - Tectonic interpretation of VARNET 96 Lines A + B (Vermeulen *et al.* 2000). All velocities are in kilometers per second. It is extremely important to realize that the interpreted thicknesses of Upper Paleozoic strata in these sections does not reflect extensional geometry but rather that portion of the stratigraphy remaining following considerable Variscan shortening. The position of the VARNET lines is indicated in figure 1.4.

CKL Cork-Kenmare Line, DCF Dunmanus Castletown Fault (or Dunmanus Fault), KMFZ Killarney-Mallow Fault Zone, NKL North Kerry Lineament.

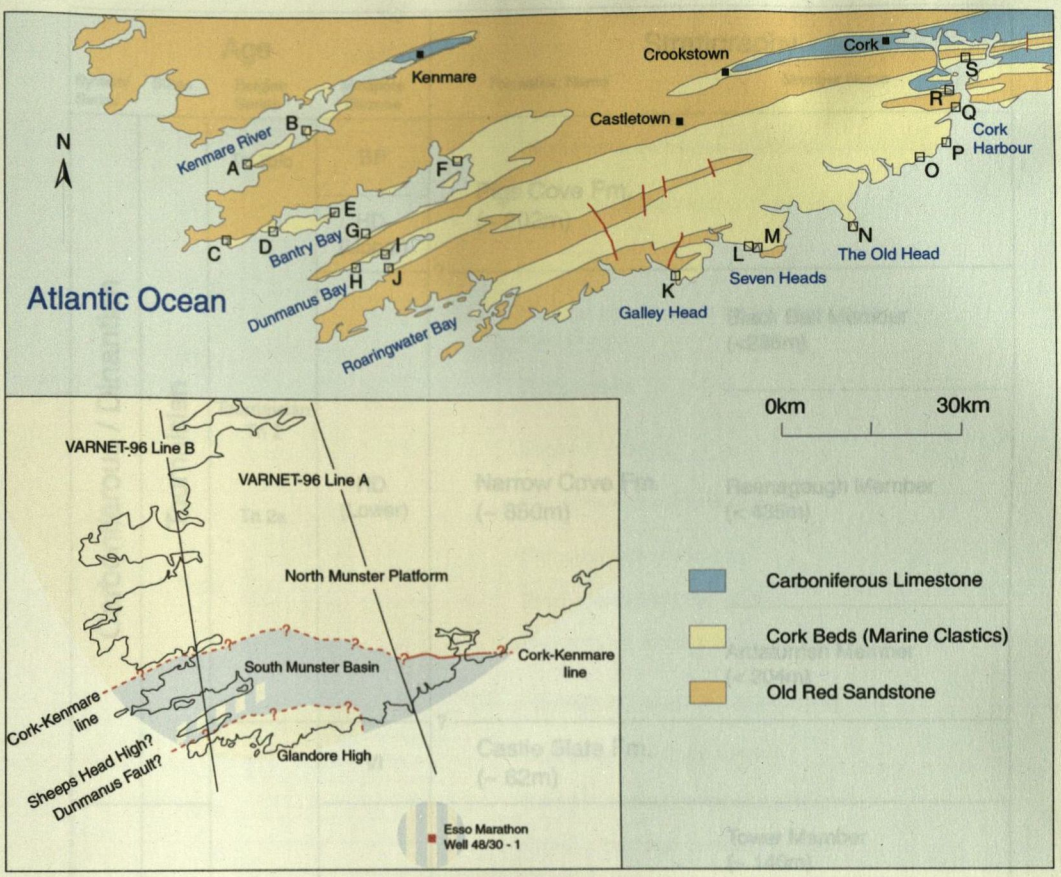


Figure 1.4 - Geological map of southern Ireland with locations of logged sections. The chapters that these are discussed in is shown below.

- Chapter Three (Kenmare River sections) A - Ballycrovane, B - Collorus

- Chapter Four (North Bantry Bay sections) C - Cahermore, D - Fair Head, E - Bere Island, F - Reenagough Point

- Chapter Five (South Bantry Bay and Dunmanus Bay sections) G - South Bantry Bay, H - Dooneen, I - Reenmore, J - South Dunmanus,

- Chapter Six (South County Cork and Cork Harbour sections) K - Galley Head, L - Lions Cove, M - Dunworly Bay, N - The Old Head of Kinsale, O - Nohoval Cove, P - Roberts Head, Q - Myrtleville, R - Curraghbinny, S - Cuskinny.

Inset - Location of structural features and principal depocentres of the South Munster Basin. Evidence for the location of the Dunmanus Fault comes from the VARNET B line (Vermeulen *et al.* 2000).

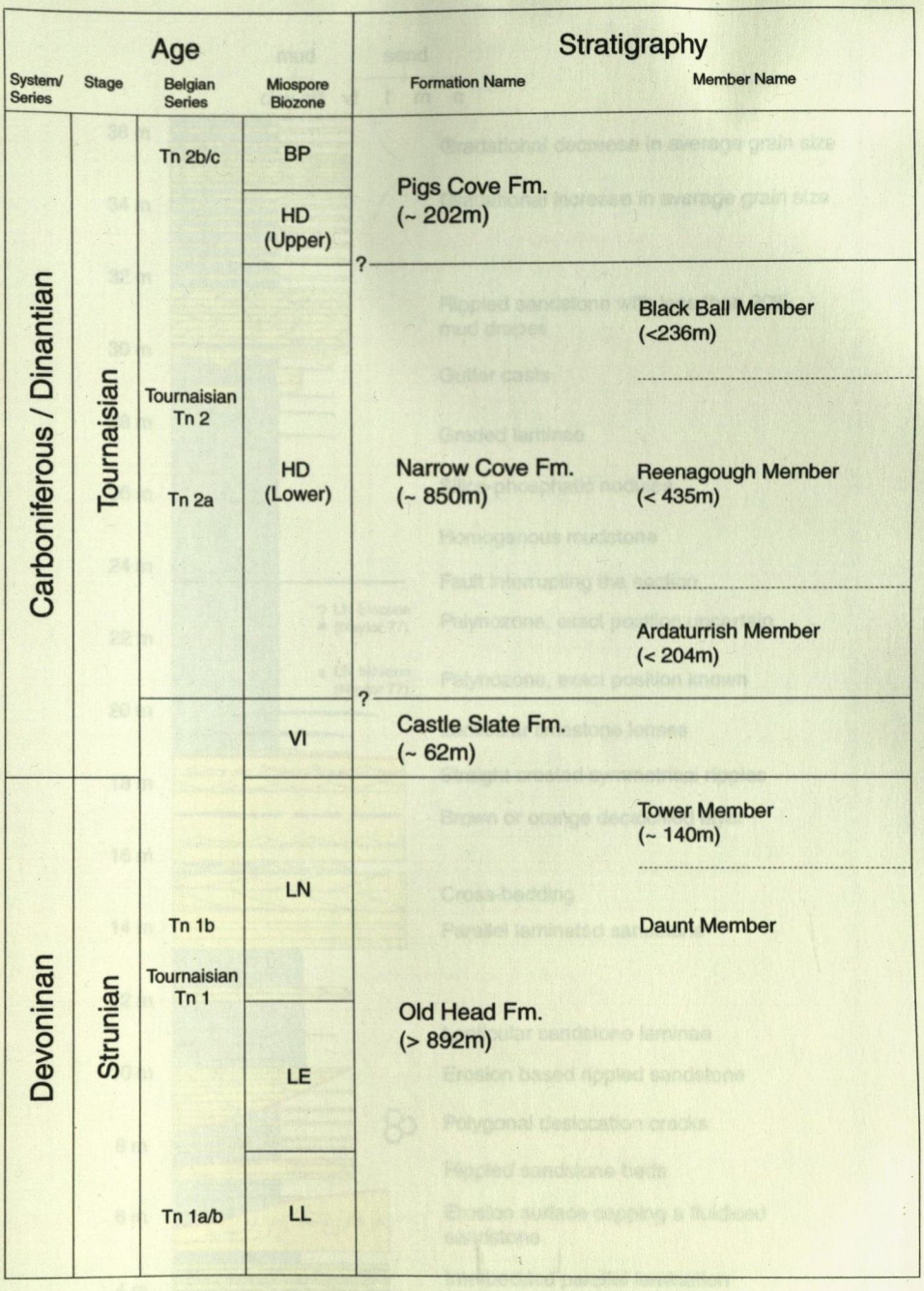


Figure 1.5 - Stratigraphic terminology employed in this study (with maximum thicknesses). The thickness of the Old Head, Castle Slate and Pigs Cove Formations are taken from the Old Head of Kinsale section (Naylor 1969) in the east of the basin whilst the thickness of the Narrow Cove Formation is taken from the Cahermore section situated on the north side of Bantry Bay. The miospore scheme is taken from Higgs *et al.* (1988) and O'Liathain (1992) whilst the correlation between miospore zones and the Belgian Series is taken from Wagner (2001).

Legend

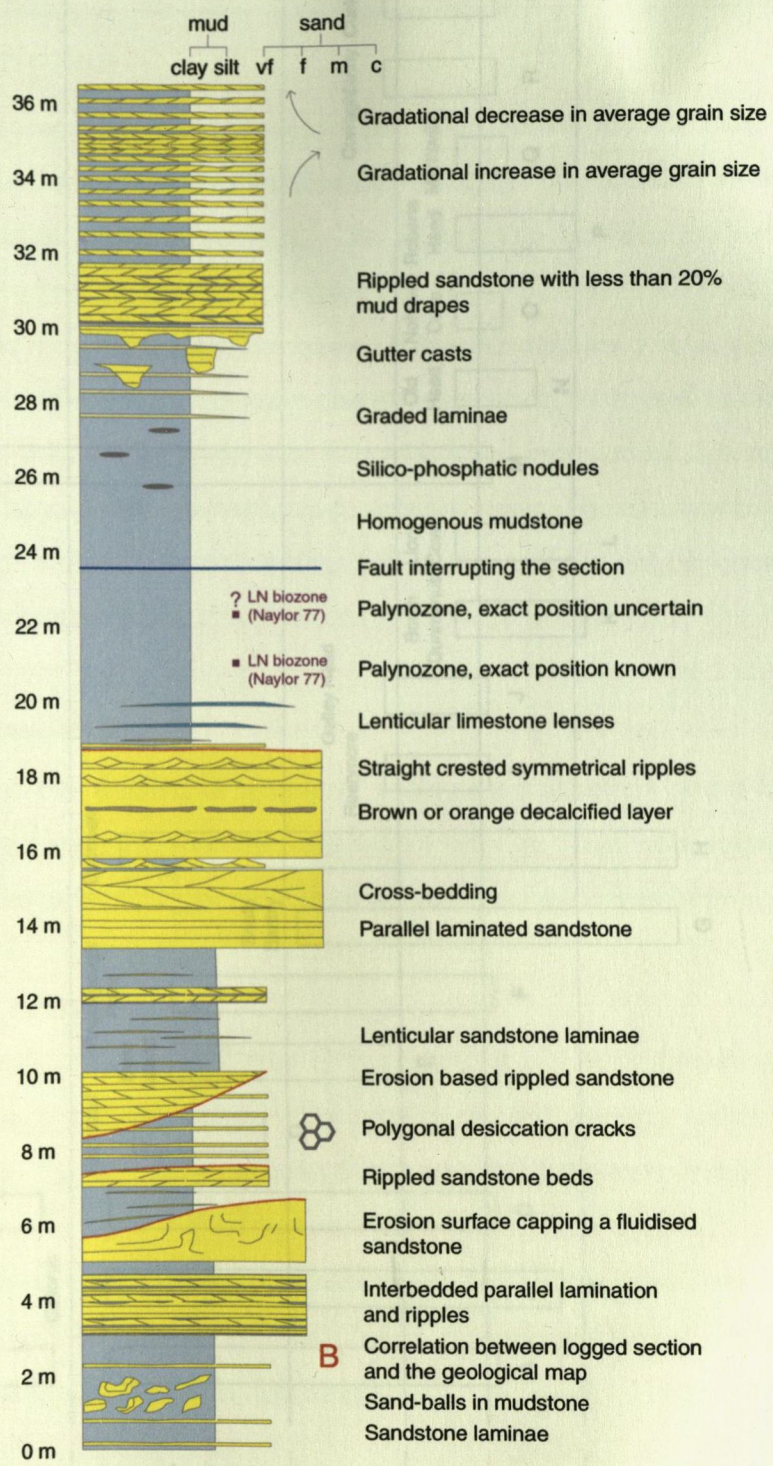


Figure 1.6 - Legend for the logged sections displayed in chapters 3-6. It should be noted that the symbol used to depict symmetrical wave ripples on the logs is only applied where unequivocal evidence exists that the ripple was wave generated (i.e. straight bifurcating crest lines and a symmetrical profile). In instances where these features are not present but where wave genesis is still postulated this is indicated in the facies column on the left-hand margin.

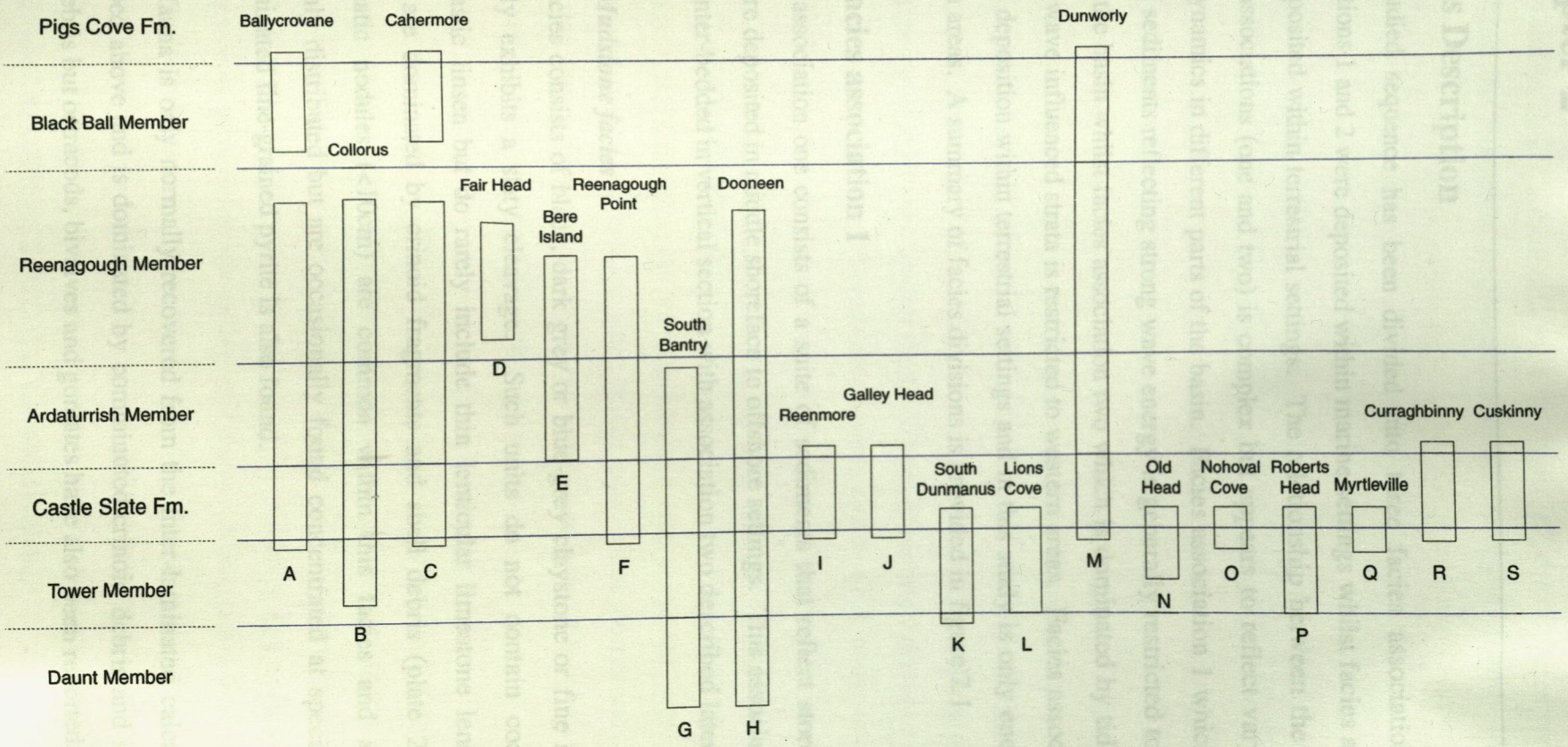


Figure 1.7 - Schematic stick plots illustrating the interpreted stratigraphic distribution of the measured sections (not to scale). The location of these sections is indicated in figure 1.4.

A - Ballycrovane, B - Collorus, C - Cahermore, D - Fair Head, E - Bere Island, F - Reenagough Point, G - South Bantry Bay, H - Dooneen, I - Reenmore, J - South Dunmanus, K - Galley Head, L - Lions Cove, M - Dunworly Bay, N - The Old Head of Kinsale, O - Nohoval Cove, P - Roberts Head, Q - Myrtleville, R - Curraghbinny, S - Cuskinny.

Chapter 2

Facies Description

The studied sequence has been divided into three facies associations. Facies associations 1 and 2 were deposited within marine settings whilst facies association 3 was deposited within terrestrial settings. The relationship between the two marine facies associations (one and two) is complex but appears to reflect varying marine hydrodynamics in different parts of the basin. Facies association 1 which contains a suite of sediments reflecting strong wave energy is generally restricted to the eastern part of the basin whilst facies association two which is dominated by tide and lower energy wave influenced strata is restricted to western areas. Facies association three reflects deposition within terrestrial settings and in this study is only encountered in western areas. A summary of facies divisions is provided in figure 2.1.

2.1 Facies association 1

Facies association one consists of a suite of sediments that reflect storm influence and were deposited in middle shoreface to offshore settings. This association may be found inter-bedded in vertical section with association two described later in the text.

2.1.1 Mudstone facies

This facies consists of black, dark grey or blue-grey claystone or fine siltstone and typically exhibits a slaty cleavage. Such units do not contain coarse grained siliciclastic linsen but do rarely include thin lenticular limestone lenses (<15cm) which are dominated by crinoid fragments and shell debris (plate 2.1). Silico-phosphatic nodules (<10cm) are common within this facies and are normally randomly distributed but are occasionally found concentrated at specific horizons. Disseminated fine-grained pyrite is also found.

Macrofauna is only normally recovered from the inter-laminated calcareous linsen described above and is dominated by comminuted crinoid debris and indeterminate shell debris but ostracods, bivalves and goniates have also been reported.

Interpretation

An open marine fauna and association with storm influenced facies (see following text) suggest that deposition progressed within an open shelf setting. Additionally, the absence of lamination within these units suggests some biogenic disruption presumably within an oxygenated environment.

The calcareous linsen which are sometimes encountered in this facies were probably transported ocean-wards from marginal settings by storm generated geostrophic currents. Prior to such events, the growth and accumulation of this shell debris was probably facilitated by periods of reduced sediment flux to the shelf. Similarly, the development of nodules, disseminated pyrite and high organic content within this facies appear to indicate low rates of deposition. This facies was therefore probably most prevalent during periods of transgression when high generation of accommodation in terrestrial and marginal settings caused deposition in these regions at the expense of deposition on the shelf. Where limestone linsen are absent from this facies water depth may have higher (below storm wave-base) or depositional rates higher.

2.1.2 Graded laminae facies

This facies comprises claystone or fine siltstone inter-laminated with graded and non-graded laminae and in some cases gutter casts. The proportion of sandstone within this facies varies considerably but rarely exceeds 30% whilst the changes themselves usually occur gradually (plate 2.2).

The facies is dominated by flat and scour based graded laminae that exhibit a fining-up micro-sequence from sandstone or siltstone into clay-stone that is normally less than 1cm thick but which may thicken overlying erosive scours such as gutter casts (<5cm). Non-graded laminae (normally < 0.5cm in thickness) may also be common and likewise display either flat or scoured bases. Non-graded laminae vary from tabular to lenticular and in some instances display regular increases and decreases in thickness laterally (pinch and swell) that is probably representative of incipient ripple formation. The average thickness of both graded and non-graded laminae is normally greatest where bulk sandstone content is highest.

Gutter casts, which are almost ubiquitous in storm deposits (Myrow 1992), are common within this facies and have dimensions varying from a few millimetres depth and width (plate 2.3) to at least 530cm across and 35cm deep. Gutter casts are occasionally in-filled with mudstone (plate 2.4) but are more normally sandstone filled (very fine to coarse grades), this sometimes includes mud chips. The basal and central portions of many gutter casts are dominated by horizontal or inclined parallel lamination (inclination < 20°) but this often culminates in a symmetrical rippled zone. Grading is not normally well developed within the stratified basal and central portions of the gutter cast fill (see plate 2.5 for an exception to this) probably because the infilling sand sized material was liberated from well-sorted beach and shoreface settings (Morton 1981). However graded sequences may be found overlying this and are often laterally connected with graded laminae on the adjoining gutter margin. Gutter casts may also be laterally connected with thin parallel laminated or rippled sandstone units but are also commonly isolated and discrete. In profile gutter casts usually exhibit high depth to width ratios and steep even overhanging margins whilst their geometry may be bi-lobed, irregular or hour glass in form (Myrow 1992) and larger gutter casts commonly display a 'steers head' like geometry (plate 2.6). Further morphological detail of gutter casts is provided in figure 2.2.

In some instances it is clear that the gutter filling process involved several episodes of deposition. Such multi-generation infill is best demonstrated where beds of sandstone alternate with dark mudstone within the gutter cast (figure 2.3). However, successive sandstone packages containing variably inclined stratification may also represent different generations of fill.

Pot marks, tool marks and flutes were not encountered and it was difficult to find good plan views of gutter cast shape however orientation appears to have been roughly N-S or NW-SE which is in agreement with measurements taken by Bamford (1988). Bioturbation is dominated by a low diversity assemblage normally consisting of horizontal burrows typically 2-3mm in diameter.

Interpretation

This division reflects deposition of shelf mudstone during prolonged quiescent episodes that were periodically interrupted by short-lived storm events. The facies was therefore deposited within a relatively distal shelf setting.

In most cases the tempestite sequence begins with an erosional surface that sometimes includes gutter casts and which was probably formed during the climax of the storm event when shear exerted on the sea-bed was highest. As in most other ancient storm deposits gutter casts within this succession are usually oriented at high angles to the coastline. This probably indicates that peak shear was oriented in this direction (Leckie and Krystinik 1989a,b,c; Higgs 1990, Myrow 1992, 1994) although this is disputed by Chakraborty (1995) and does not mean that this was the time averaged transport direction (Duke 1991; Snedden and Swift 1991; Hart *et al.* 1991; Browne 1994). As the storms waned, sand and silt was preferentially deposited within topographic lows such as gutter casts where current velocities were reduced. Early stage deposition of sand was typically parallel laminated but this was often followed by a symmetrical rippled sequence that was in turn sometime capped by a graded sequence formed by settling of sand and silt from suspension (Reineck and Singh 1972). In no cases was the waxing part of the storm sequence recorded.

Storm events that transported high volumes of sediment were able to infill gutter casts completely whilst events that transported less sand were not. Consequently these gutters remained either empty or only partially filled. Gutter casts that retained their topographic expression until the later stages of a storm event were prone to developing an attenuated graded sequence. Gutter casts that remained unfilled following the initial storm event were likely to act as sediment traps during subsequent storms (multiple-fill gutters). These secondary in-filling event layers are usually rippled throughout rather than parallel laminated perhaps because they were deposited during smaller magnitude storm events than those responsible for gutter generation.

When symmetrical ripples are encountered it is clear that deposition progressed above effective storm wave base and the unit reflects a distal offshore transitional setting. However, in portions of the stratigraphy that do not include symmetrical

ripples or gutter casts it is less clear whether deposition occurred above or below this level and it is possible that parts of this facies were deposited in an offshore rather than offshore transitional setting.

The high depth to width ratio and the 'steers head' like geometry displayed by many large gutter casts are unique among down-cutting surfaces generally and are believed to have resulted from two separate erosional episodes. The first of these was associated with the generation of the wide saucer shaped gutter top that is smooth in outline and is similar in profile to erosional swales found in sandstones. The second erosional phase involved sequential down-cutting within the central portion of the gutter, this portion typically displays high depth to width ratios and is sometimes rougher and more irregular in form than the saucer shaped scour at the gutter cast top (figure 2.2). It is suggested that the wide saucer shaped scours resulted from a sudden, instantaneous increase in turbulence at the bed, perhaps caused by a wave breaking or by in instability in the overlying combined flow. Once this scour had been generated it focused local turbulence associated with the oscillatory wave stroke and perhaps a superimposed off-shore directed storm current within the scour. This together with the large increases in strength that mud commonly exhibits within the upper few centimetres of the bed surface (McCave 1985) allowed pronounced down-cutting. Alternatively the process is evolutionary, in this case an initial scoop shaped scour developed and grew within the unconsolidated clay at the bed surface until it began to impinge upon the lithified mudstone below. This was more easily eroded than the cohesive clay on the sediment surface thus allowing rapid down-cutting.

2.1.3 Symmetrical rippled facies

This facies comprises symmetrical ripples developed within well-sorted siltstone to coarse sandstone; these are commonly draped with mudstone. Beds are up to 80cm in thickness and may be delineated by changes in the average thickness of sandstone linsen, changes in the proportion of sandstone to mudstone or by low angle erosion surfaces.

Ripples are found either within pinching and swelling sandstone lenses or within scoop based and sigmoidal sandstone packages. These may be bound either by mud drapes (Plate 2.7) or discontinuity surfaces. Ripple crests are usually undulatory or

obscure but are occasionally straight (Plate 2.8) whilst wavelength ranges between 5-40cm and height between 0.5-4cm. In profile, ripples are sinusoidal, may exhibit a symmetric or slightly asymmetric form and are often in form discordance with internal stratification. Ripple fore-sets tend to sweep between adjacent crests (concave up) and may also drape ripple crests (convex up) whilst their orientation may vary between uni-modal and bi-modal even between adjacent crests. These features are typical of wave-generated ripples (De Raaf *et al* 1977). Ripple morphology is provided in further detail in figure 2.4.

The facies is sub-divided based on the proportion of sandstone to mudstone, three divisions are differentiated (Reineck 1968);

Mudstone dominant (0-33%) sub facies. Dominated by lenticular and wavy bedded symmetrical ripples.

Mixed mudstone /sandstone (33-66%) sub facies. Includes lenticular or flaser bedding but is normally dominated by wavy bedding.

Sandstone dominant (66-100%) sub facies. Dominated by wavy and flaser bedding.

Vertical changes in the bulk sandstone and mudstone content of this facies may be abrupt or gradational. Perhaps the most frequent and dramatic abrupt changes are those where muddy units overly sandy units. However sandstone rich units may also abruptly overly muddy units although there is more commonly some increase in sandstone content immediately prior to this. The most frequent gradational changes in sand/mud content are coarsening up (CU) sequences (<2m thick) but fining up (FU), fining up then coarsening up (FUCU) and coarsening up then fining up sequences are also encountered (CUFU). These patterns are consistent with those described by De Raaf *et al.* (1977).

Symmetrical ripples are often found inter-bedded with thin parallel laminated beds that are typically 0.5-6cm thick and regularly exhibit symmetrically rippled tops (wavelengths of between 5-30cm) and are sometimes overlain by a graded sequence. The upwards transition from parallel lamination into symmetrical ripples may occur gradually through an intermittent wobbly lamination (figure 2.3) but may also be truncational (plate 2.9). These beds are often scour based and in some cases

lenticular and thus possibly form in a continuum from gutter casts. Graded laminae and gutter casts are only common in the mudstone dominant and mixed mudstone / sandstone portion of this facies (plate 2.10).

Bioturbation is most prolific in units where parallel lamination and large-scale symmetrical ripples are common but varies considerably in abundance even between similar lithofacies. Burrows are commonly around 0.7cm in diameter and may be either horizontal or vertical (plates 2.11 and 2.12), straight, meandering or branching and sometimes exhibit spreite. These features probably reflect *Rhizocorallium* and *Ophiomorpha* ichnogenera. In rare cases *Lockeia Siliquaria* (which is formed by suspension feeding bivalves) is also present. Together, these ichnogenera probably reflect a Cruziana ichnofacies which characterises the region between daily wavebase and storm wavebase (Frey and Pemberton 1985).

In units where parallel lamination and large-scale symmetrical ripples are not common bioturbation is typically less prolific and dominated by smaller diameter, typically horizontal burrows usually around 1-3mm in diameter.

Interpretation

This division reflects alternating deposition of shelf mudstone during quiescent periods and generation of symmetrical ripples and parallel lamination during storm events. The rounded profile exhibited by most ripples as well as the bi-modal distribution of cross lamina orientation suggest that water depth was high in comparison to wavelength (Allen 1979; Collinson 1982) and that the Stokes drift component was normally small. The abundance of mud drapes overlying symmetrical ripples within this section (particularly within the mudstone rich and mixed subfacies) indicate that wave activity was usually sporadically rather than continually active upon the seabed. This, together with the development of a Cruziana type ichnofacies, probably indicates that deposition generally progressed below fair weather wave base in an offshore transitional setting. However, symmetrical rippled units lacking mud drapes may have formed within a shoreface setting.

During a typical storm event an erosional phase was followed by deposition within depressions such as gutter casts where current velocities were reduced. With further flow reduction more widespread deposition occurred allowing thin but laterally continuous sand sheets to form. The thickest of these were normally horizontally laminated at their bases and symmetrically rippled at their tops whilst thinner layers were normally symmetrically rippled. It is unclear if the symmetrical ripples found throughout the thinner layers are first formed structures or whether they result from cannibalisation of an earlier formed parallel lamination. The nature of the transition from parallel lamination into symmetrical ripples (gradual or truncational) probably reflects the rate of sediment addition at this time. The poor preservation of straight ripple crests generally in this facies is thought to result from the thick intra-ripple mud-drapes which influence weathering style.

Gutter casts are typically oriented roughly orthogonal to the palaeo-coastline and are therefore attributed to oscillatory wave motion. Strangely, gutter casts (which are perhaps the most dramatic erosional features) are only common in the mud rich presumably more offshore portions of this facies, although this distribution is also reported from other storm influenced sections (Johnson and Baldwin 1996). This may reflect a land-wards decrease in oscillation generated shear at the bed surface as a result of wave attenuation upon a low gradient shelf. However, gutter casts are also generally absent underlying thicker storm generated sandstone beds even where these are found within relatively mudstone rich packages that otherwise include gutter casts. This perhaps indicates that loose sand transported during waxing and peak storm stages afforded some protection to the underlying sea-bed as the storms peaked.

The large range of sandstone / mudstone proportions exhibited in this facies are explained either by changing sandstone supply from an adjacent coastline or in terms of changing proximity to this coastline.

2.1.4 HCS Facies

This facies consists of low angle hummocky lamination developed within very fine and fine sandstone; however, this facies is rare. Stratification is developed within flat-based beds up to 10cm in thickness that display long wavelength symmetrical

rippled tops. It appears that the low angle symmetrical hummocks first grow then decrease in size (figure 2.5). In some cases these beds display erosion generated symmetrical rippled tops. Further comment is hindered by the rarity of these bedforms and poor lateral exposure. These bedforms are found in association with symmetrical rippled facies, gutter casts and both graded and non-graded laminae. No bioturbation was recorded.

Interpretation

The increasing steepness and decreasing wavelength of these bedforms upwards may indicate an evolutionary change from hummocky bedforms into symmetrical wave ripples. However, the upper symmetrical rippled surface displayed by these bedforms is erosional in nature and is therefore not necessarily the result of a continuum in this process. The presence of erosional symmetrical ripples suggest that late stage supply of sandstone from suspension had become negligible thus preventing further agradation of the bed therefore terminating the preservation of transitional type bedforms. Alternatively these wave-rippled tops were generated during subsequent storms. The erosive generation of symmetrical ripples at the bed top and lack of constructive lamination associated with these suggest that unidirectional currents were active in the water column overlying the bedform and that these were capable of removing the product of this erosion. Although extremely rare, these bedforms lend weight to the existence of the accretionary hummocky type bedforms generated experimentally by Arnott and Southard (1990) under oscillatory conditions.

2.1.5 Cross-bedded sandstone facies

This facies comprises cross stratification developed within well-sorted fine to medium grained sandstone which sometimes contains mud chips and/or small quartz pebbles. Beds are up to 50cm thick and are bound by flat or gently scoured surfaces. Cross-beds are typically 10-25cm high but may reach 50cm and are typically discontinuous along strike. Sets display strongly asymptotic bottom sets and rarely dip at angles exceeding 20° (plates 2.13 and 2.14). Such cross-stratification is often inter-bedded with parallel lamination and ripple cross-lamination as well as thin mudstone layers. Cross-beds appear to suggest variable palaeo-flow although

measurement of this from wave cut surfaces is likely to be rather inaccurate. The facies rarely includes any sign of bioturbation.

Interpretation

Determining the origin of cross-bedding is hindered by a lack of accurate palaeo-current information although the studies of Bamford (1988) suggests that asymmetric bedforms from this level display a fairly random palaeoflow pattern. It is well known that both trough and tabular cross-bedding develops within the shoreface of both barred (Hunter *et al.* 1979; Clifton 1981) and non-barred (Clifton *et al.* 1971; Bourgeois 1980) coastlines and that these display a wide variety of orientation. On-shore directed cross-bedding results from transformations in the surface wave-form as the coast is approached (wave build up zone) whilst offshore directed cross-bedding is developed by rip currents and within rip channels. Cross-bedding is also commonly oriented parallel to the coast as a result of littoral drift (Clifton *et al.* 1971; Howard and Reineck 1981). In addition it is also possible that some cross-beds were generated by tidal currents, fluvial outflow or geostrophic currents, indeed the latter were probably responsible for occasional low angle offshore directed cross-strata developed within more distal symmetrical rippled units (plate 2.14).

2.1.6 Amalgamated parallel laminated sandstone facies

This facies comprises parallel laminated very fine to medium grained sandstones. These are usually minerologically mature, light grey or white in colour and typically lack evidence for parting lineation. Beds range from 5-30cm in thickness and occur in sharp-based amalgamated sequences up to 9m thick. Beds are usually bound by shallow scours (< 30cm in depth) but in some cases thin and often lenticular heterolithic packages are preserved between parallel laminated units.

The parallel lamination developed within this facies exhibits an undulatory form (dips < 4°) that often mimics the geometry of an underlying scour. In some instances scours are scoop shaped and are infilled with lamination that thicken into the scour and flatten upwards (figure 2.6). Although these resemble SCS they are normally isolated amidst lower angle parallel lamination (plates 2.15 and 2.16).

This facies division is commonly associated with cross-bedded and symmetrical rippled facies but rarely include bioturbation presumably because of the high energy depositional conditions. However some units do contain vertical burrows (up to 1.6cm wide 14cm deep) which tend to emanate from particular horizons suggesting periods of colonisation and horizontal mazes are also occasionally encountered. These features probably reflect development of *Skolithos, Diplocraterion* (*Parralelum, Habichi* and occasionally *Polyupsilon*) and *Ophiomorpha* ichnogenera. This ichnogenera assemblage reflects the Skolithos ichnofacies which is typical of high wave or current energy (Pemberton *et al.* 1992). The only larger body-fossils preserved are rare carbonised plant stems, which are 1-3mm in width and of indeterminate length encountered on Galley Head and Seven Heads.

Interpretation

This facies division reflects deposition of sandstones under upper flow conditions. In most cases beds display an undulating erosive surface at their base presumably generated during major storm events. However, it is unclear whether this surface and the overlying parallel lamination are genetically related. If they are, then the overlying beds represent proximal tempestite beds in which the frequency of successive storms was sufficient to prevent the preservation of the fair weather sequence. Alternatively, if the erosive surfaces are not genetically related to the overlying bed then the overlying planar laminated sandstone may have accumulated gradually during fair weather conditions. Amalgamated packages of parallel laminated sandstone may reach up to 9m in thickness and are believed to have formed within the shore attached sandy shore-face rather than in large migrating sand ridges. The sharp, erosive lower contact that these packages usually exhibit is not compatible with such bed-forms.

The lack of well-developed parting lineation in this facies may result because of differences in the hydrodynamics of oscillatory or combined flow compared to unidirectional flow. Alternatively a geostrophic component active at high angles to the wave approach caused obliquity between the on-shore and offshore oscillatory currents thus inhibiting development of parting lineation.

The well developed but isolated swale shaped scours that are sometimes found in this facies are believed to have been generated from scour and fill rather than by the passage of bed-forms. It is possibly that the scouring event responsible for such structures was similar to that responsible for generating the upper saucer shaped portions of some gutter casts

2.2 Facies association 2

Facies association two comprises units that are either heterolithic or are inter-bedded with heterolithic units and regularly include bi-modal current patterns. Facies association two does not include well-developed graded beds or gutter casts but may be found inter-bedded in vertical section with units containing these elements (facies association one).

2.2.1 Sandstone laminated mudstone facies

This facies comprises cleaved mudstone that is typically black or dark grey in colour and includes thin light grey or brown sand/silt-stone laminae (<4mm in thick). These laminae usually exhibit sharp upper and basal surfaces and may be tabular, lenticular or pinch and swell laterally (plates 2.17 and 2.18). In some instances the intervening mudstone layers include dark grey silico-phosphatic nodules which are usually randomly distributed although nodular horizons are sometimes also encountered. Units of sandstone laminated mudstone are commonly delineated by gradual vertical changes in thickness or lithology but may also be bound by erosional surfaces of varying scale (plate 2.19).

This facies may form within coarsening up (CU), fining up (FU), coarsening up then fining (CUFU) up or fining up then coarsening up packages (FUCU). It may also alternate repeatedly with asymmetric or symmetric rippled facies (plate 2.20). Bioturbation is common but rarely prolific and is dominated by horizontal and vertical burrows normally 2-3mm in diameter (occasionally up to 7mm in diameter).

Interpretation

This facies division reflects alternating mudstone and sandstone deposition within a mixed tide and wave influenced environment (see following text). The mudstone

intervals accumulated when the wave or tidally generated currents were reduced or when mud concentrations were particularly high whilst sandstone intervals formed when currents exceeded the movement threshold of silt or sand and when supply of this material was available. At these times sand migrated across the muddy substrate and accumulated as thin parallel laminated units or as incipient ripples (pinch and swell) depending on current velocity. The fluctuating energy conditions inherent in the genesis of this facies may result from tides or from seasonal events such as additional input of sand from storms or rivers. Similarly, the repeated alternation that is sometimes developed between this facies and rippled facies (asymmetric or symmetric) may reflect tidal or seasonal cycles. It is also likely that some of these units reflect localised development of bedload parting (Harris *et al.* 1995)

2.2.2 Small scale symmetrical rippled facies

This facies comprises relatively small scale symmetrical ripples developed within siltstone to fine sandstone and is normally heterolithic. Beds are usually less than 90cm in thickness and may be delineated by vertical changes in thickness, lithology or shallow erosional surfaces. Symmetrical ripples display wavelengths of between 1cm and 6cm, heights of 1mm to 5mm and ripple index values that always exceed 5 and often exceed 20 thus suggesting that both rolling grain and vortex ripple types are present (Bagnold 1946; Miller and Komar 1980b). Ripple crests vary between straight (plate 2.21) and undulatory and commonly bifurcatate but crestal interference patterns are rare (plate 2.22). In profile, ripples are normally sinusoidal although trochoidal forms are sometimes developed where wavelength is small and lamination tends to sweep between adjacent crests (concave up) and sometimes drapes ripple crests (convex up). Foresets vary between uni-modal and bi-modal in style even between adjacent crests however it appears that the majority of fore-sets are oriented northward. Fluidisation is rare in comparison to other sandstone rich facies within facies association 2.

The facies is sub-divided based on the proportion of sandstone to mudstone (Reineck 1968). Three divisions are differentiated;

Mudstone dominant (0-33%) sub facies. Lenticular and wavy bedded symmetrical ripples and non-graded sandstone laminae that often display pinch and swell structures dominate this division.

Mixed mudstone / sandstone (33-66%) sub facies. This division may include lenticular or flaser bedding but is normally dominated by wavy bedding. Non-graded sandstone laminae may also be found. In some cases randomly distributed silico-phosphatic nodules (<10cm) are found within both the mudstone dominant and mixed mudstone/sandstone sub-facies.

Sandstone dominant (66-100%) sub facies This division is dominated by wavy and flaser bedding. Mud drapes within this facies often drape ripple crests but generally thicken into adjacent troughs.

This facies is often found inter-bedded with horizontal laminated units (< 10cm) that display symmetrically rippled tops, it is also found associated with asymmetric ripples, cross-beds and desiccation cracks. In some cases this unit also includes brown or orange pock-marked weathering horizons that probably result from decalcification (Pracht 1994).

Bioturbation is common and sometimes prolific and often consists of a relatively low diversity *Arenicola marina* dominated assemblage (burrows usually 2-3mm) which is particularly common within the mixed mudstone and sandstone sub-facies. In some cases horizontal burrows of up to 1.4cm in width were also recorded and these probably reflect *Ophiomorphia* or *Rhizocorallium* ichnogenera.

Interpretation

This facies division reflects alternating episodes of mudstone deposition and generation of wave formed symmetrically ripples. The mudstone accumulated when orbital velocities were reduced and symmetrical ripples formed when orbital velocities exceeded the threshold for movement of silt or sand which is around 0.15-0.25 m sec^{-1} (Terwindt 1981) and when supply of this material was available. The thin parallel laminated found inter-bedded with this facies were probably generated when current velocities exceeded 1 m sec^{-1} (Terwindt 1981).

The coast facing orientation of many fore-sets suggests generation within fairly shallow water (Newton 1968; Allen 1979; Allen 1981a). Likewise, very small period trochoidal shaped micro-ripples are likely to have formed in shallow perhaps even partially emergent conditions (Collinson and Thompson 1982). Estimates of

wave period (Allen 1981b) suggest a maximum of about 2 seconds suggesting wave fetch did not exceed 10km. This remarkably low figure is discussed later in the text (chapter seven).

Symmetrical rippled facies may dominate large portions of the stratigraphy and is interpreted to reflect wave influence within a shallow shelf or inter-tidal flat setting. Where this facies is inter-bedded with erosive based tidal facies it is likely that it accumulated principally on the flats surrounding tidal channels. In these areas rates of sedimentation are likely to have been lower thus perhaps explaining why bioturbation is more intense and convoluted bedding less common.

2.2.3 Asymmetric rippled facies

This facies comprises asymmetric ripples developed in coarse silt to fine grained well-sorted sandstone. Units are commonly heterolithic and exhibit sharp grain size separation between the rippled sandstone (light grey) and the clay or silt dominant mudstone drapes (dark grey). Ripples are found either in flat-based sandstone lenses or within discontinuous lenses that are typically more elongate than those associated with symmetrical ripples. These may be bound either by mud drapes or discontinuity surfaces. Asymmetric ripples are usually 1-3cm high, exhibit wavelengths of less than 25cm, have tabular, tangential or troughed fore-sets and undulatory, catenary or linguoid crests. Palaeo-flow measurements may display uni-modal or bi-modal patterns and herring-bone structures are common (plates 2.24 and 2.25). Soft sediment deformation is also common. Beds are usually less than 1.4m thick and may be delineated either by vertical changes in thickness, lithology or by erosion surfaces. The latter range from shallow scours to major channel enclosing features up to 7m in depth and over 150m in width and may be mantled with mud chips of up to 8cm in length. Internal stratification is predominantly horizontal but may become inclined overlying channel margins (<17°) where beds usually on-lap channel margins (plate 2.26) but occasionally down-lap onto channel floors.

The facies is sub-divided based on the proportion of sandstone to mudstone (Reineck 1968), three divisions are differentiated;

Mudstone dominant (0-33%) sub facies. This division is dominated by wavy and lenticular bedding and may contain silico-phosphatic nodules.

Mixed mudstone /sandstone (33-66%) sub facies. This division may display lenticular, wavy or flaser bedding types. Inter-laminated mudstone units typically thickens into ripple troughs. In some cases randomly distributed silico-phosphatic nodules (<10cm) are found within both the mudstone dominant and mixed mudstone/sandstone sub-facies.

Sandstone dominant (66-100%) sub facies. This division may display wavy or flaser bedding types. In wavy bedded sequences mudstone units thicken into the troughs whilst in flaser bedded units mudstone drapes are typically lens shaped and drape the lower fore-set and bottom-set regions.

This facies may form within coarsening up (CU), fining up (FU), coarsening up then fining (CUFU) up or fining up then coarsening up packages (FUCU). Asymmetric ripples rarely merge laterally with parallel lamination but are often intricately inter-laminated in vertical section. Asymmetric ripples are also observed to alternate repeatedly with parallel lamination and also to replace it upwards in vertical section. Asymmetric ripples may also be inter-bedded with symmetrical ripples, cross-beds and sandstone laminated mudstone. Bioturbation is rare within this facies but occasionally includes worm tubes assigned to *Arenicola Marina*.

Interpretation

This facies division reflects alternating episodes of mudstone deposition and generation of current formed asymmetrical ripples. The mudstone accumulated when current velocities were low or when suspended mud concentrations were high whilst ripples were generated when velocities exceeded the threshold for movement of silt or sand and when supply of this material was available. Bi-modal palaeo-currents, frequent mud drapes, channels and small-scale cyclicity suggest a strong but fluctuating reversible flow that is likely to have been tidal in origin (De Raaf and Boersma 1971). However, the thickness of many mud layers suggests that these often accumulated over more than one tidal slack (Terwindt 1981).

Asymmetric ripples are commonly associated with prominent erosional surfaces but are also found within tabular beds distant from such structures, thus generation of this facies may have proceeded both within tidal channels and within a shallow shelf

setting. However, the low abundance and diversity of bioturbation suggest stress factors such as rapid deposition or salinity fluctuation (Bromley 1996).

Ripple morphology probably resulted from the velocity and perhaps also the longevity of the causative flow. Earliest formed ripples tend to be quite straight and continuous crested but with gradual increase in velocity ripples take on a more 3 dimensional form. Ridges and hollows parallel to flow becomes more common and scour pits become better defined. Such changes probably reflect changes in turbulence close to the bed (Collinson and Thompson 1982).

The cyclicity that is sometimes found within this facies (either in grain-size or bed-form alternation) may result from seasonal or tidal cycles whilst the occasional vertical replacement of parallel lamination by ripples is possibly symptomatic of migrating channel sequences. Mud drapes were probably deposited at times of high and low water and perhaps also during the neap phases of the tidal cycle when current velocities were reduced. During these times mud accumulated preferentially within ripple troughs where velocities were lower and where removal during erosional reactivation was less likely.

2.2.4 Climbing ripple facies

This rare facies comprises asymmetric climbing ripples developed in beds of very fine and fine sandstone. These beds exhibit sharp and sometimes erosive lower surfaces and sharp or gradational upper surfaces. The ripples may exhibit super-critical or sub-critical angles of climb (inclinations of up to 15°) and in all cases laminae thicken from the lee to the stoss sides of the ripple form.

The best example of this facies is found in the upper part of the Old Head Formation in the Reenagough Point section where 5 sandstone beds containing climbing ripples oriented to the south-west are inter-bedded with dark mudstone. In this case the beds appear to thin over 10-20m in a down-current direction

Interpretation

The asymmetrical form of these ripples suggest that they were generated by unidirectional currents whilst thickening of laminae from lee to stoss sides suggest

that these migrated at least in part by slip face avalanching (Jopling *et al.* 1968). These units are therefore believed to reflect some form of mouth-bar deposit but their origin is rather enigmatic.

2.2.5 Miscellaneous rippled facies

In many cases it was not possible to unambiguously distinguish between asymmetric and symmetric ripple types. The main reason for this is the similarity in profile of ripples generated by short period reversing flow produced by waves and the longer period reversing flow produced by the tidal wave. For instance shoaling waves are likely to produce asymmetric ripples. It is also likely that the form of many ripples result from the effects of both wave and tidal processes. The facies is sub-divided based on proportions of sandstone and mudstone. These divisions are;

Mudstone dominant (0-33%) sub facies. Lenticular and wavy bedding.

Mixed mudstone /sandstone (33-66%) sub facies. Dominated by wavy bedding.

Sandstone dominant (66-100%) sub facies. Dominated by flaser and wavy bedding.

Interpretation

This division was deposited in a paralic setting dominated by short period waves and tides. It may also be prevalent in areas transitional between asymmetric and symmetric rippled facies, for instance on channel margins, tidal flats or upon a shallow shelf.

2.2.6 Parallel laminated facies

This facies comprises parallel laminated, very fine to medium grained sandstones. These are usually white or light grey in colour, well-sorted and often exhibit parting lineation. Individual beds are up to 90cm thick but are normally between 2-30cm whilst amalgamated units do not exceed 8m in thickness. Beds and groups of amalgamated beds may be delineated either by vertical changes in thickness, stratification type, lithology or by erosion surfaces. The latter, which often underlie units of this facies, range from shallow undulating scours to major channel bounding features of up to 6m depth and are commonly mantled with mud chips (< 12cm in length). Parallel lamination is normally horizontally stratified but inclined stratification (< 7°) may also be found particularly within channel fill sequences

(plate 2.26). Inclined strata tend to on-lap channel margins but occasionally down-lap the channel floor forming large-scale epsilon cross-stratification up to 2.4m thick. Stratification may also dip and thicken into shallow scours and has possibly been mistaken for swaley cross-stratification. Parallel lamination may merge laterally with massive or fluidised bedding (including sand volcanoes) and is commonly intimately inter-bedded with linguoid crested asymmetric ripples. Parallel lamination may alternate randomly or cyclically, or be replaced upwards with asymmetric rippled facies which is in some cases heterolithic. Parallel lamination is also found inter-bedded with symmetrical ripples (plate 2.27) and cross bedding.

Interpretation

This facies division is found in association with tide and wave influenced facies but is particularly prevalent in portions of the section where both asymmetric ripples and tidal channels are prominent. This probably indicates that tidal currents were the principal agent responsible for genesis of this facies. High deposition rates within the tidal channels may explain the abundance of convoluted bedding and the paucity of bioturbation within this facies. It is unclear if the high velocity of these currents within tidal distributary channels was generated during the normal tidal cycle or if these were augmented with other processes such as river outflow. However, the lack of unidirectional south directed palaeo-current measurements in many sections suggest that fluvial enhancement of ebb-currents was not normally important in final deposition of these divisions. The cyclical variation between horizontal lamination and asymmetric ripple cross lamination seen in some units is likely to have originated either from the tidal cycle or seasonal changes.

Although many thick parallel laminated units are intimately associated with tidal facies, thinner beds are often found in association with symmetrical ripples and may themselves display a symmetrically rippled top. Such units are likely to be storm rather than tide generated

2.2.7 Cross-bedded sandstone facies

This facies comprises cross-bedded fine to medium grained sandstone that is typically white or light grey in colour and well sorted. Fore-sets normally dip at less than 35° and may be tabular, tangential or troughed. Bed-form height is usually less

than 30cm (but may reach 60cm) and palaeo-flow patterns may be uni-modal or bi-modal (plate 2.28). Beds are typically erosionally bound and range from shallow undulating surfaces to major channel-bounding features. Both basal scours and fore-sets may be mantled with mud chips (< 10cm).

Fore-sets do not appear to be arranged within tidal bundles but reactivation surfaces are sometimes displayed. Although it is not normally clear whether groups of cross-beds were constituent in larger bedforms, a package from the Bere Island section exhibits compelling similarities with sand-waves described by Boersma and Terwindt (1981). This example is shown in figure 2.7.

Cross-beds are usually found inter-bedded with asymmetric ripples and parallel lamination. In some cases this facies includes brown or orange pock-marked weathering horizons that probably result from decalcification (Pracht 1994).

Interpretation

This facies reflects the development of tide generated straight or sinuous crested dunes predominantly within tidal channels but to a lesser extent upon adjacent tidal flats and within shallow shelf settings. Terwindt (1981) suggests that the threshold for this type of bedforms is around 0.5-0.6 m sec^{-1}. The rarity of these structures relative to other tidal facies is ascribed to the fine grain size of the studied sequence which is often below that of the dune stability field. This may explain the prevalence of cross bedding within tidal channels as these are likely to include the coarsest grain sizes as well as highest velocities.

2.2.8 Sand-ball facies

This facies comprises cleaved black to dark grey claystone containing sand balls derived from overlying units (<30cm diameter). Individual units do not exceed 1m in thickness and are often underlain by erosive surfaces (ranging from shallow scours to major channel-enclosing features) and overlain by sandstone rich facies.

Interpretation

This facies division reflects deposition of mud from suspension within a setting dominated by both tides and waves followed by a phase of gravitational instability

during which sand-balls were generated. This instability suggests that initial mud deposition was rapid and that this progressed either when currents became sufficiently reduced to allow settling of mud from suspension or when suspended mud concentrations were particularly high (> 100mg l^{-1} (McCave 1971). The close association between this facies and both erosion surfaces and sandstone rich facies suggest that deposition probably progressed within a distributary setting, possibly during major flooding events. A possible analogy of this is the Mahakam Delta of Indonesia where Gastaldo *et al.* (1995) record suspended mud concentrations that can exceed 1000mg l^{-1}. In this example the turbidity maximum related to the position of the salt wedge migrates with the tide affecting almost the whole delta plain and mud may be deposited during a current slack of several hours.

2.3 Facies association 3

Facies association three reflects deposition within terrestrial settings and comprises non-heterolithic units often displaying uni-modal south directed palaeo-currents.

2.3.1 Amalgamated structured sandstone facies

This facies comprises well sorted, very fine to medium grained sandstone that is usually light grey in colour and may be rippled, parallel laminated or cross-bedded. These bed-forms all indicate roughly south directed palaeo-flow. Beds are typically lenticular and bound by scour surfaces but in rare cases may include lenticular mudstone or heterolithic units. In most cases sandstone beds are stacked forming thick amalgamated packages and these typically overlie a prominent erosion surface. In some cases erosion surfaces appear to bound channels (plate 2.29) that may be saucer shaped or box shaped (steep margins up to 75°) in profile and the basal portion of these amalgamated packages may include mud chips of up to 14cm in length (plate 2.30). The facies may be dominated by either cross-bedding or parallel lamination but inter-bedding of these and ripple cross-lamination is also common however no obvious or repeatable stacking pattern was noted within amalgamated packages. Parallel lamination and cross-beds commonly merge laterally with massive or fluidised units.

Cross-stratification is up to 1.1m in height and sometimes displays trough shaped fore-sets but tabular forms often with slightly asymptotic bottom-sets are most common. Foresets normally dip at between 8°-30°. Parallel lamination often forms within thick scour based beds and commonly exhibits parting lineation that is typically oriented roughly N-S (plate 2.31). Stratification is normally horizontal but is sometimes inclined within channel sequences and may onlap channel margins or form low angle epsilon cross-bedding which down-lap channel floors. Mud chips are sometimes found within the bottom sets of such structures. Asymmetric ripples are usually 1-3cm high and have tabular, tangential or trough shaped fore-sets and undulatory, catenary or linguoid crests.

Occasionally amalgamated sandstone packages include a brown or yellow-brown unit that is patchy but laterally traceable and often very soft (plate 2.32). No bioturbation or macro-fauna was identified from this facies.

Interpretation

This facies division reflects deposition within southerly flowing fluvial channels although the presence of heterolithic units preserved between some of the sandstone packages seems to indicate periods when tides influenced the dynamics of these channels. The unusual yellow and brown units exposed within some sandstone packages may reflect palaeosol development following channel migration or abandonment.

2.3.2 Thin tabular bedded sandstone facies

This facies comprises thin (<40cm), flat based and isolated beds of very fine and fine sandstone that are inter-bedded with poorly sorted massive siltstone facies. Beds are normally massive or rippled but may also be parallel laminated and cross-bedded. All bedforms indicate southerly directed palaeo-flow. This facies is transitional with amalgamated structured sandstone facies and the small-scale sand stringers found in poorly sorted silty units (see following text). No bioturbation or macrofauna was recorded.

Interpretation

This facies division reflects non-channelised fluvial deposition upon an alluvial /coastal plain and may represent crevasse splays. The facies was probably generated during river flooding events.

2.3.3 Poorly sorted siltstone facies

This facies comprises very poorly sorted silt, silty-sandstone and silty-claystone that is normally light grey in colour. Beds are often thick (< 1.8m) and exhibit sharp or scoured bases (usually < 3cm relief). However, upper surfaces are often truncated by strongly down-cutting erosion surfaces associated with amalgamated structured sandstone facies. Internal stratification is usually absent (massive) but some units include poorly preserved sandstone or mudstone stringers which are typically highly disrupted by vertical burrows (< 4mm in diameter). Some units also contain ripples, these may be asymmetric in which case they are usually less than 2cm in height and south-directed or symmetrical in which case they are of small scale (wavelength < 3cm) and trochoidal or sinusoidal in profile (plate 2.33). Desiccation cracks and brown decalicified layers may also be found within this facies (plate 2.34). This facies is often inter-bedded with thin tabular bedded sandstone units usually less than 40cm thick. These may be cross-bedded, rippled or parallel laminated but are most commonly massive. Bioturbation includes horizontal and vertical burrows normally less than 4mm in diameter but occasionally up to 1.3cm. A log cast 26cm long and 1.6cm in diameter was recorded from a bedding surface in the Ballycrovane section (figure 3.1).

Interpretation

This facies division reflects deposition of clay, silt and very fine sandstone within a fluvial plain setting perhaps during phases of high accommodation generation. Deposition was probably incremental (seasonal?) and is thought to have resulted from river flooding events. The symmetrical micro-ripples occasionally found within this facies were probably generated in puddles or small lakes formed by high river discharge or perhaps during marine flooding events such as storm surge or spring tides. The reason for the general absence of primary sedimentary structure within the facies is unclear but the degree of biological disruption within sandstone stringers may indicate that burrowing or plant rootlets was responsible for this.

Facies	Sign	Description	Setting
Facies association 1 - Storm influenced marine facies			
Mudstone facies	1.1	Homogeneous mudstone, sometimes with calcareous linsen	Offshore to offshore--transition
Graded laminae facies	1.2	Mudstone containing graded laminae and gutter casts	Offshore transition
Symmetrical rippled facies	1.3	Symmetrical ripples with varying sandstone content	Offshore transition to lower shoreface
HCS facies	1.4	Hummocky cross stratified sandstone	Offshore transition to lower shoreface
Cross-bedded sandstone facies	1.5	Trough and tabular cross-bedded sandstone	Shoreface
Amalgamated parallel laminated sand facies	1.6	Parallel laminated sandstone often including low angle scours	Shoreface
Facies association 2 - Tide and low wave energy marine facies			
Sandstone laminated mudstone facies	2.1	Mudstone containing sandstone laminae but lacking graded beds	Coastal to shallow shelf
Small scale symmetrical rippled facies	2.2	Small wavelength symmetrical ripples with varying sandstone content	Coastal to shallow shelf
Asymmetric rippled facies	2.3	Asymmetric rippled sandstone with varying sandstone content	Coastal to shallow shelf
Climbing ripple facies	2.4	Climbing asymmetric ripples	Coastal to shallow shelf
Miscellaneous rippled facies	2.5	Ripple cross-lamination of undiscernible origin	Coastal to shallow shelf
Parallel laminated facies	2.6	Thick parallel laminated sandstone units often associated with downcutting surfaces	Distributary channels to coastal
Cross-bedded sandstone facies	2.7	Cross-bedded sandstone units often displaying bi-modal palaeocurrent patterns	Distributary channels to coastal
Sand-ball facies	2.8	Sand-balls developed in mudstone, commonly associated with downcutting surfaces	Distributary channels
Facies association 3 - Terrestrial facies			
Amalgamated sandstone facies	3.1	Thick and often erosive based sandstone units containing south oriented bed-forms	Fluvial axis
Thin-bedded sandstone facies	3.2	Thin, tabular beds of sandstone containing south oriented bed-forms	Crevasse splay and river flooding events
Poorly sorted siltstone facies	3.3	Poorly sorted massive siltstone containing symmetrical ripples and desiccation cracks	Flood plain

Figure 2.1 - Summary of facies and facies associations. The column headed 'sign' refers to the abbreviation used on the left hand column of the logged sections and to the section of chapter two in which that facies is described.



Plate 2.1 - The basal part of the Castle Slate Formation includes several thin lenticular limestone lenses (orange) less than 15cm thick (Ballycrovane 6m).



Plate 2.2 - Small gutter casts rotated by bedding parallel shear. Significant changes in thickness and frequency of sandstone beds, graded beds and gutter casts are seen in vertical section. These changes are generally gradational (Ballycrovane 585m).

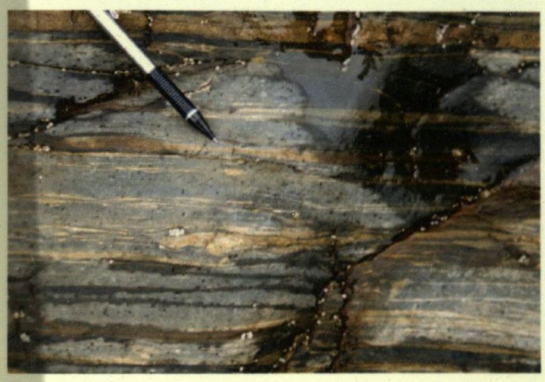


Plate 2.3 - Small gutter casts underlying graded laminae result in abundant lenticular sandstone lenses that are sometimes difficult to distinguish from incipient ripple forms (Dunworly 119m).



Plate 2.4 - A shallow scoop shaped scour is developed within graded laminae facies and is infilled by mudstone and thin laminated siltstone (Dunworly 64m).

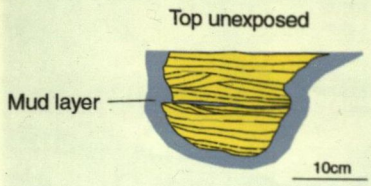


Plate 2.5 - Shallow scoop shaped gutter cast. Unusually, the gutter fill is graded, the basal 1cm of the gutter cast consists of very coarse quartzose sandstone and this is overlain by fine sandstone (Dunworly 130m).

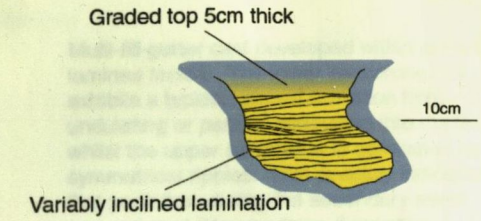


Plate 2.6 -Typical 'steers head' shaped gutter cast. Adjacent laminae are deflected due to post-depositional compaction. The gutter cast has also been rotated slightly due to bedding parallel shear (Dunworly 117m).

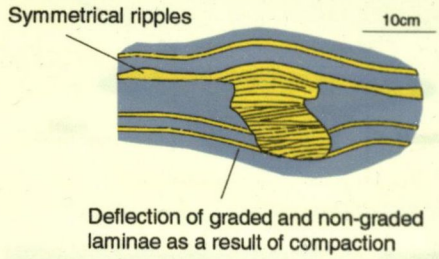
Dunworly Bay



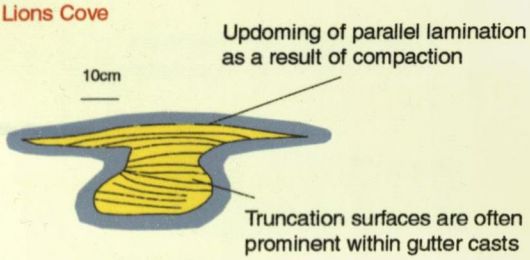
Dunworly Bay



Dunworly Bay



Lions Cove



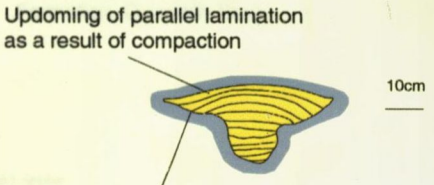
Typical 'steers head' geometry

Dunworly Bay



Asymmetric downcutting exaggerated by post-depositional sheer

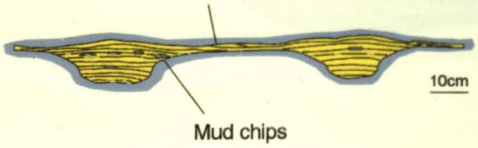
Dooneen, North Dunmanus Bay



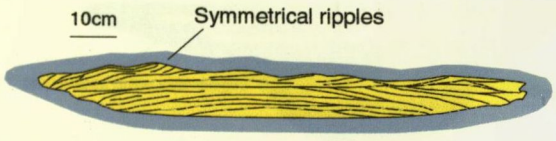
Apparent down-lap resulting from compaction

Dunworly Bay

Ripples in upper portion overly a truncation surface and were possibly generated during a later reworking event



Dunworly Bay



Apparent doming within the central portions of this large and shallow gutter cast results from compaction

Dunworly Bay

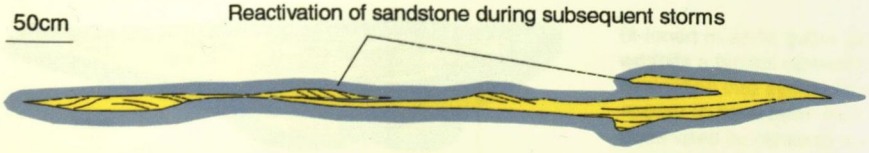
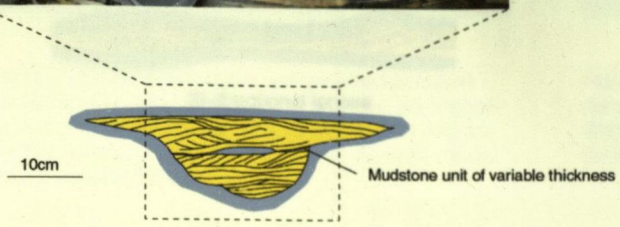


Figure 2.2 - Sketches of gutter cast morphology, the geographical location of these sketches is indicated in red.

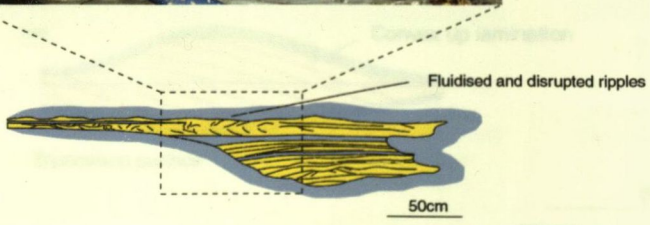


Multi-fill gutter cast developed within graded laminae facies. The lower sandstone unit exhibits a typical upward transition from undulating or parallel lamination into ripples. whilst the upper sandstone is dominated by symmetrical ripples. This possibly indicates that peak flow during the secondary event was reduced (Narrow Cove Formation, Dunworly Bay).

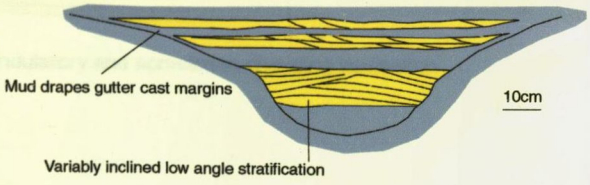


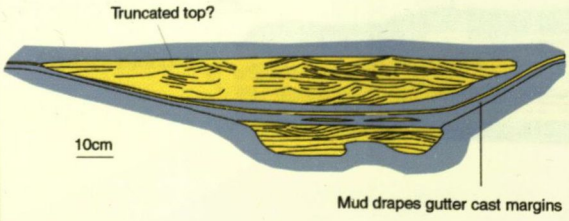


Margin of a multi-fill gutter cast exhibiting several generations of infilling. Symmetrical ripples are present both within the early and late fill. The uppermost portion of the fill has been partially fluidised (Narrow Cove Formation, Dunworly Bay).



Multi-fill gutter cast. Initial erosion and gutter cast generation was not immediately followed by deposition of sandstone suggesting that the formative flow entrained little or no sand. Alternatively the sand entrained in the flow was flushed right through the system (Old Head Formation, Lions Cove).





Bi-lobed multi-fill gutter cast. The lower sandstone exhibits a typical upwards transition from parallel lamination into symmetrical ripples the top of which appear to have been truncated. The upper unit is dominated by climbing symmetrical ripples but it is unclear if these were deposited during a single event or multiple events (Old Head Formation, Lions Cove).

Figure 2.3 - Multi-fill gutter cast - sketches

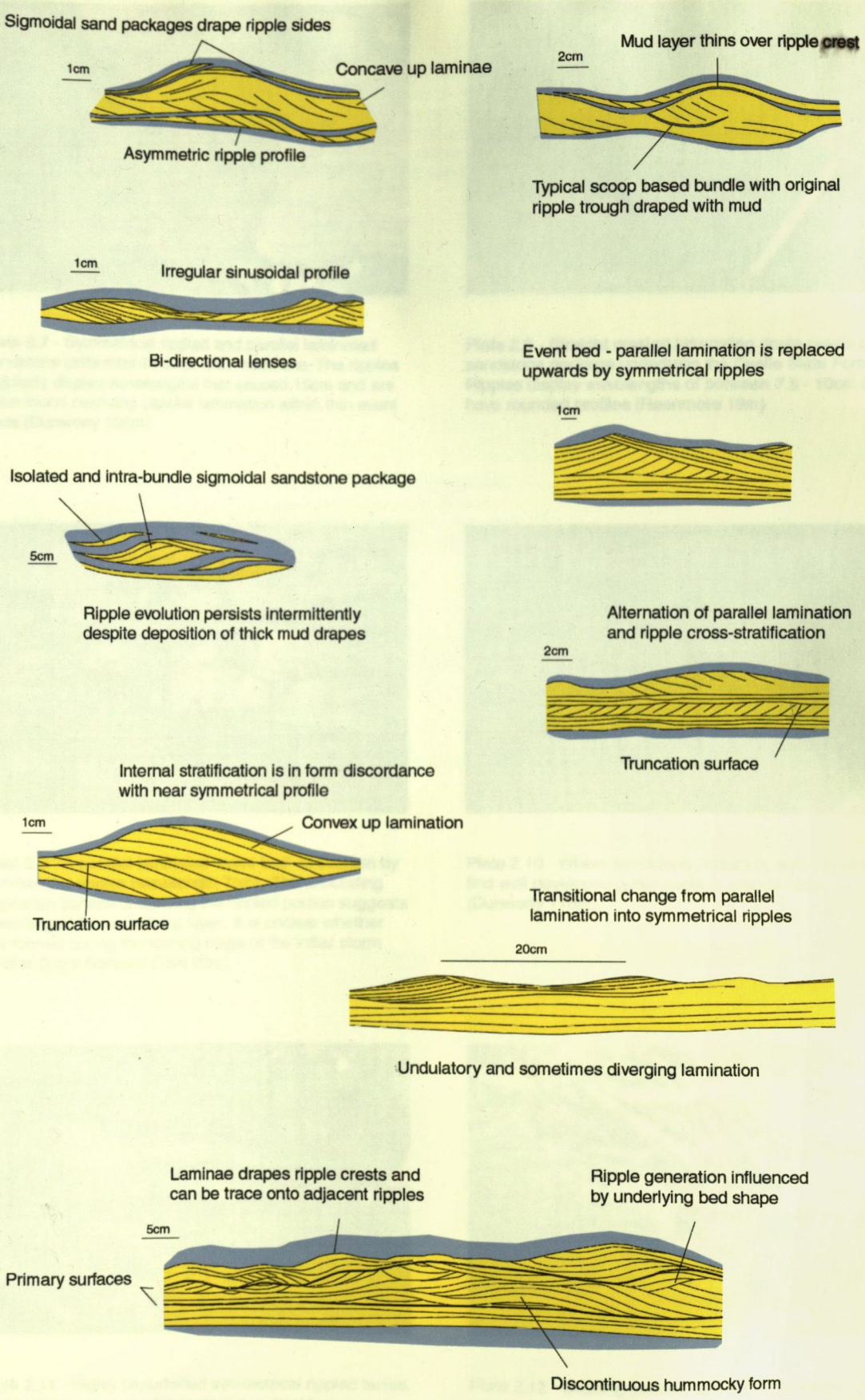


Figure 2.4 - Sketches from Dunworly Bay (Narrow Cove Formation) indicating some of the morphological features that are typical of Symmetrical ripples



Plate 2.7 - Symmetrical rippled and parallel laminated sandstone units inter-bedded with mudstone. The ripples regularly display wavelengths that exceed 15cm and are often found overlying parallel lamination within thin event beds (Dunworly 108m)



Plate 2.8 - Straight crested bifurcating ripple crests cap a sandstone package underlying the Castle Slate Formation. Ripples display wavelengths of between 7.5 - 10cm and have rounded profiles (Reenmore 19m)



Plate 2.9 - A parallel laminated 'event bed' is overlain by symmetrical ripples (wavelength 7cm). The undulating truncation surface underlying the rippled portion suggests reworking of the underlying layer. It is unclear whether this formed during the waning stage of the initial storm or later (log 2 Nohoval Cove 23m).



Plate 2.10 - Where sandstone content is high it is rare to find well developed gutter casts or graded beds. (Dunworly 116m).

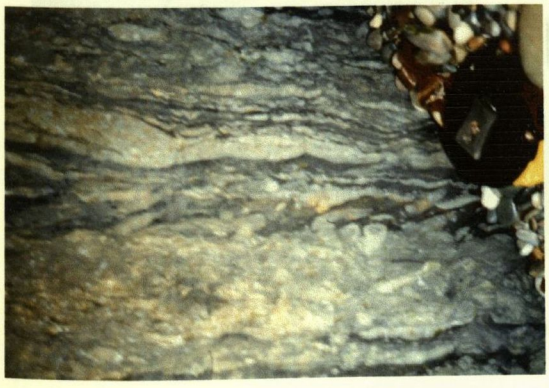


Plate 2.11 - Highly bioturbated symmetrical rippled facies. Horizontal burrows predominate but vertical burrows are also common, both exhibit diameters of less than 1.4cm (log 2 Nohoval Cove 23m).

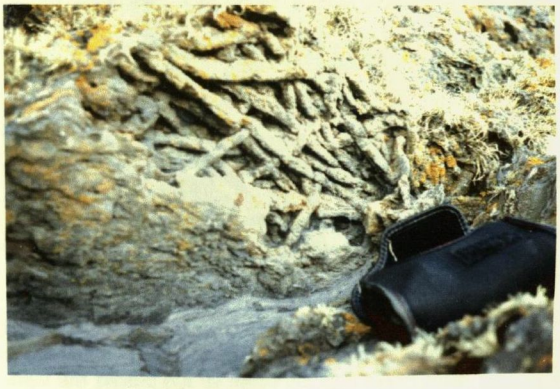
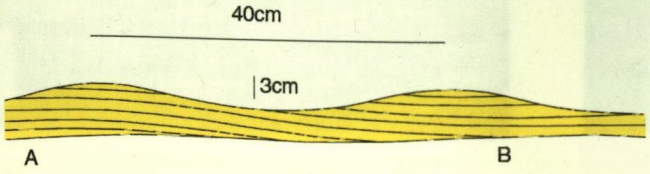


Plate 2.12 - Bedding parallel network of planolites burrows exposed within symmetrical rippled facies. These are typically around 5mm in diameter (log 2 Nohoval Cove 36m).

Possible hummocky stratification. An accretionary hummock appears to have developed around point A and then grown in size reaching point B. The bedform then either decreases in size or intervening swales are infilled. The large scale symmetrical ripples developed on the bed top appear to be entirely erosional.



Possible hummocky stratification. Large scale, low angle hummocky bedforms appear to transform into progressively higher angle and reduced wavelength forms. As with the example above, this process appears to culminate in an erosional phase of large-scale symmetrical ripple generation.

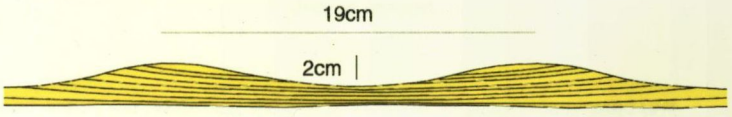


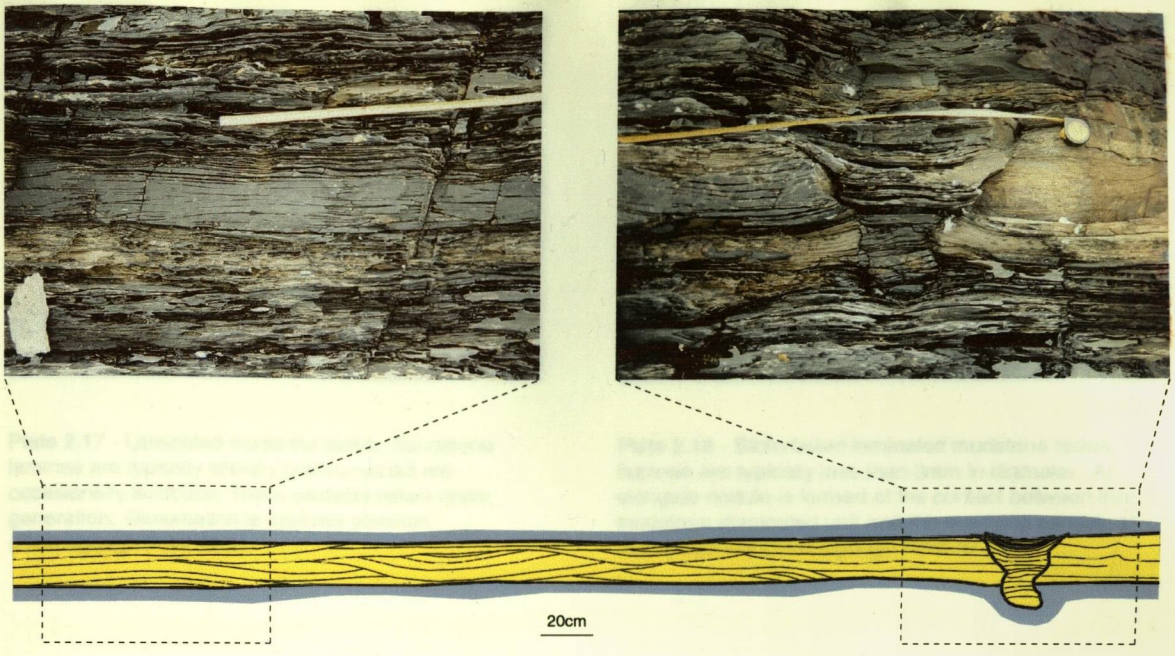
Figure 2.5 - Upwards transformation of HCS, Old Head Formation, Lions Cove.



Plate 2.13 - Cross stratified units picked out by granules of vein quartz (Myrtleville 18m).



Plate 2.14 - Low angle cross-stratification directed to the south west. Foresets which are oriented roughly south--east are picked out by flattened mud clasts. The bedform was probably generated by offshore directed geostrophic currents (Dunworly 107.5m).



Possible accretionary hummock. Alternatively the apparent downlap onto the base of this bed may represent compaction of gentle onlap onto the margins of a shallow scour

Gutter cast incising through a parallel laminated sandstone bed (20cm thick). The steep margins suggest partial lithification of the sandstone unit prior to erosion.

Figure 2.6 - A series of scoop shaped intra-bed scours are developed within a predominantly parallel laminated unit developed within the Narrow Cove Formation (Dooneen 266m).



Plate 2.15 - Swale shaped scours isolated with a parallel laminated package (Lions Cove 159m).



Plate 2.16 - Amalgamated parallel laminated sandstone package. These are typically sharp based and topped and include numerous intra--bed scour surfaces (Lions Cove 124m).



Plate 2.17 - Laminated mudstone facies. Sandstone laminae are typically laterally continuous but are occasionally lenticular. These probably reflect ripple generation. Bioturbation is relatively common (Reenagough Point 20m).



Plate 2.18 - Bioturbated laminated mudstone facies, burrows are typically less than 3mm in diameter. An elongate nodule is formed at the contact between the mudstone dominated unit and the overlying sandstone dominated unit (Reenagough Point 37.7m).



Plate 2.19 - Large scale down-cutting surfaces formed within laminated mudstone facies at the base of the Old Head Formation (South Bantry Bay 78m).



Plate 2.20 - Alternating wavy bedded rippled units and sand laminated mudstone units overly a rippled sandstone package. The package includes horizontal burrows up to 1.2cm in diameter (Reenagough Point 431m).



Plate 2.21 - Straight and sometimes bifurcating symmetrical ripple crests. Ripple wavelength is 5cm (Dooneen 428m).



Plate 2.22 - Crestal interference pattern. Ripples are straight crested and symmetrical. Wavelengths are 4cm and 5cm (Dooneen 63m).

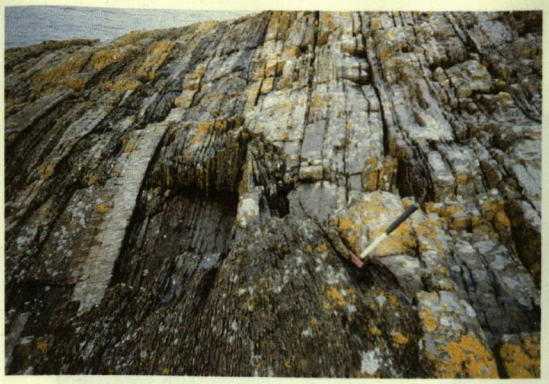


Plate 2.23 - Channel margin. Tabular bedded sandstone units are incised by a channel structure. This is infilled with wavy bedded heterolith which onlap the channel margin (Cahermore 499m).



Plate 2.24 - Interlaminated parallel lamination and 'herring bone' asymmetric ripples (Cahermore 843m).



Plate 2.25 - Interlaminated parallel lamination and 'herring bone' asymmetric ripples. Parallel laminated units are generally enclosed within asymmetric ripples oriented to the right (south) suggesting ebb dominance (Cahermore 852m).



Plate 2.26 - lateral accretion surfaces dip to the right (west) within a sandstone filled channel (Bere Island 187m).



Plate 2.27 - Parallel lamination with occasional inter--calated ripples (Cahermore 850m).



Plate 2.28 - Cross-beds displaying 'herring bone' type stratification (Fair Head 140m).



Ebb-dominated sand-wave with rippled reactivation surfaces formed during the subordinate flood tide

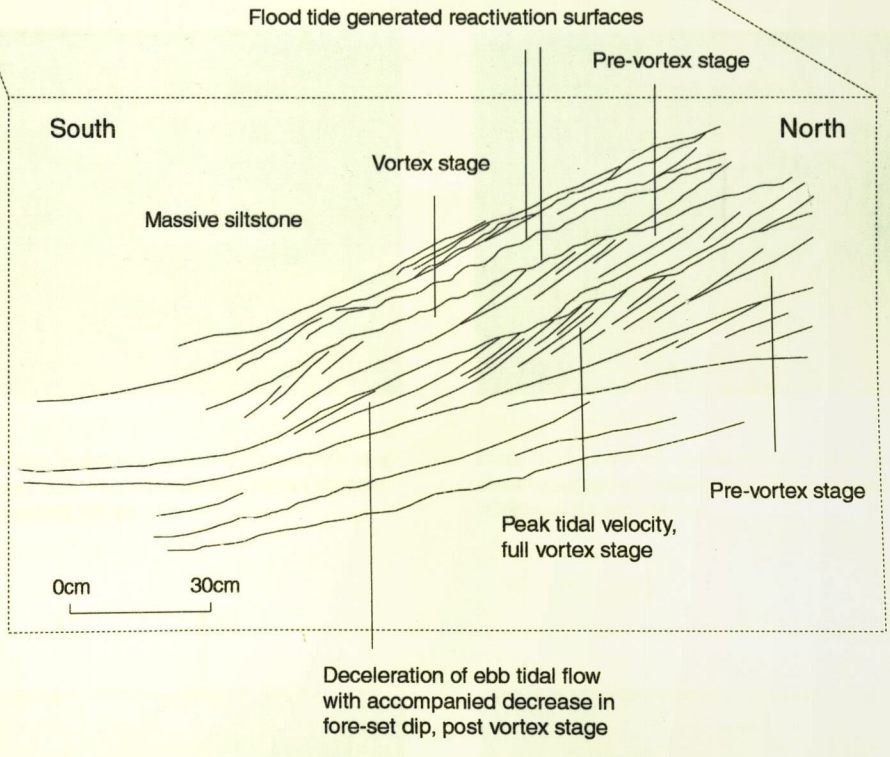


Figure 2.7 - Bere Island (341m) - A sequence of superimposed cross-beds exhibits increasing then decreasing foreset dip probably reflecting corresponding change in flow velocity during the ebb tide (southerly orientation). Rippled reactivation surfaces mark the subordinate flood tide. These features closely resemble the sand-waves described by Boersma and Terwindt (1981) and Allen (1984).

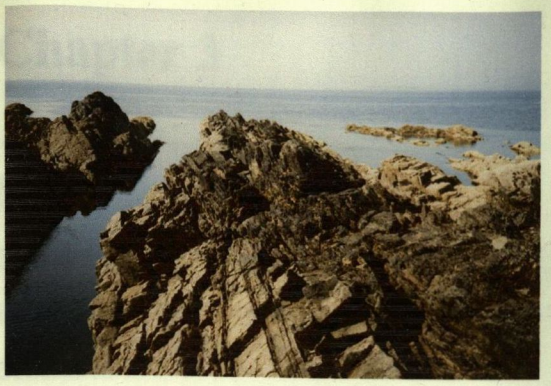


Plate 2.29 - Saucer shaped fluvial channel infilled with cross-bedded sandstone (Collorus).



Plate 2.30 - An intraformational conglomerate dominated by mud chips forms the basal portion of a channel sequence (Collorus (top) 141m).



Plate 2.31 - Parting lineation upon the basal surface of a parallel laminated unit. The lineation is oriented roughly NE-SW (Ballycrovane 189m).



Plate 2.32 - Laterally persistent brown or orange weathered zone. These may reflect palaeosol horizons (Collorus (base) 196m).

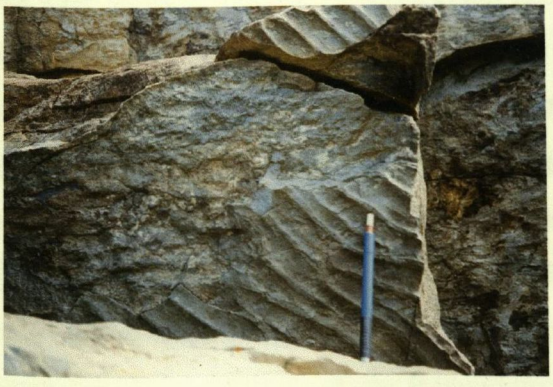


Plate 2.33 - Small scale trochoidal symmetrical ripples (wavelength 2.5cm) that reflect periods of flooding upon the fluvial plain (Ballycrovane 172m).



Plate 2.34 - Polygonal, sandstone filled and downward tapering desiccation structures (Ballycrovane 278m).

Chapter 3

South Kenmare River

The description and interpretation of the sections analysed in this project is provided in chapters 3-6 depending on geographical location (figure 1.4). This chapter describes two sections from the south side of Kenmare River (figure 3.1). This area was situated adjacent to the basin margin during basin development (figure 1.4) and consequently these sections exhibit a more proximal package than that developed in sections situated further to the south. The stratigraphy of these sections is dominated by facies belonging to associations 2 and 3 (figure 2.1). All maps, plates and logs referred to in this section may be found at the end of the chapter.

3.1 Ballycrovane

The logged section runs from immediately below the Castle Slate Formation south-east of Kilcatherine Point [0619 0532] northwards around Kilcatherine Point until the base of the Pigs Cove Formation [0615 0536], details are given in figure 3.1 (map A) and figure 1.7. The logged section is 588m thick but around 120m of section is believed to be missing from the upper part of the Reenagough Member and lower part of the Black Ball Member as a result of faulting (based on mapping by Husain 1957). The section may be accessed by a track leading to Kilcatherine Point.

Van Veen (1981) reports an LN miospore assemblage from 50m below the base of the Old Head Formation in this section and from various levels throughout this unit and unusually from the middle part of the Castle Slate Formation. However this is disputed by O'Liatháin (1992) who reports VI assemblages from 0.52m, and 2.8m above the base of the Caste Slate Formation and from 0.5m below the top of this unit. This discrepancy may result from mis-identification of the Castle Slate Formation by Van Veen (1981). O'Liatháin (1992) also records a VI miospore assemblage from 0.5m below the top of the Castle Slate Formation, HD assemblages from 5m above the base of the Reenagough Member and from 3m below the top of this unit whilst an HD (upper) assemblage is reported from 0.3m above the base of the Pigs Cove Formation.

Old Head Formation

Only the upper portion (~7m) of the Old Head Formation is included in this study and this probably consists of facies belonging to facies association 2. At the base of this section between 0m - 4.2m the sequence consists of wavy bedded mudstone and contains symmetrical ripples. The package, which is richer in sandstone than the underlying sequence probably reflects deposition within a wave influenced inner-shelf setting whilst the increase in sandstone content relative to the underlying sequence suggests increased coastal proximity.

Between 4.2m - 6m the sequence consists of a massive to parallel laminated or trough cross-bedded sandstone unit with sharp upper and lower surfaces. This package is enclosed by mudstone and probably reflects deposition within a lowstand shoreface setting or within a transgressive sand sheet reworked from earlier strata.

At the top of this sequence between 6m - 7m the succession is dominated by laminated mudstone and includes a series of lenticular limestone lenses containing crinoid fragments and indeterminate shell debris. This was probably deposited during a phase of relative sea-level rise when low rates of nutrient supply to the shelf allowed filter feeding biota to flourish.

Castle Slate Formation

Between 7m - 10m the Castle Slate Formation consists of dark grey homogenous mudstone and probably reflects deposition within an offshore setting (facies association 1?) during a phase of relative sea-level rise. The thickness of this (~3m) is less than that found in sections further south (7-10m).

Narrow Cove Formation

The Ardaturrish Member exposed between 10m - 181.2m is of comparable thickness (171m) to that measured in the Reenagough section (204m), the Cahermore section (182m) and the Bere Island section (184m) and consists of facies belonging to facies associations 2 and 3 (figure 2.1).

At the base of this unit between 10m - 20m the sequence begins with mudstone rich facies but exhibits an increase in sandstone content upwards which probably reflects an increase in coastal proximity. The overlying package from 20m - 87.3m is poorly exposed but includes relatively sandstone rich rippled units that may reflect deposition within a coastal or inner shelf setting.

Between 87.3m - 141.2m the exposure improves somewhat and the succession is clearly dominated by sandstone. This sequence includes asymmetric ripples and cross-beds each of which indicate palaeo-flow to the south and south-east. The dominance of southerly directed bedforms suggest strong fluvial influence although the continued presence of mud drapes within many units also indicates that tidal influence was of at least local importance.

Between 141.2m - 181.2m the sequence changes rather dramatically from that exposed below in that it consists of massive or laminated siltstone units (plate 3.1) inter-bedded with thin tabular sandstone beds. The poor grain size separation developed throughout this package (i.e. non-heterolith), the presence of desiccation structures and the prevalence of south directed bedforms within the inter-bedded sandstone units suggest deposition within a fluvial plain setting. It is unclear whether the dramatic reduction in sandstone content at this level results from autocyclic or allocyclic control.

This is followed at 181.2m by a prominent down-cutting surface (plate 3.5) which marks the base of the Reenagough Member and an abrupt increase in sandstone content compared to the underlying sequence. However, as in the underlying Ardaturrish Member this package consists of facies belonging to facies associations 2 and 3 (figure 2.1).

At the base of this section between 181.2m - 234.3m the sequence is dominated by sandstone packages containing cross-bedding, parallel lamination, convolute bedding (plate 3.3) and ripples (bi-modal palaeo-flow patterns) and bound by erosion surfaces or thin rippled heterolithic units (plate 3.2). These features probably reflect deposition within a tide influenced deltaic or estuarine setting.

This is overlain between 234.3m - 300m by a sequence consisting of alternating parallel laminated or cross-bedded sandstone units and siltstone packages. Sandstone units include down-cutting surfaces and bedforms that suggest palaeo-flow to the south-east whilst siltstone packages exhibit poor grain size separation (i.e. non-heterolithic) and include small-scale symmetrical ripples and desiccation structures (plate 3.6). These features indicate deposition within a terrestrial setting with variation between flood plain and fluvial channel settings. However it is unclear whether these changes result from autocyclic or allocyclic control.

From around 308m - 370m the sequence is dominated by sandstone units containing parallel lamination, cross-beds and ripples (plate 3.7), these are sometimes bound by down-cutting surfaces. Cross-beds indicate variable palaeo-flow and are occasionally draped with mudstone. This sequence probably reflects deposition within a tide influenced coastal setting such as a delta or an estuary although parts of the sequence may have accumulated within inner-shelf and fluvial settings.

From 370m - 488m the sequence is less sandstone rich but includes down-cutting surfaces, mud units containing sand balls, parallel laminated and rippled sandstone units and wavy bedded heterolith. These features are often arranged into a distinctive vertical sequence that commence with strongly down-cutting erosive surfaces overlain by mudstone rich units containing sand balls. This is followed by wavy bedded then flaser bedded rippled sandstone and is often capped with a parallel laminated sandstone unit. Although far from clear, it is possible that these packages reflect a transgressive deltaic or estuarine sequence. Each sequence commences with an erosive-based distributary complex subject to rapid deposition of mudstone due to the intruding salt wedge (thus development of sand-balls). The increase in sandstone content overlying this reflects the approach of the estuary mouth or delta front region whilst the parallel laminated package at the top of the sequence reflects deposition within an inner shelf setting and overlies the wave or tide ravinement surface.

At 488m a major WNW-ESE trending dextral fault interrupts the sequence and probably cuts out around 120m of section (see Husain 1957). The sequence to the east of this forms part of the Black Ball Member which consists of relatively mudstone rich units that are perhaps transitional between facies associations 1 and 2.

The logged section recommences on the coastal section where the major fault reaches the sea and initially (488m - 559.6m) consists of alternating mudstone rich and sandstone rich facies. Sandstone rich zones packages are dominated by ripples and are typically bound by relatively sharp upper and lower surfaces whilst mudstone rich zones may include ripples and sandstone laminae. Variation between these units probably reflects changes in coastal proximity with sandstone rich units deposited in a lower shoreface setting and mudstone rich units deposited within a shelf setting. The sharp basal and upper surfaces of the sandstone rich shoreface packages indicate that these developed in response to sea-level fall and reflect forced regressions (Posamentier *et al.* 1992).

Higher in the Black Ball Member between 559.6m - 584.3m the succession is more sandstone rich and is dominated by ripples but also includes a prominent cross-bedded sandstone package that includes a mud chip lag at its base (570.4m - 575.3m). The majority of this sequence is believed to have been deposition within an inner-shelf setting dominated by waves and tides and was possibly deposited during a high stand of relative sea-level when sediment supply began to exceed accommodation generation. However the surface underlying the cross-bedded sandstone unit may correlate with the thick coastal package developed at the top of the Cahermore section (781.4m - 858.2m) and is interpreted as a sequence boundary. The sharp upper surface of the cross-bedded sandstone unit is perhaps a wave ravinement surface and this is overlain by a proximal shelf sequence deposited during the early stages of transgression.

Pigs Cove Formation

At the base of the Pigs Cove Formation at 584.3 the succession exhibits a rapid transition from the sandstone rich facies of the underlying sequence to storm influenced mudstone rich facies belonging to facies association 1 (figure 2.1). The basal 50cm of this package contains small gutter casts and occasional ripples but the overlying sequence normally includes only thin sandstone laminae (plate 3.4). These features reflect a pronounced land-wards shift of facies belts probably resulting from drowning of the adjacent basin margin area (North Munster Shelf - see figure 1.4) during a rise of relative sea-level.

3.2 Collorus

Two logged sections are described from the Collorus section. These probably overlap such that the upper part of the basal section duplicates the basal 20-40m of the upper section although it is difficult to make precise correlation and this is further hindered by a lack of palynological information. However, as the base of section represents the first appearance of marine strata in this section this is tentatively correlated to the Old Head Formation [0719 0586]. It is unclear whether the basal section extends upward to the base of the Narrow Cove Formation [0723 0591]. The dominance of fluvial sandstones in the upper section perhaps suggest that this runs through a portion of the Narrow Cove Formation {[0724 0595] -[0725 0599]}. Details of both logs are given in figure 3.1 (map B) and figure 1.7. The section may be accessed from a track leading from the main Eyeries - Lauragh road.

Basal section

The base of the measured section (0m - 20.1m) clearly includes heterolithic lithologies which are dominated by symmetrical ripples but also include parallel lamination, cross-bedding and desiccation cracks. These features probably indicate deposition within a coastal setting such as inter-tidal flats and are important because they seem to mark the first appearance of marine strata. Unfortunately the overlying sequence between 20.1m - 45m is not exposed. Above this exposure gap (45m - 156m) the sequence is dominated by terrestrial flood plain facies (facies 3.3) and to a lesser extent by structured sandstone units reflecting fluvial channels (plate 3.9). Indeed, only between 50m - 54m and 64m - 82m is the section composed of marine facies and these probably reflect development of marginal tidal flats. However at the top of the basal section (156m - 198m) heterolithic lithologies reflecting coastal and shallow marine settings reappear and are found inter-bedded with relatively thick and often sharp based fluvial sandstone units. These are generally dominated by parallel lamination and south directed cross beds and sometimes include decalcified layers that may represent palaeosols (plate 3.10). The alternation between the mudstone rich marine facies and the sharp-based fluvial sandstone packages probably results from changes in relative sea-level. During periods of low relative sea-level exposure of the shelf probably led to a phase of fluvial incision into the underlying marine strata. However when base level then began to rise again the associated generation

of accommodation probably allowed accumulation of first fluvial and then estuarine strata as the pace of relative sea-level rise accelerated. This transition is sometimes marked by a tidal ravinement surface (e.g. 165.5m, 174m 186m) or by the appearance of mud drapes on foresets (155m). As relative sea-level continued to rise these coastal settings were replaced by shallow marine strata (156m - 162m, 165.5m - 169.5m, 176m -180m).

It is interesting to speculate that the increased prevalence of marine strata in the upper part of the basal section may correlate with the prominent transgressive packages found in the upper 30-50m of the Old Head Formation in sections across the basin.

Upper section

The upper section may be separated into three separate lithological packages, a basal flood plain and fluvial channel dominated sequence (0m - 56m) a central fluvial channel dominated package (56m - 262m) and an upper coastal and shallow marine influenced package (262m - 296m).

The basal package (0m - 56m) which is rather tectonised consists of a mix of fluvial sandstones and finer grained flood plain facies, the latter are particularly prevalent between 12m - 34m. The increased presence of fluvial plain facies within this package relative to that above may reflect either changes in the position of the principal fluvial axis or changes in the rate at which accommodation was generated.

Between 56m - 262m the sequence is dominated by thick fluvial sandstone packages containing cross-beds, parallel lamination and asymmetric ripples. Normally bedforms indicate palaeo-flow patterns directed to the south but in some cases these are countered by north directed structures perhaps indicating tidal influence. Sandstone units may be inter-bedded with homogenous siltstone horizons that probably represent preservation of flood plain strata during periods of accommodation generation and more rarely with wavy or flaser bedded heterolithic units which further testify to periods of marine influence.

Towards the top of the measured section (262m - 296m) there is a pronounced increase in the prevalence of marine strata which reflect deposition within a variety of coastal and proximal shallow marine settings. The change from terrestrial to marine settings at this stage perhaps indicates a phase of accommodation dominance and a landwards shift in facies belts at this stage.

It is interesting to compare the similarity in thickness and style of this section generally with the lower to central part of the Narrow Cove Formation exposed at Ballycrovane to the west. In each case a thick package of cross-bedded sandstone around 200m in thickness shows an upward transition into finer grained marine influenced strata (Reenagough Member?).

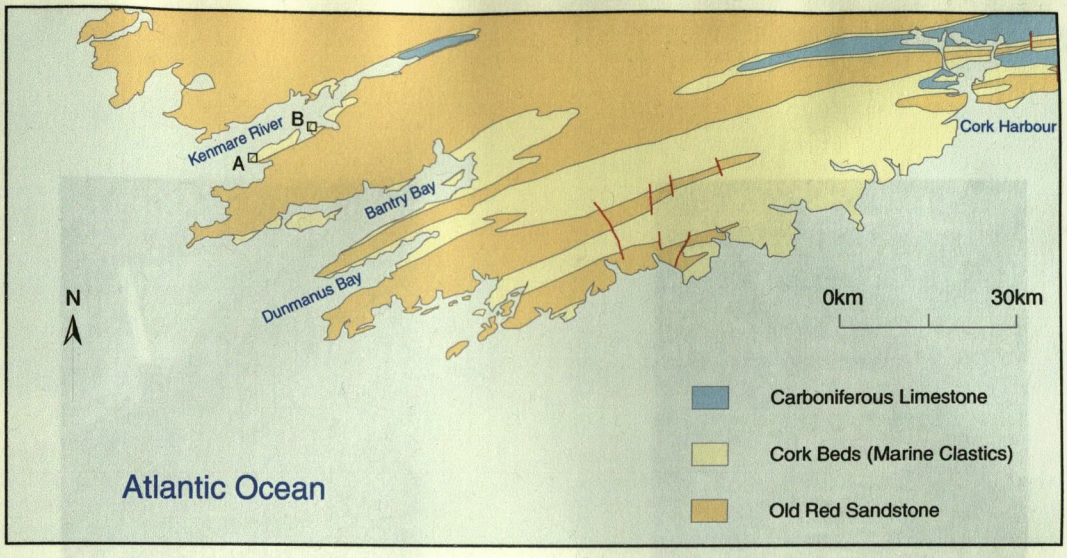
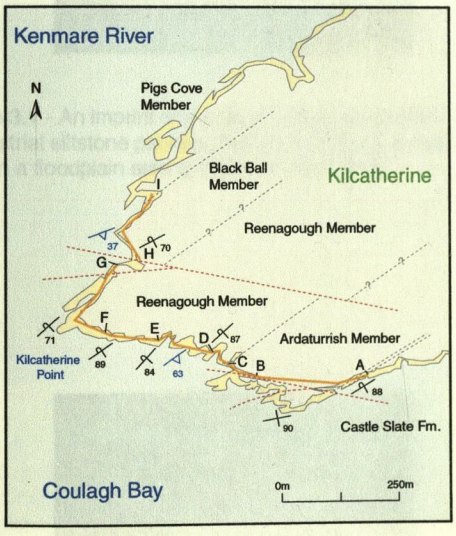
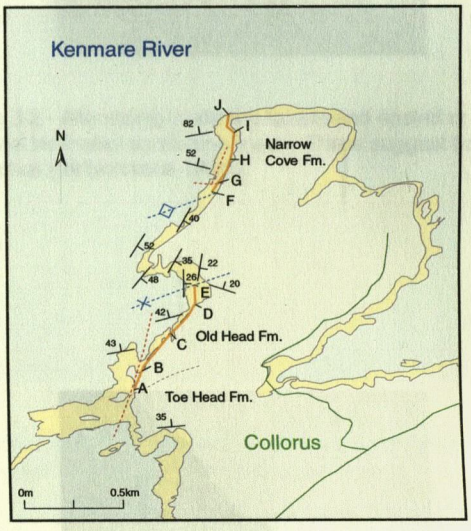


Figure 3.1 - Location of logged sections from the south side of Kenmare River.



Map A - Ballycrovane, Kenmare River.



Map B - Collorus, Kenmare River.



Plate 3.1 - An imprint of a small log developed within a terrestrial siltstone package that was probably deposited within a floodplain setting (Ballycrovane 152m).



Plate 3.2 - Alternating mudstone lenses and rippled or parallel laminated sandstone linsen. These suggest tidal influence (Ballycrovane 182m).



Plate 3.3 - Fluidised cross-bedding developed at the top of a thick channelised sandstone complex (Ballycrovane 186.5m).



Plate 3.4 - Prominent flooding surface developed at the transition between the Narrow Cove and Pigs Cove Formations (Ballycrovane 584.3m).

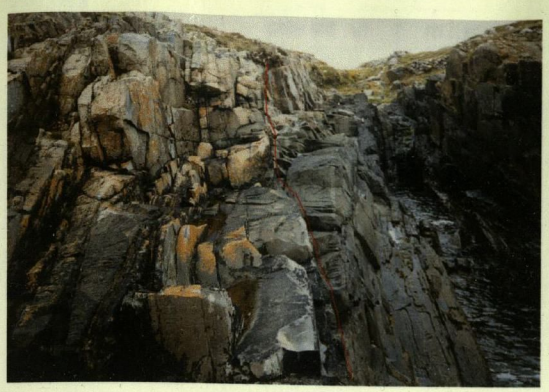


Plate 3.5 - Tidal ravinement surface separates well bedded terrestrial floodplain silts (right) from tidally generated cross-bedded sandstone (left) across an erosion surface which downcuts by at least 3m (Ballycrovane 181m).



Plate 3.6 - Sandstone filled polygonal downward tapering cracks with mud curls. These are interpreted to have formed by desiccation (Ballycrovane 278m).

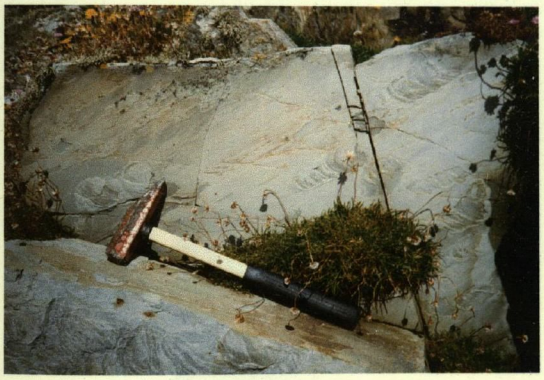


Plate 3.7 - View of the underside of a parallel laminated bedding surface cut by the scour pits of a series of asymmetric ripples in the overlying package. Note that the ripple orientation is parallel to parting lineation in the underlying bed (Ballycrovane 350m).



Plate 3.8 - Intraformational conglomerate overlying an undulating erosive surface (Collorus 99m).

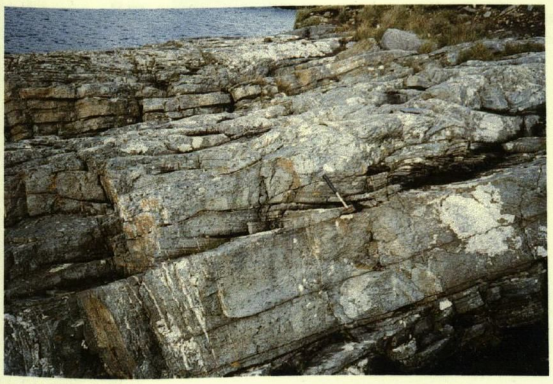
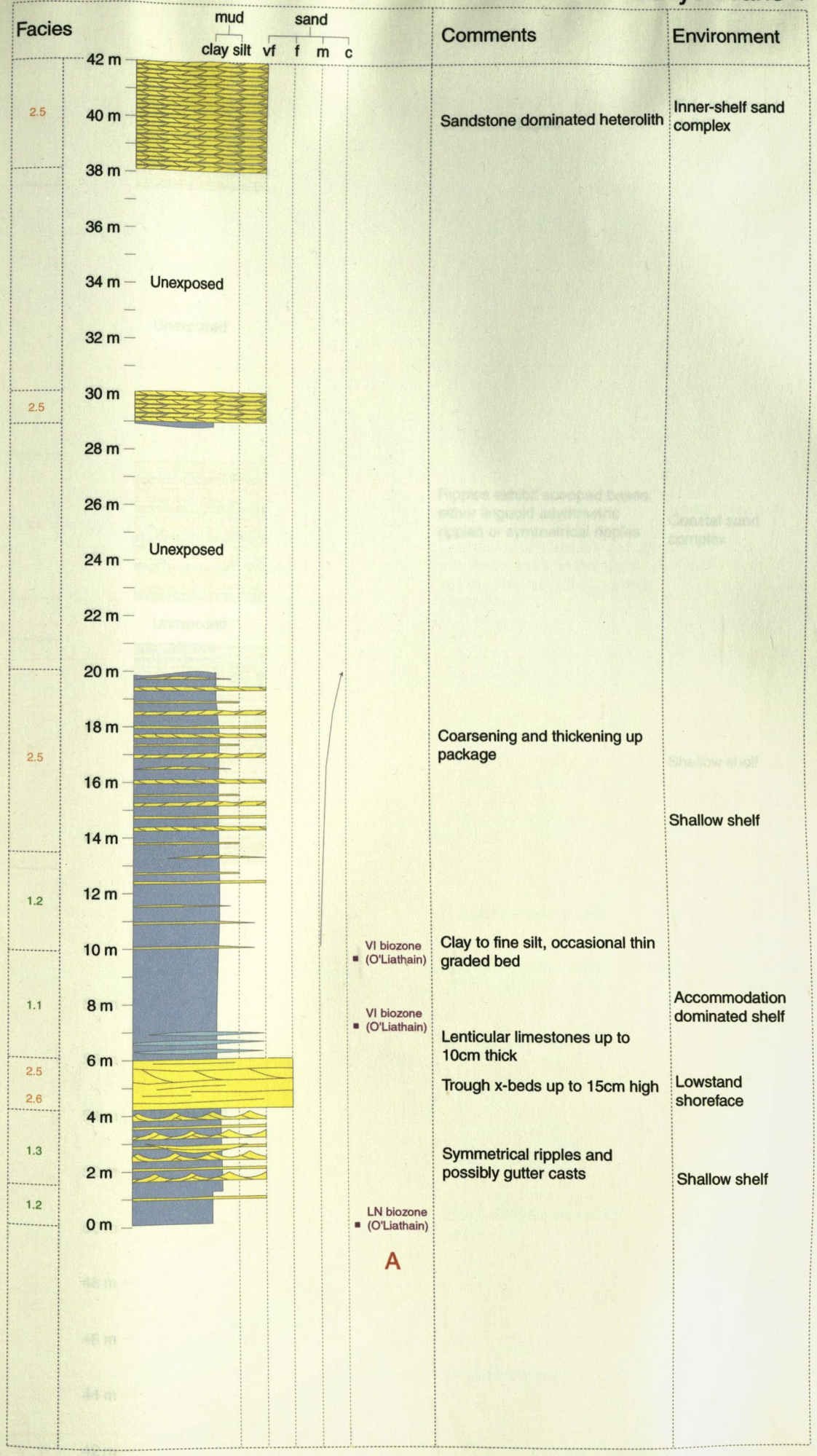


Plate 3.9 - South trending cross-beds generated within a fluvial setting (Collorus (base) 107m).

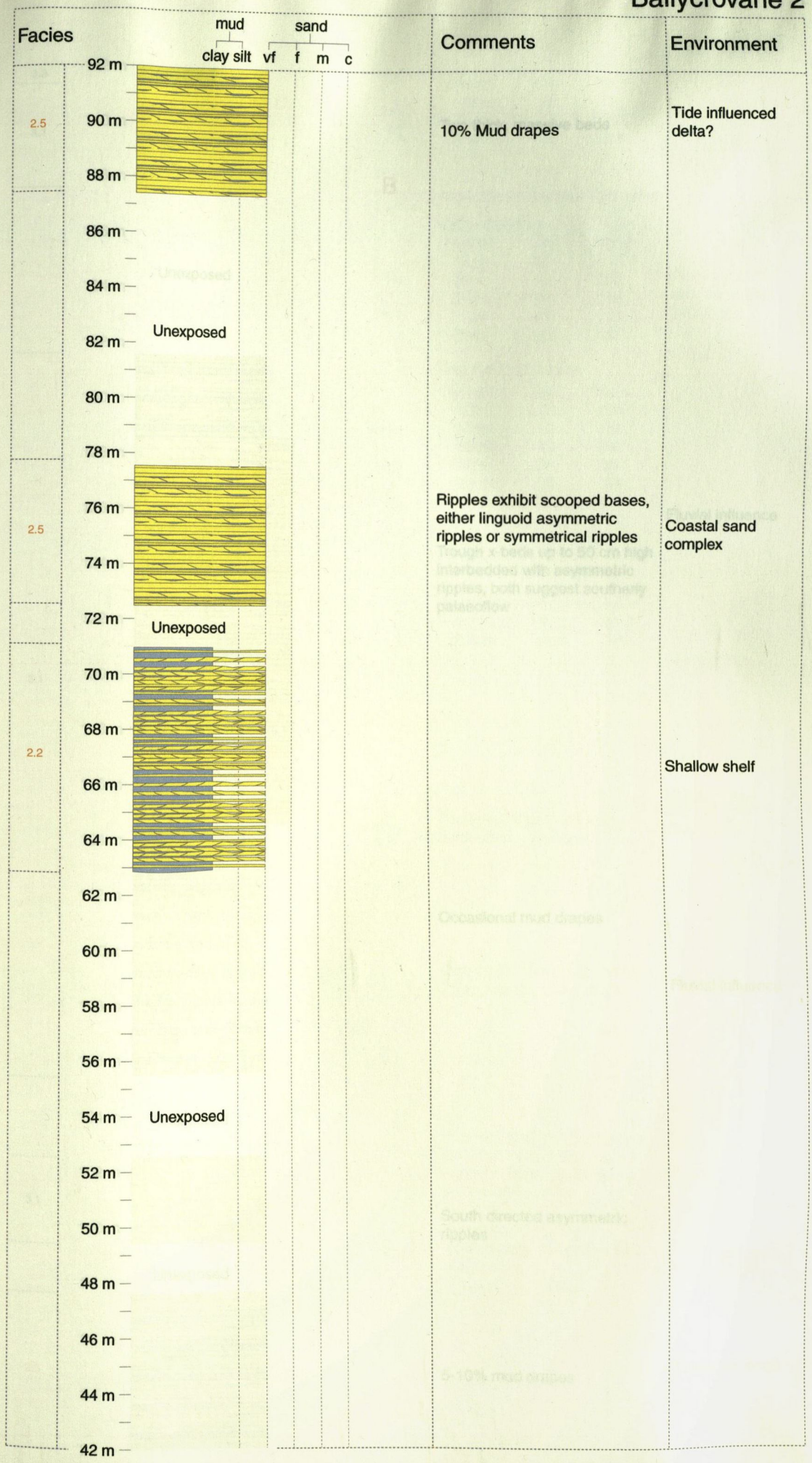


Plate 3.10 - Prominent erosion surface downcuts into a parallel laminated sandstone unit. The channel fill is mantled with mudstone and sandstone clasts (Collorus (base) 174m).

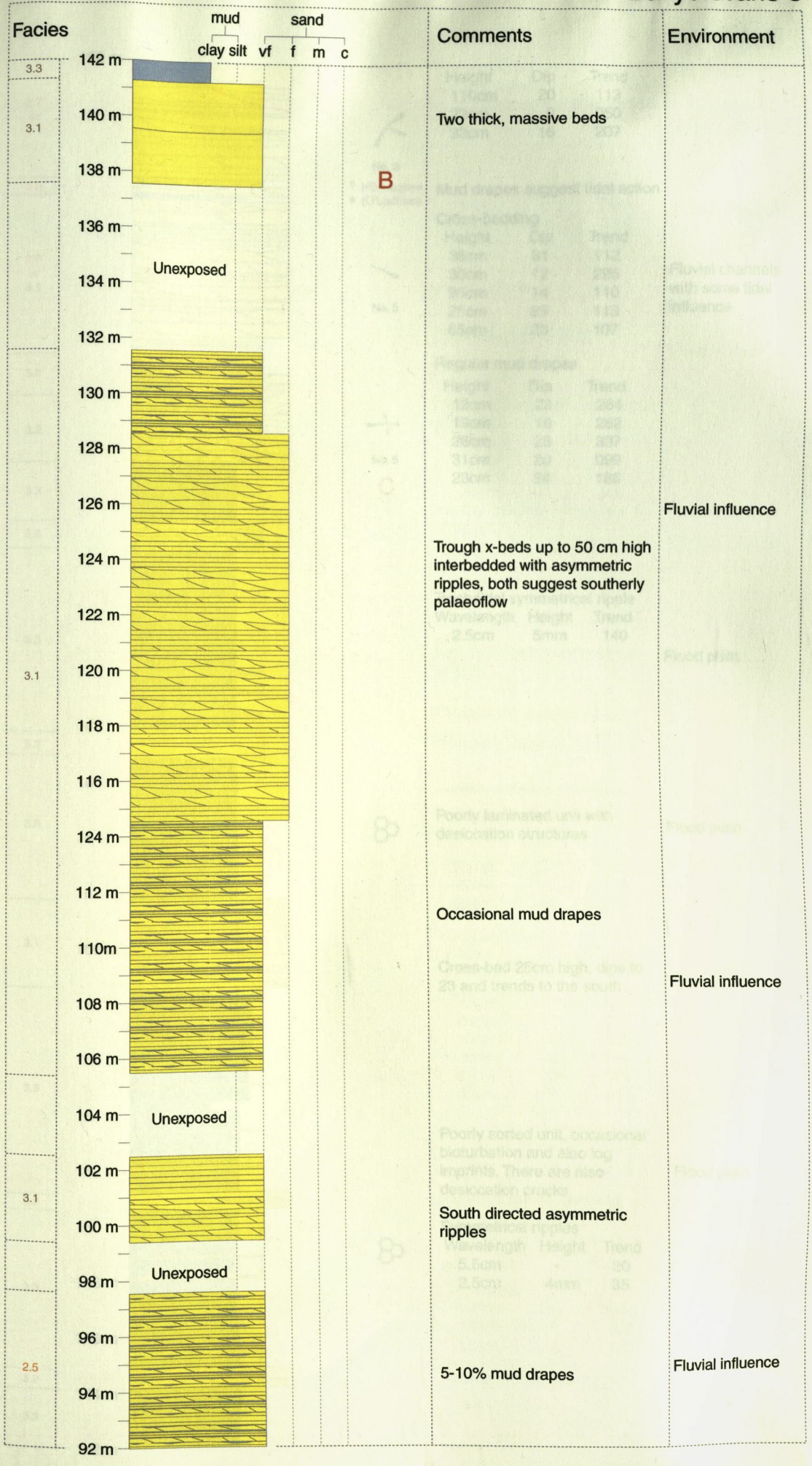
Ballycrovane 1



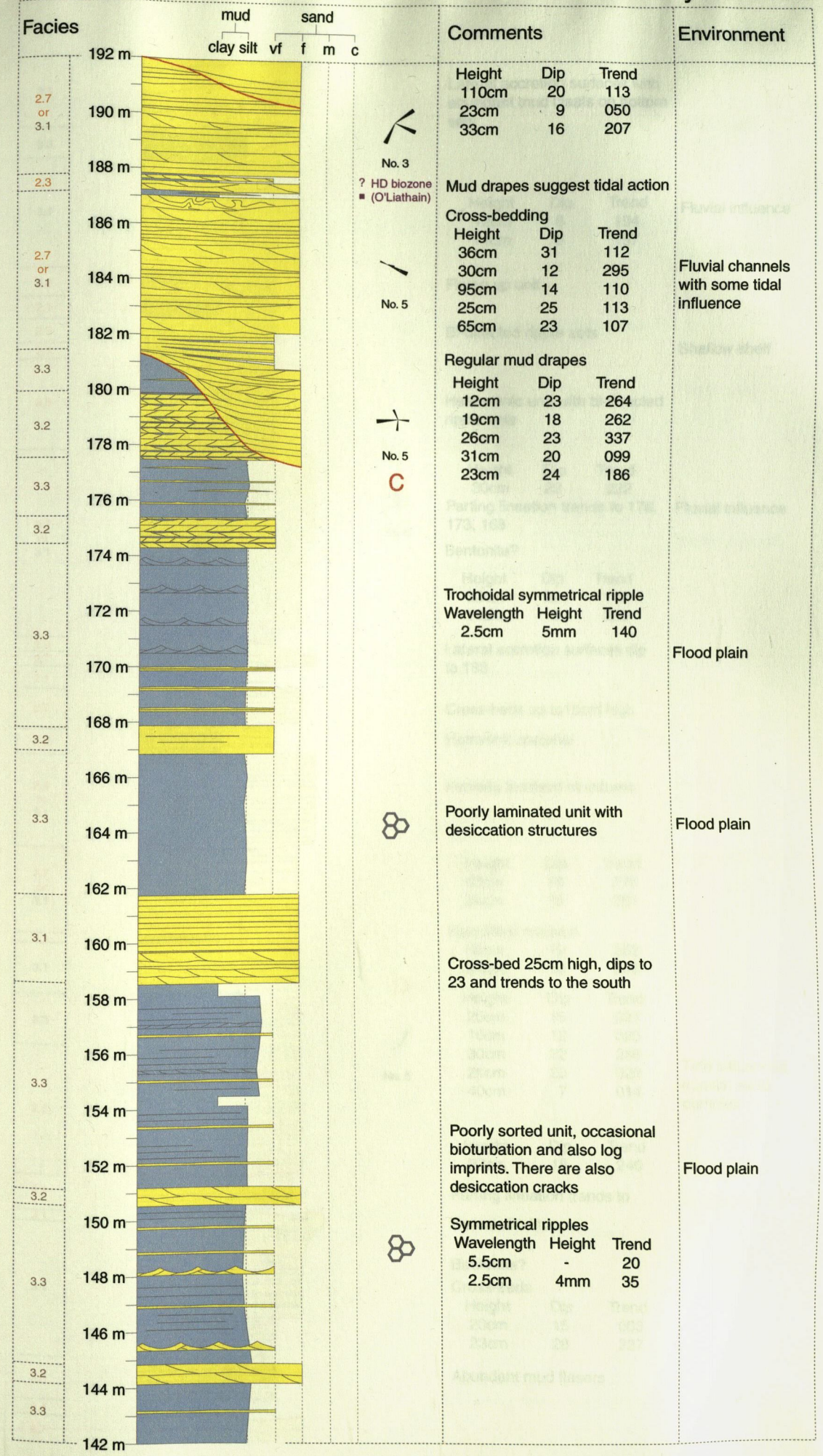
Ballycrovane 2



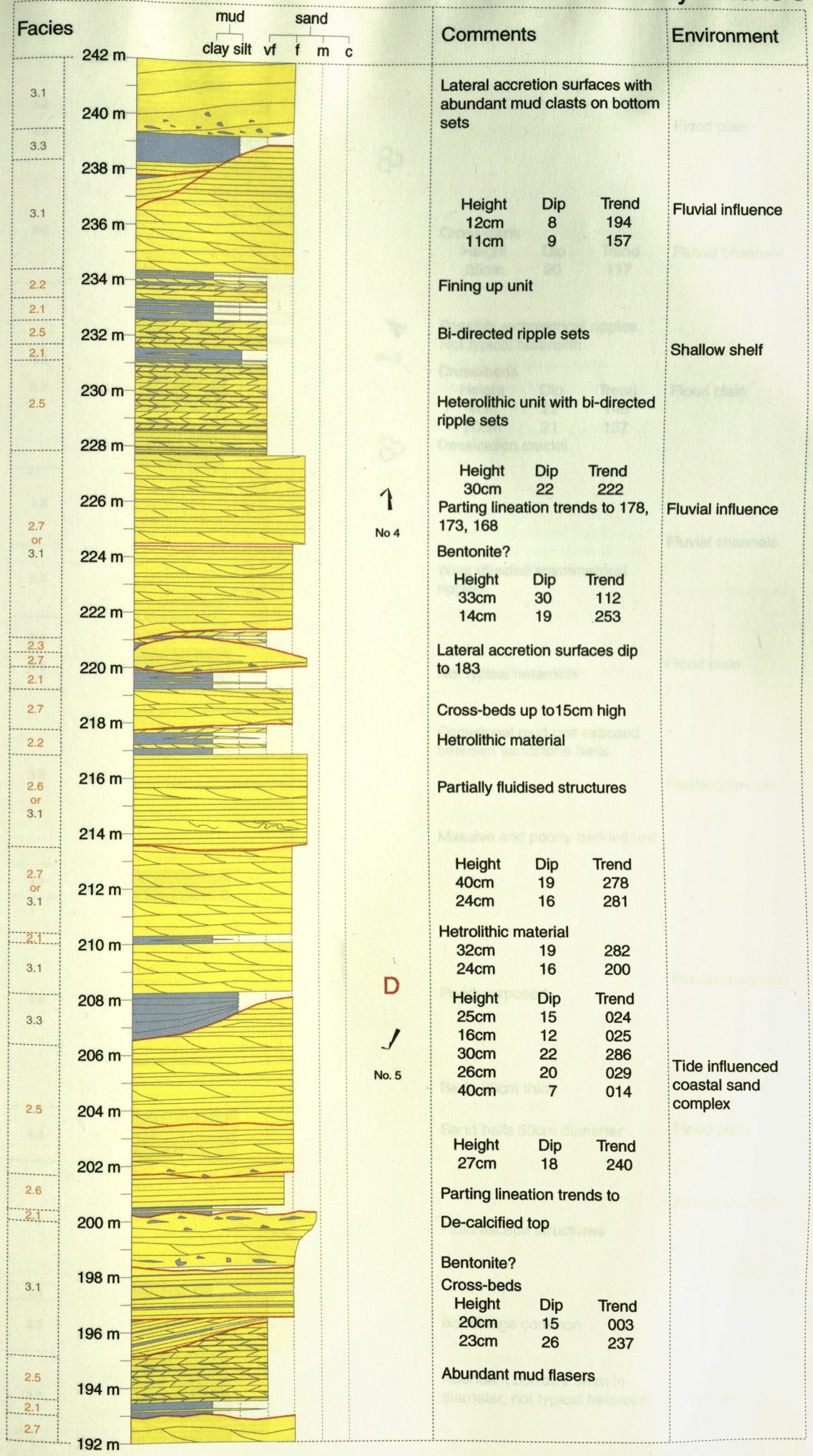
Ballycrovane 3



Ballycrovane 4



Ballycrovane 5



Comments

Lateral accretion surfaces with abundant mud clasts on bottom sets

Height	Dip	Trend
12cm	8	194
11cm	9	157

Fining up unit

Bi-directed ripple sets

Heterolithic unit with bi-directed ripple sets

Height	Dip	Trend
30cm	22	222

Parting lineation trends to 178, 173, 168

Bentonite?

Height	Dip	Trend
33cm	30	112
14cm	19	253

Lateral accretion surfaces dip to 183

Cross-beds up to15cm high

Hetrolithic material

Partially fluidised structures

Height	Dip	Trend
40cm	19	278
24cm	16	281

Hetrolithic material

32cm	19	282
24cm	16	200

Height	Dip	Trend
25cm	15	024
16cm	12	025
30cm	22	286
26cm	20	029
40cm	7	014

Height	Dip	Trend
27cm	18	240

Parting lineation trends to

De-calcified top

Bentonite?

Cross-beds

Height	Dip	Trend
20cm	15	003
23cm	26	237

Abundant mud flasers

Environment

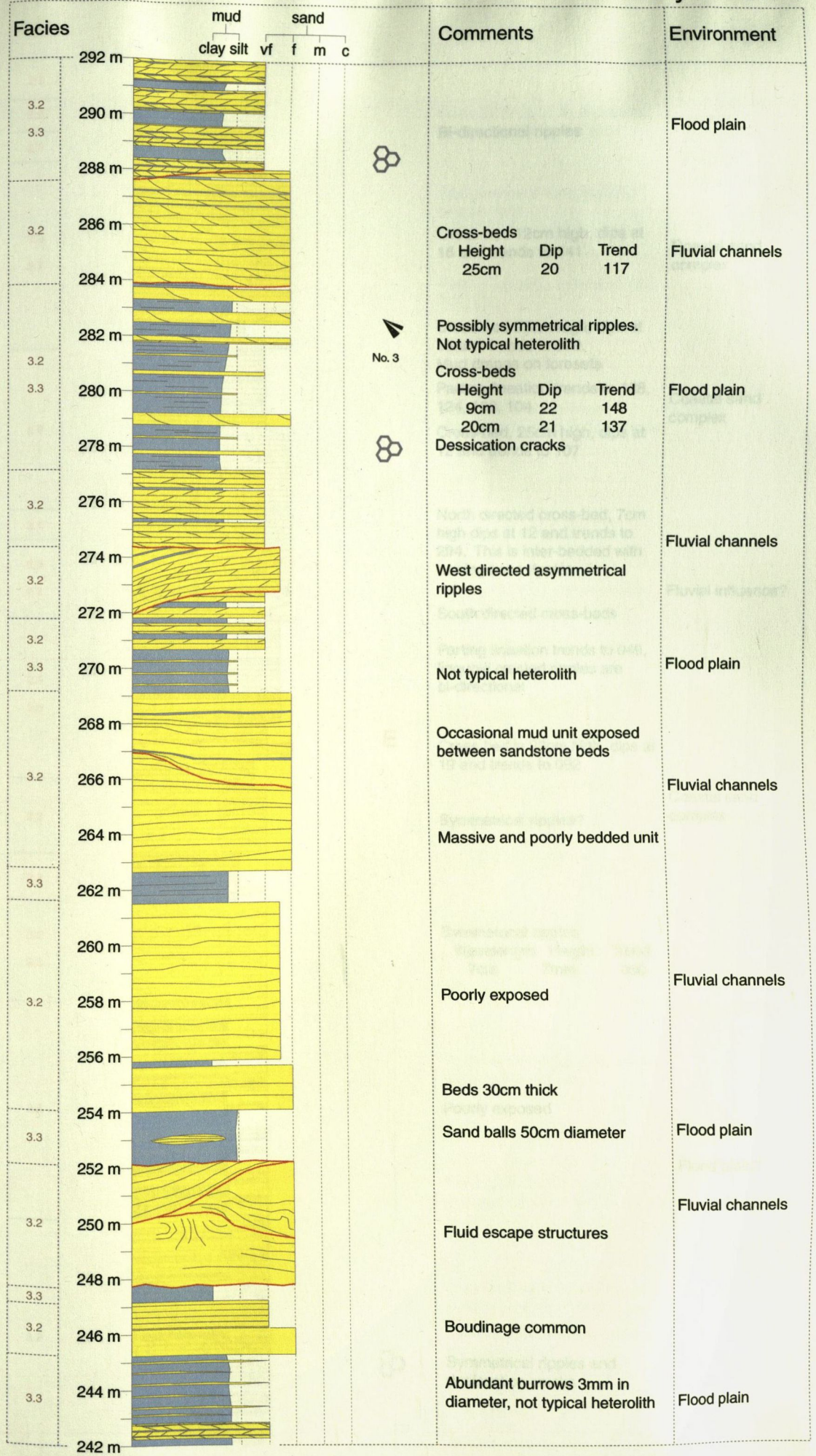
Fluvial influence

Shallow shelf

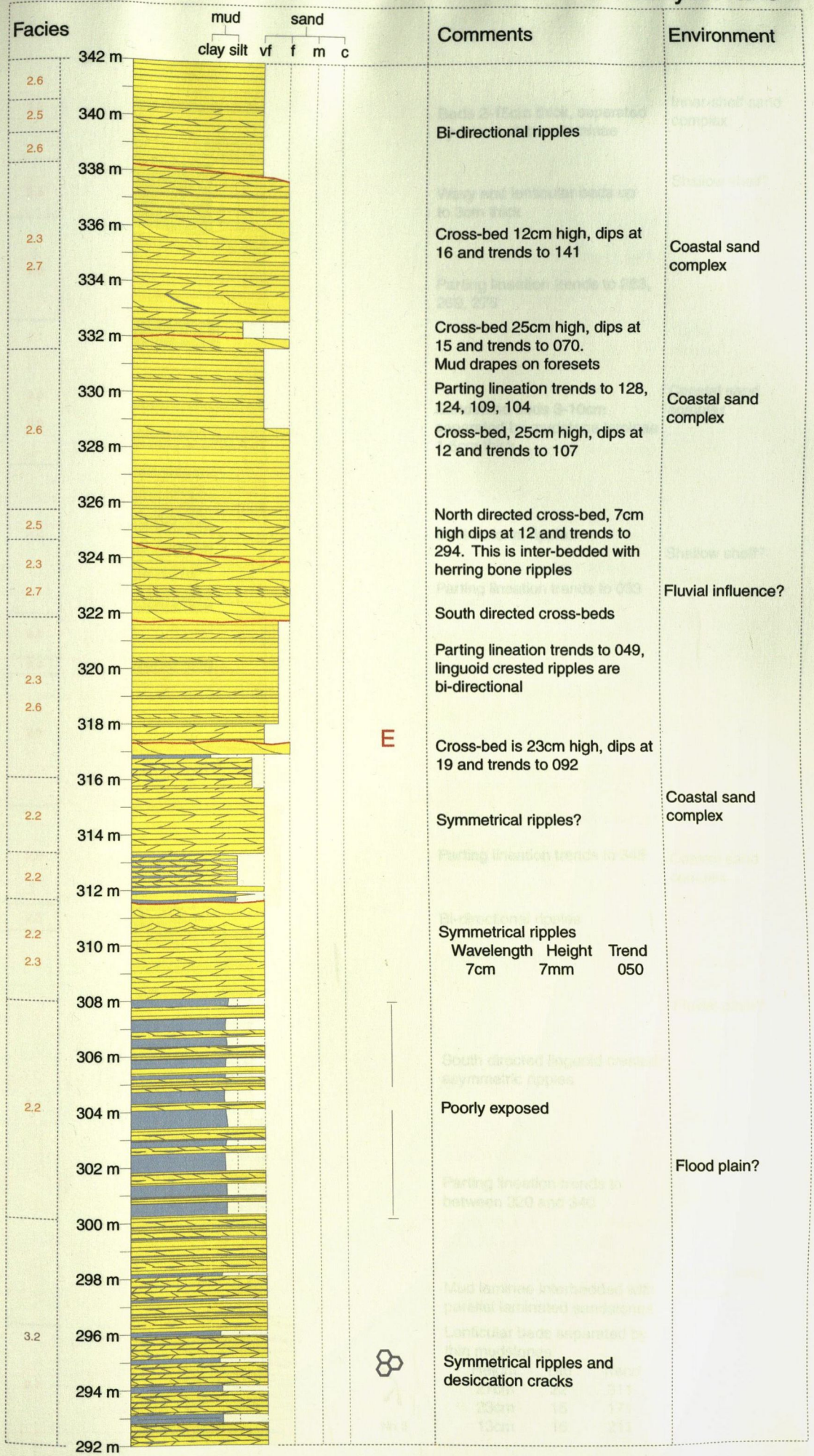
Fluvial influence

Tide influenced coastal sand complex

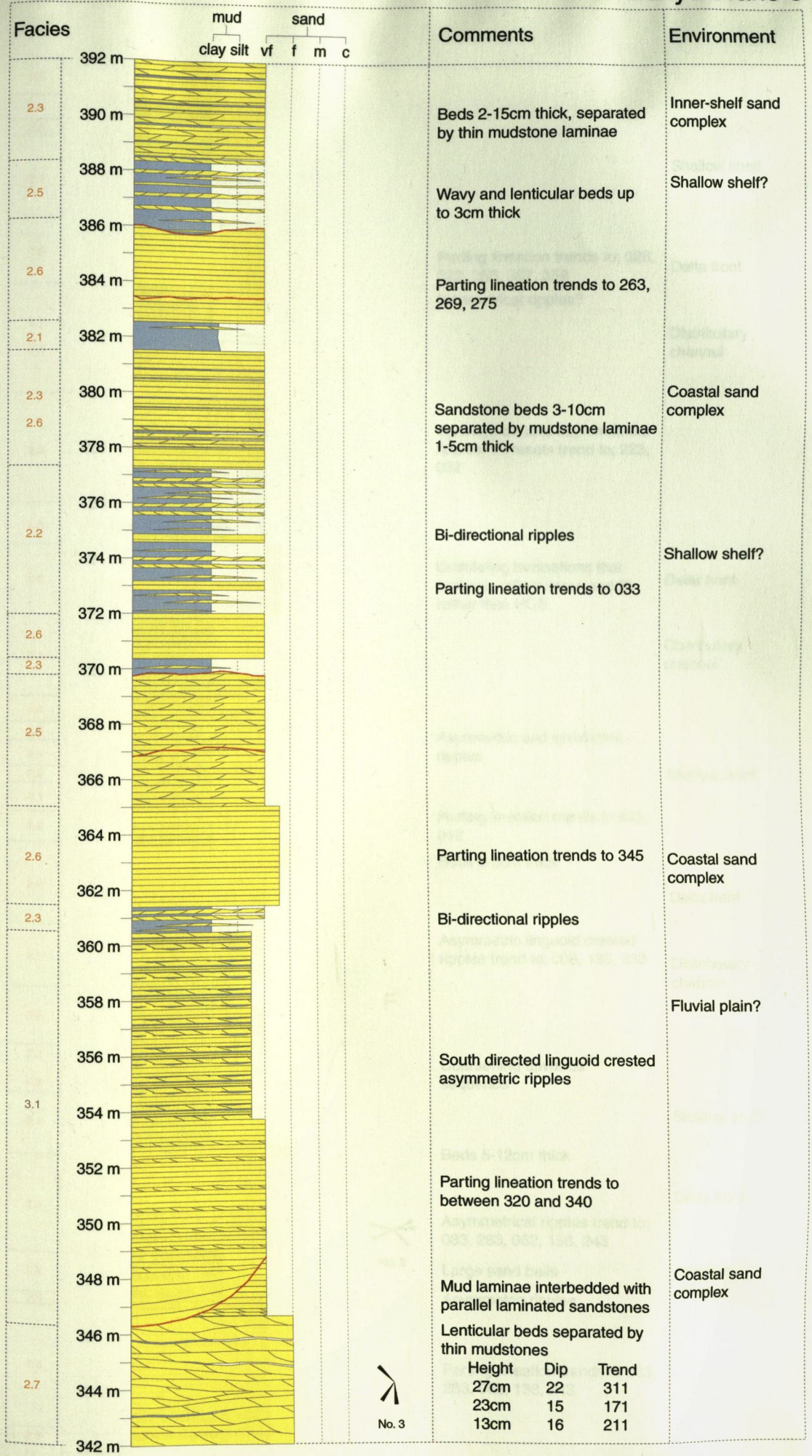
Ballycrovane 6



Ballycrovane 7



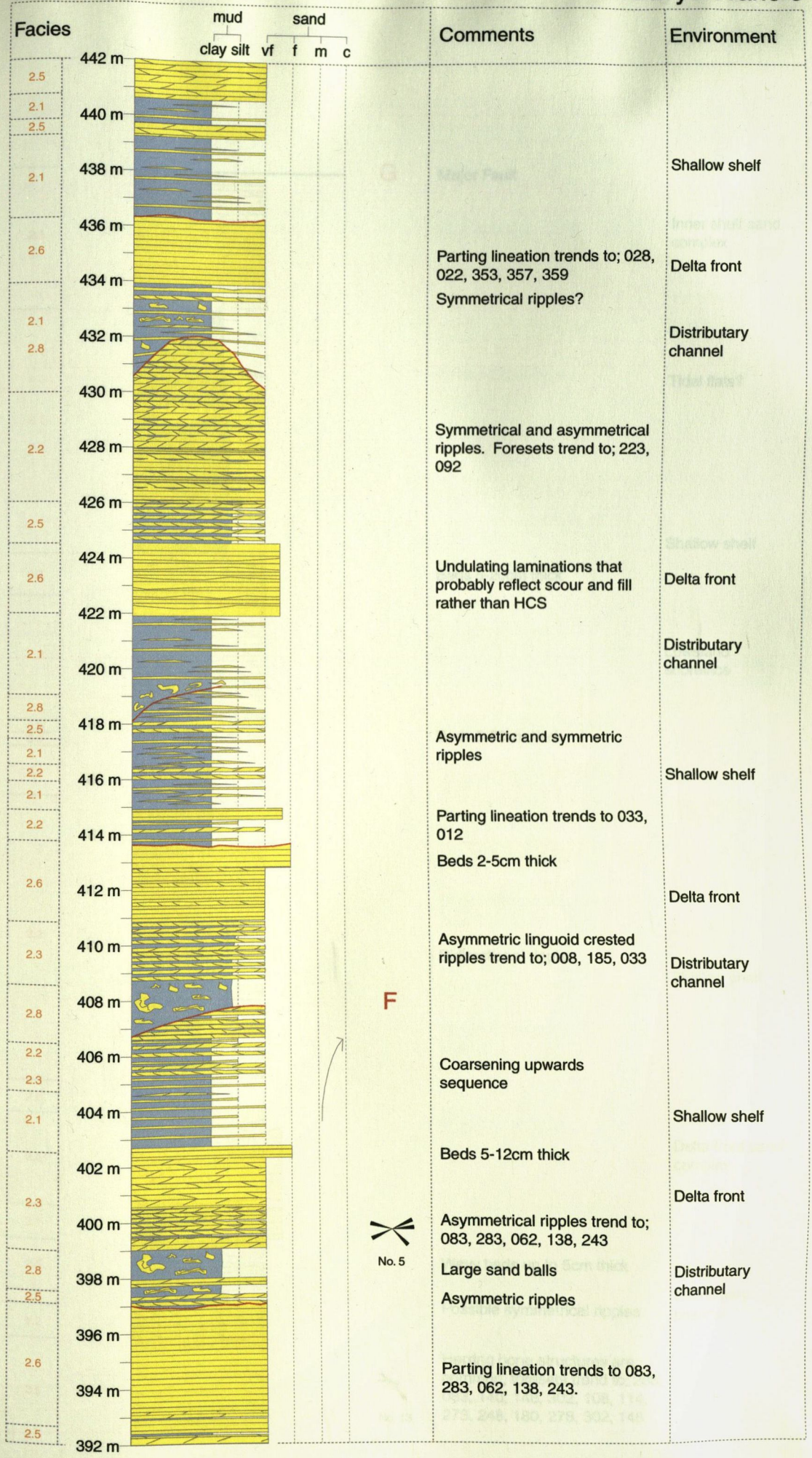
Ballycrovane 8



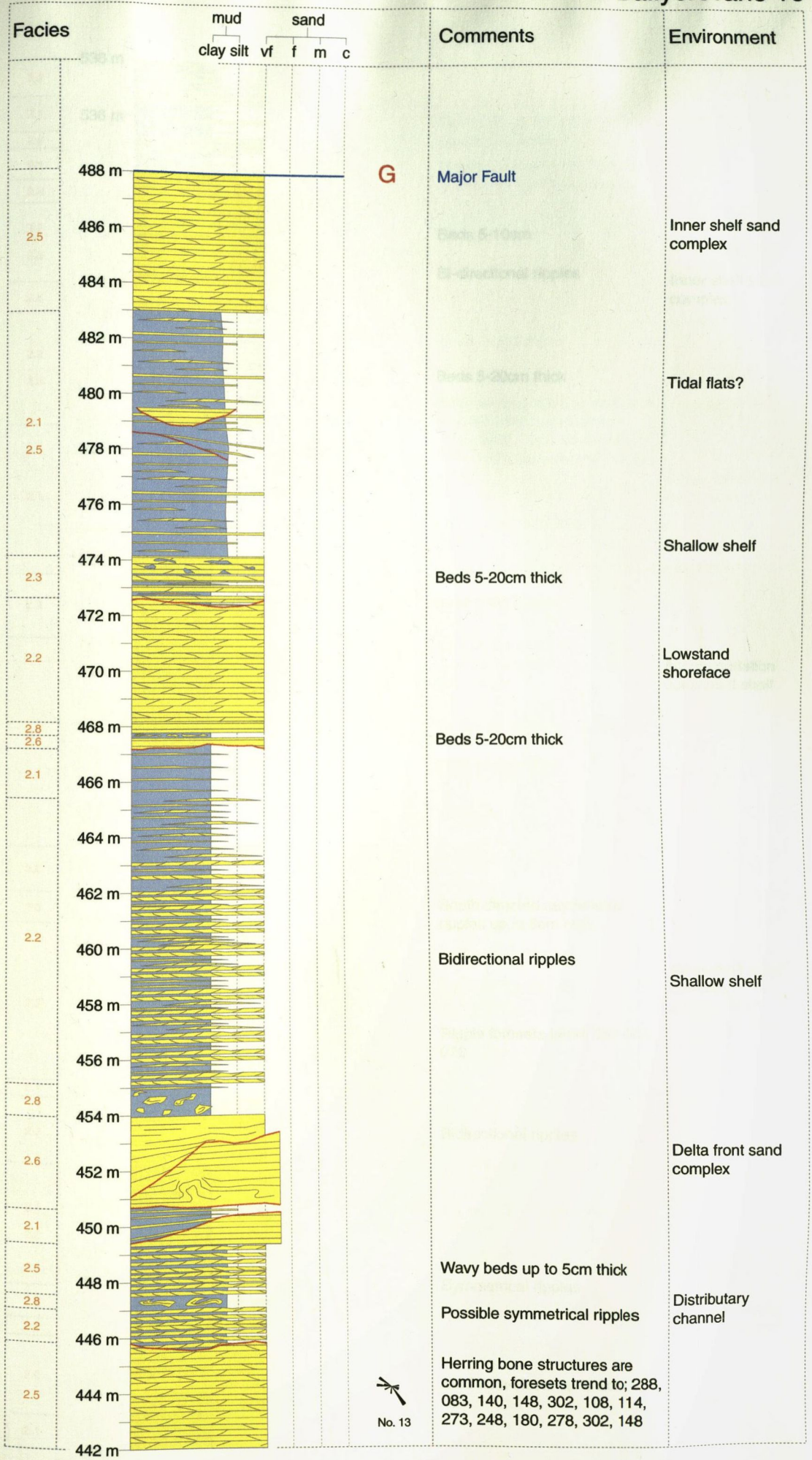
Comments	Environment
Beds 2-15cm thick, separated by thin mudstone laminae	Inner-shelf sand complex
Wavy and lenticular beds up to 3cm thick	Shallow shelf?
Parting lineation trends to 263, 269, 275	
Sandstone beds 3-10cm separated by mudstone laminae 1-5cm thick	Coastal sand complex
Bi-directional ripples	
Parting lineation trends to 033	Shallow shelf?
Parting lineation trends to 345	Coastal sand complex
Bi-directional ripples	
South directed linguoid crested asymmetric ripples	Fluvial plain?
Parting lineation trends to between 320 and 340	
Mud laminae interbedded with parallel laminated sandstones	Coastal sand complex
Lenticular beds separated by thin mudstones	

Height	Dip	Trend
27cm	22	311
23cm	15	171
13cm	16	211

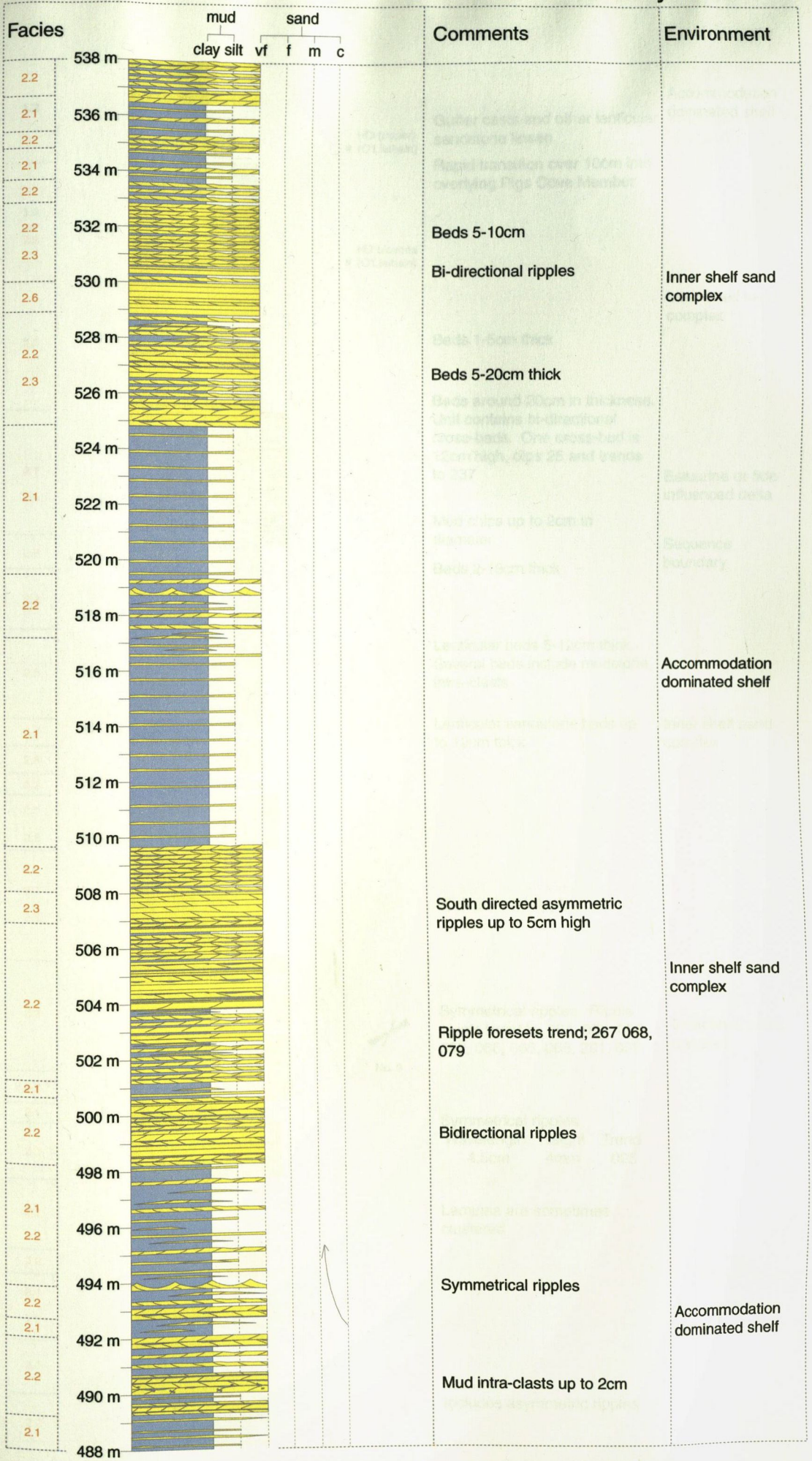
Ballycrovane 9



Ballycrovane 10



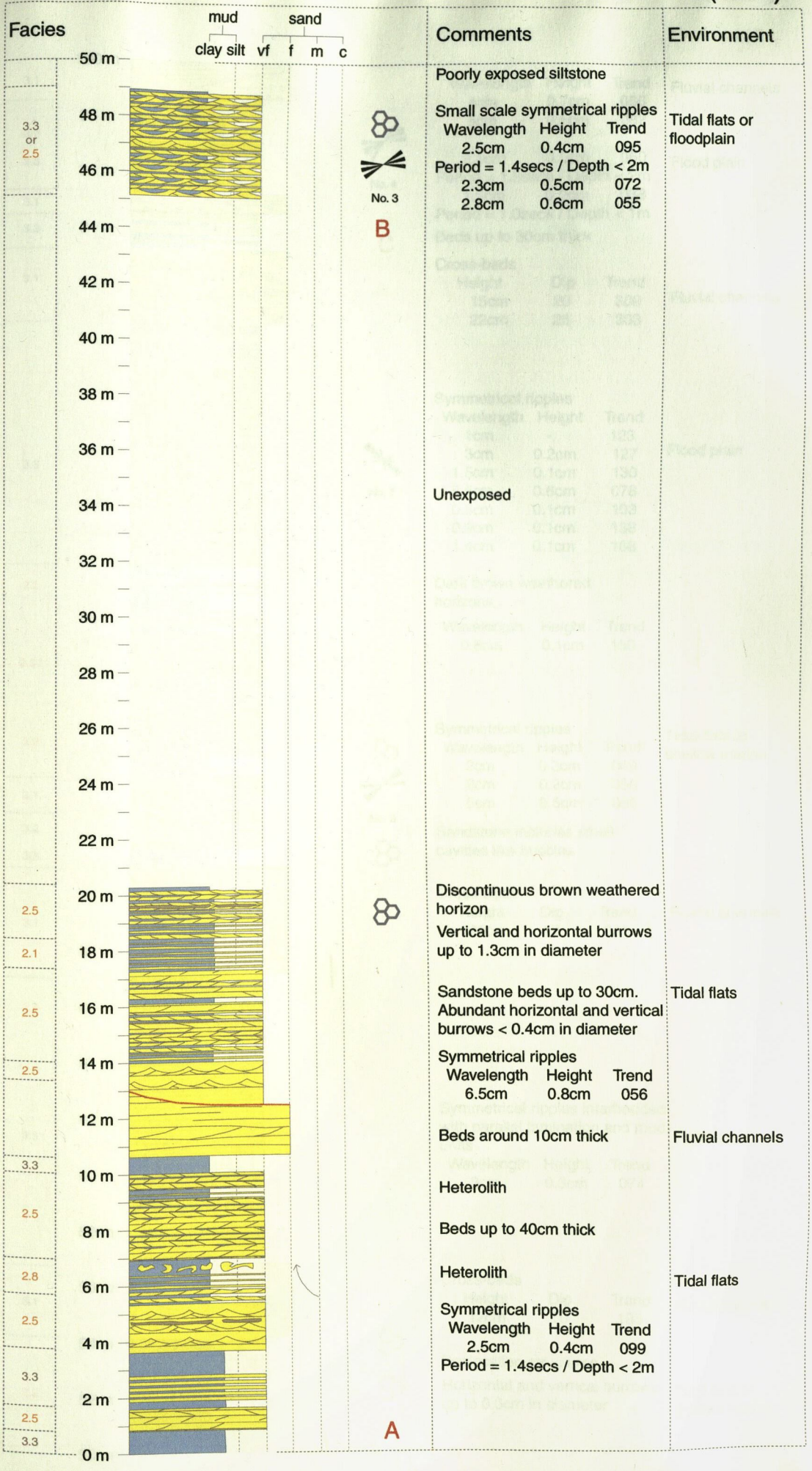
Ballycrovane 11



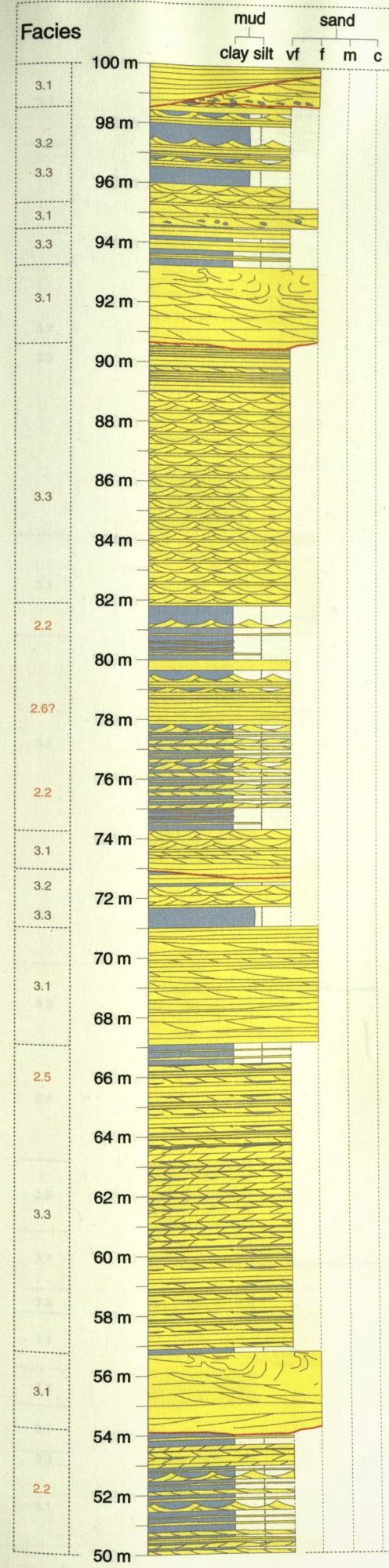
Ballycrovane 12



Collorus (base) 1

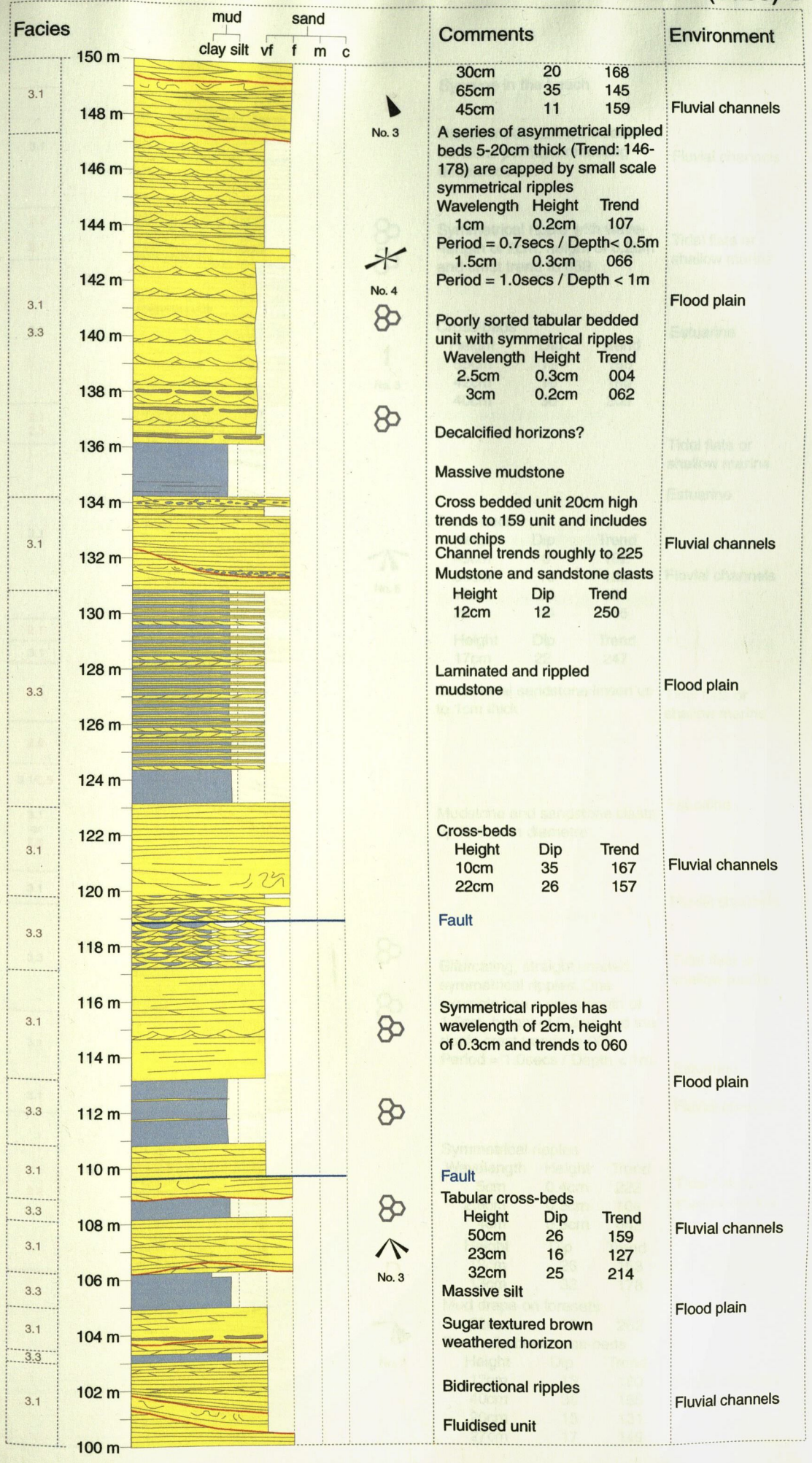


Collorus (base) 2

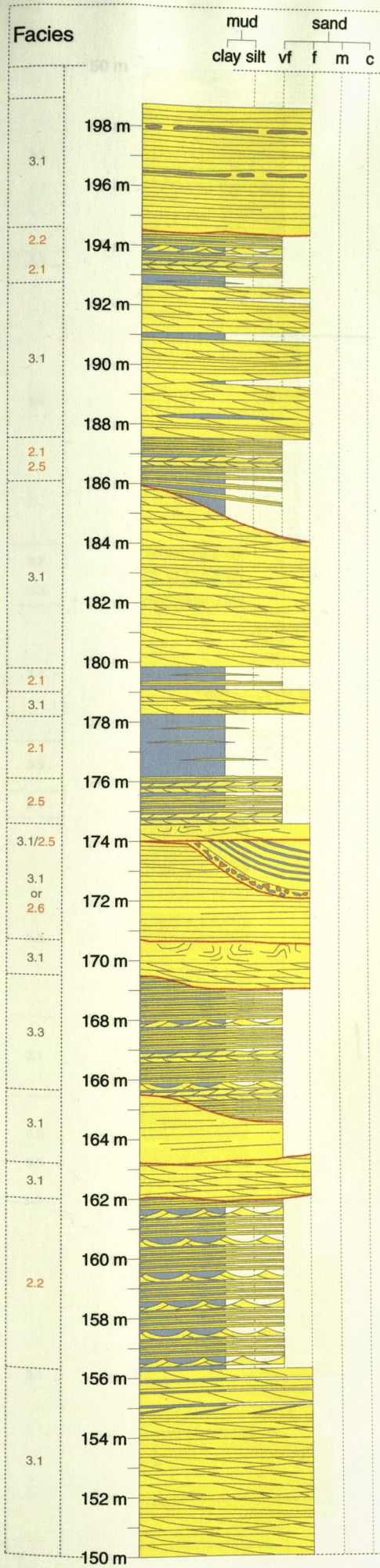


Comments	Environment
Wavelength Height Trend 4cm 0.7cm 056 5cm 0.5cm 082	Fluvial channels
2.8cm 0.5cm 060 Period = 1.5secs / Depth < 2m 1.5cm 0.2cm 038 Period = 1.0secs / Depth < 1m Beds up to 30cm thick	Flood plain
Cross-beds Height Dip Trend 15cm 20 309 22cm 26 303	Fluvial channels
Symmetrical ripples Wavelength Height Trend 1cm - 123 3cm 0.2cm 127 1.5cm 0.1cm 130 5.5cm 0.6cm 078 0.8cm 0.1cm 103 0.9cm 0.1cm 138 1.4cm 0.1cm 168	Flood plain
Dark brown weathered horizons Wavelength Height Trend 0.8cm 0.1cm 150	
Symmetrical ripples Wavelength Height Trend 2cm 0.3cm 049 2cm 0.2cm 050 5cm 0.5cm 086	Tidal flats to shallow marine
Sandstone includes small cavities like bubbles	
Cross-beds Height Dip Trend 20cm 12 241	Fluvial channels
Symmetrical ripples interbedded with parallel lamination and mud units Wavelength Height Trend 3cm 0.3cm 074	Flood plain
Cross-beds Height Dip Trend 12cm 10 185	Fluvial channels
Desiccation structures	
Horizontal and vertical burrows up to 0.3cm in diameter	Tidal flats to shallow marine

Collorus (base) 3

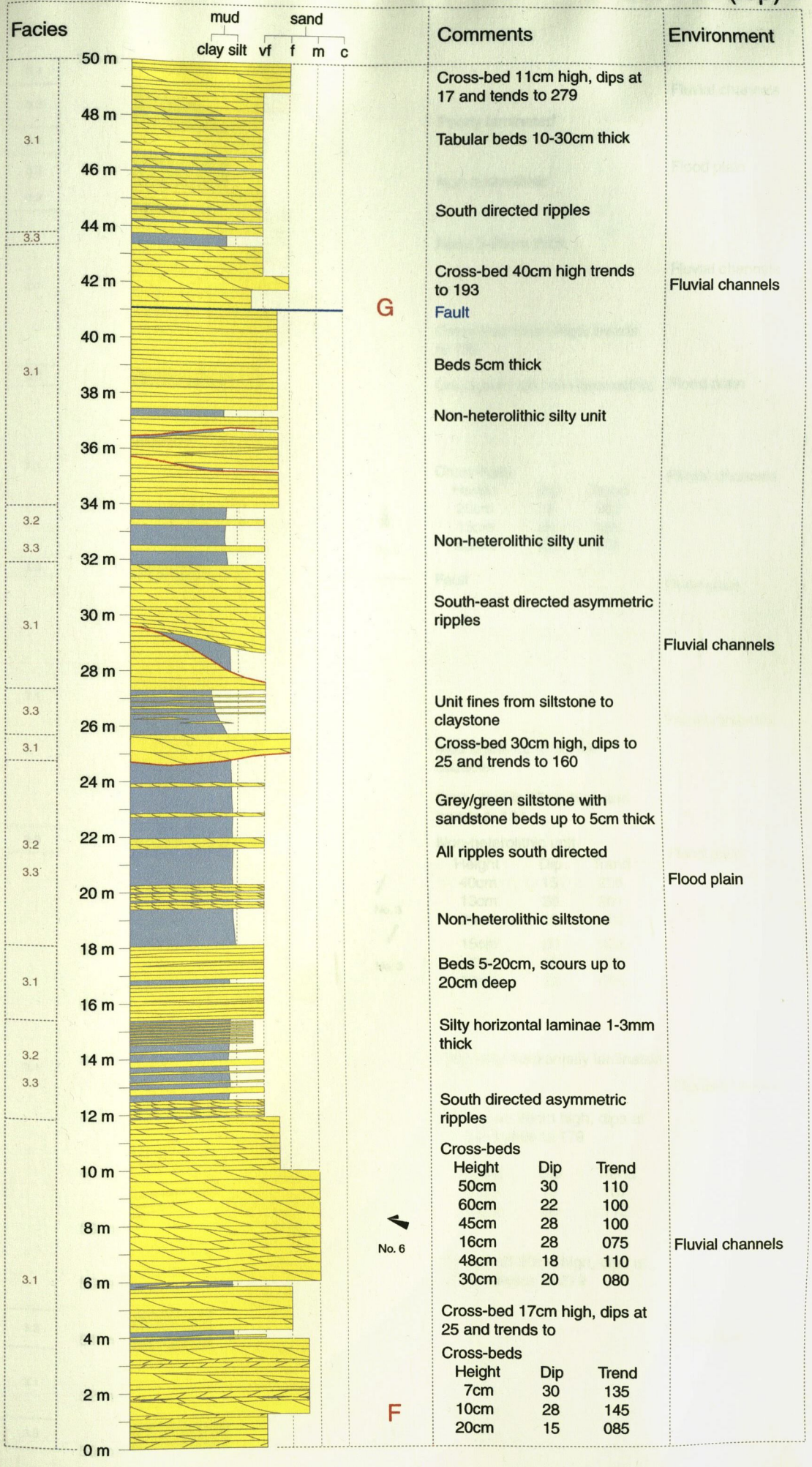


Collorus (base) 4



Facies	Comments	Environment
3.1	Syncline in the beach Discontinuous brown weathered horizons perhaps reflecting decalcification	Fluvial channels
2.2 2.1	Symmetrical ripple with wave-length of 2cm, height of 0.2cm and crest trend to 058	Tidal flats or shallow marine
3.1	Cross-beds Height / Dip / Trend 55cm / 15 / 188 42cm / 10 / 180 40cm / 30 / 205	Estuarine
2.1 2.5		Tidal flats or shallow marine
3.1		Estuarine
	Cross-beds Height / Dip / Trend 45cm / 6 / 192 34cm / 13 / 108 12cm / 28 / 161 25cm / 24 / 155 Height / Dip / Trend 17cm / 22 / 247	Fluvial channels
2.1 3.1 2.1	Occasional sandstone linsen up to 1cm thick	Tidal flats or shallow marine
2.5 3.1/2.5 3.1 or 2.6	Mudstone and sandstone clasts up to 6cm in diametre	Estuarine
3.1		Fluvial channels
3.3	Bifurcating, straight crested symmetrical ripples. One example has a wavelength of 1.5cm, height of 0.2cm and the ripple crest trends to 062 Period = 1.0secs / Depth < 1m	Tidal flats or shallow marine
3.1		Estuarine
3.1		Fluvial channels
2.2	Symmetrical ripples Wavelength / Height / Trend 5cm / 0.4cm / 222 2.8cm / 0.3cm / 104 4cm / 0.3cm / 042 Height / Dip / Trend 12cm / 26 / 153 13cm / 32 / 178 Mud drape on foresets 22cm / 16 / 262 South directed cross-beds Height / Dip / Trend 12cm / 15 / 180 40cm / 36 / 165 20cm / 15 / 131 27cm / 17 / 149	Tidal flats or shallow marine Fluvial channels
3.1		

Collorus (top) 1



Comments	Environment
Cross-bed 11cm high, dips at 17 and tends to 279	
Tabular beds 10-30cm thick	
South directed ripples	
Cross-bed 40cm high trends to 193	Fluvial channels
Fault	
Beds 5cm thick	
Non-heterolithic silty unit	
Non-heterolithic silty unit	
South-east directed asymmetric ripples	
	Fluvial channels
Unit fines from siltstone to claystone	
Cross-bed 30cm high, dips to 25 and trends to 160	
Grey/green siltstone with sandstone beds up to 5cm thick	
All ripples south directed	
	Flood plain
Non-heterolithic siltstone	
Beds 5-20cm, scours up to 20cm deep	
Silty horizontal laminae 1-3mm thick	
South directed asymmetric ripples	

Cross-beds

Height	Dip	Trend
50cm	30	110
60cm	22	100
45cm	28	100
16cm	28	075
48cm	18	110
30cm	20	080

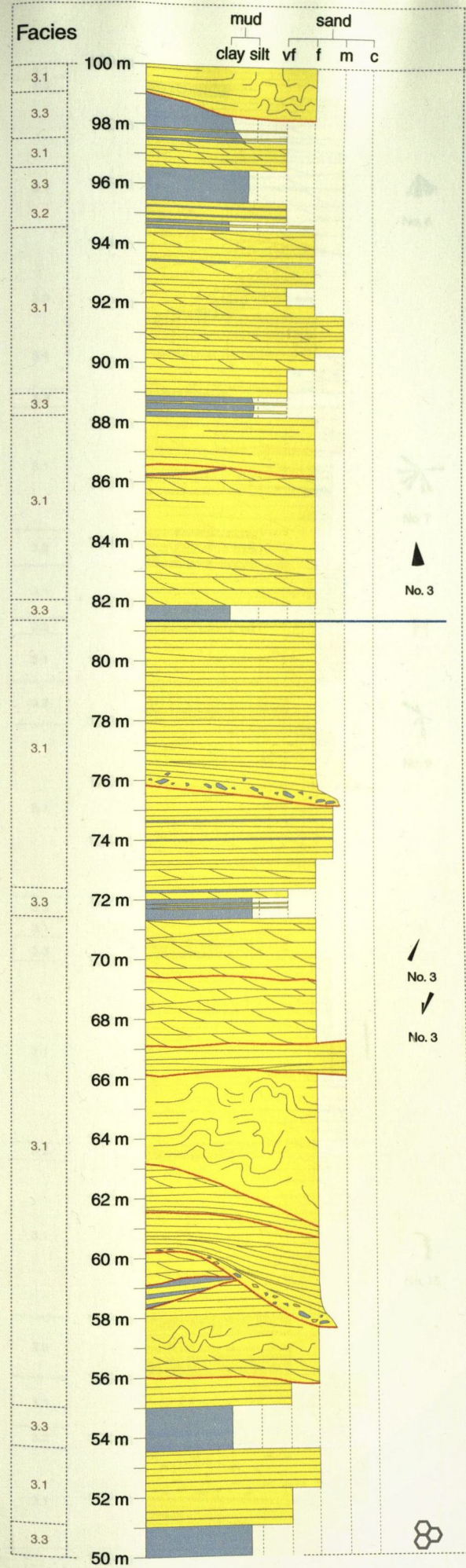
Fluvial channels

Cross-bed 17cm high, dips at 25 and trends to

Cross-beds

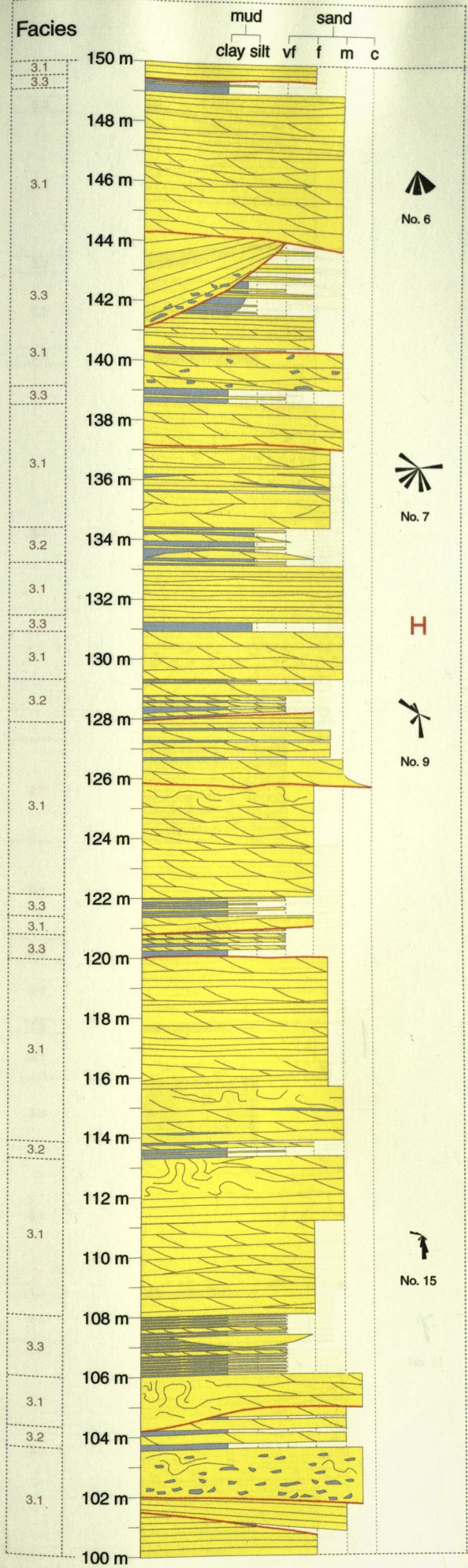
Height	Dip	Trend
7cm	30	135
10cm	28	145
20cm	15	085

Collorus (top) 2



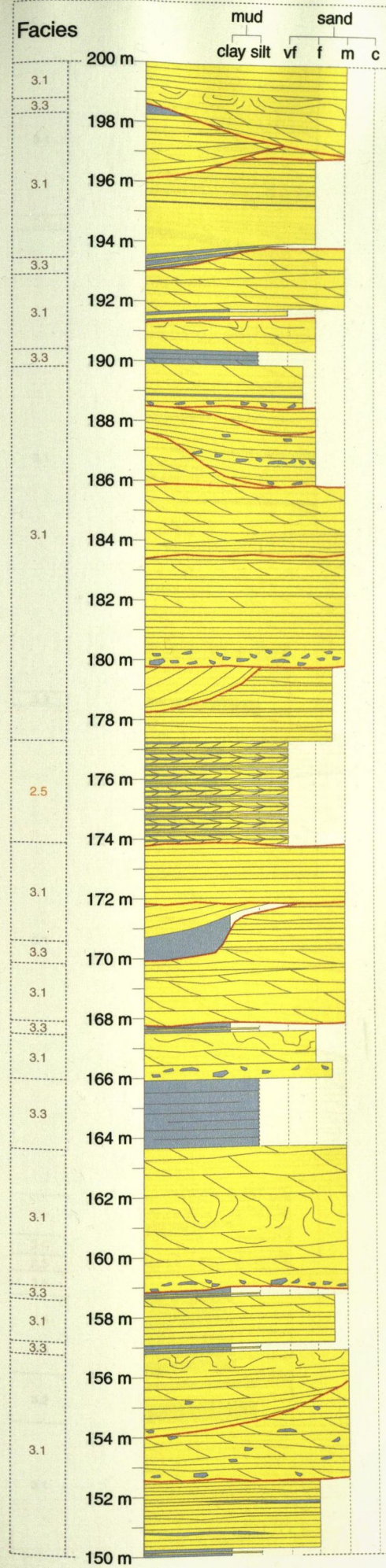
Comments	Environment
	Fluvial channels
Poorly laminated	
	Flood plain
Non-heterolithic	
Beds 3-20cm thick	
	Fluvial channels
Cross-bed 35cm high, trends to 135	
Grey/green silt, non-heterolithic	Flood plain
Cross-beds Height Dip Trend 20cm 35 162 13cm 28 185 45cm 22 170	Fluvial channels
Fault	Flood plain
	Fluvial channels
Mud clasts up to 3cm in diameter	
Cross-bed is 15cm high and trends to 131	
Non-heterolithic unit Height Dip Trend 40cm 15 206 13cm 28 201 20cm 18 202 15cm 20 022 12cm 22 009 55cm 28 024	Flood plain
Originally horizontally laminated	
	Fluvial channels
Cross-bed 28cm high, dips at 18 and trends to 179 Height Dip Trend 30cm 15 107 33cm 22 112	
Cross-bed 20cm high, dips at 26 and trends to 279	
	Flood plain

Collorus (top) 3



Comments	Environment
	Flood plain
Cross-beds Height Dip Trend 15cm 20 171 40cm 30 147 7cm 20 135 11cm 30 183 20cm 28 205 16cm 25 158	Fluvial channels
Non-heterolithic unit	Flood plain
Height Dip Trend 50cm 22 351	
50cm 18 262 14cm 24 237 20cm 26 307 40cm 15 219 10cm 18 082 14cm 30 153 24cm 24 171	Fluvial channels
Cross-bed trends to 057 Beds 30-50cm thick	Flood plain
Height Dip Trend 50cm 30 178 30cm 30 170	Fluvial channels
Asymmetric ripples oriented to: 219, 222, 307, 315, 301, 333, 112, 171, 175	
Cross-bed Height Dip Trend 35cm 30 345 42cm 40 340 11cm 28 301	Fluvial channels
Cross-bed 30cm high, dips at 28 and trends to 270 South directed ripples	Flood plain
Cross-beds Height Dip Trend 50cm 30 223 30cm 28 307 35cm 30 343	Fluvial channels
13cm 30 153 35cm 33 167	
33cm 30 175 66cm 10 183	Flood plain
Parting lineation: 285, 290, 294 9cm 23 136 14cm 17 171 25cm 30 177 55cm 11 185 32cm 30 162 18cm 20 210	
Height Dip Trend 36cm 22 171 20cm 18 167 30cm 18 171	Flood plain
Mud clasts up to 4cm in diameter Parting lineation trends to: 051, 057, 058, 064, 075, 076, 171	Fluvial channels

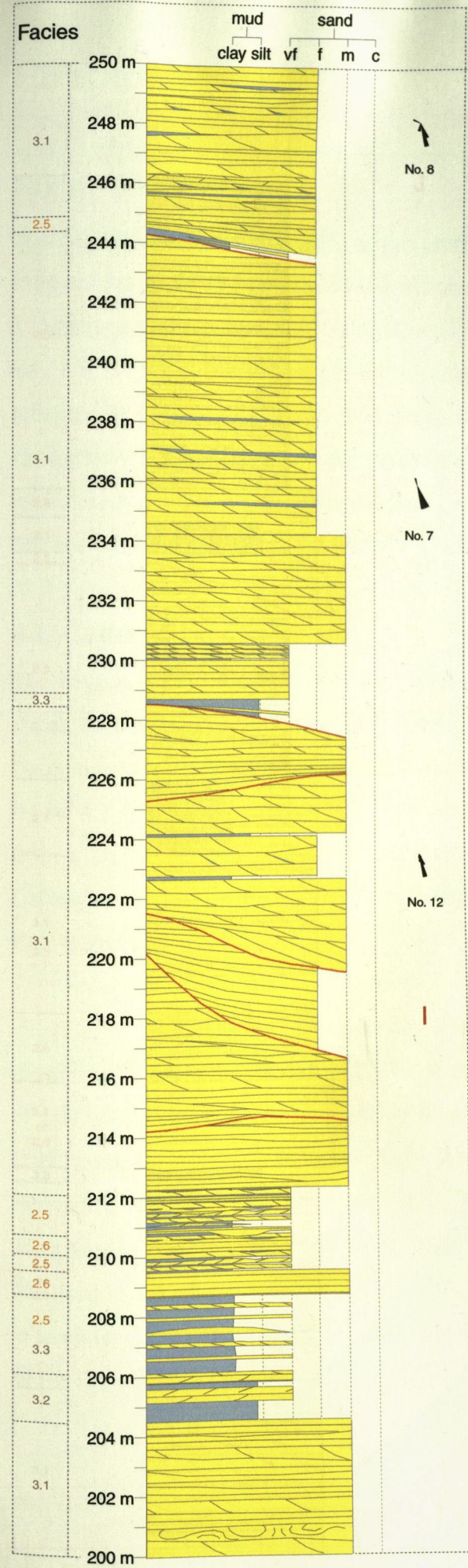
Collorus (top) 4



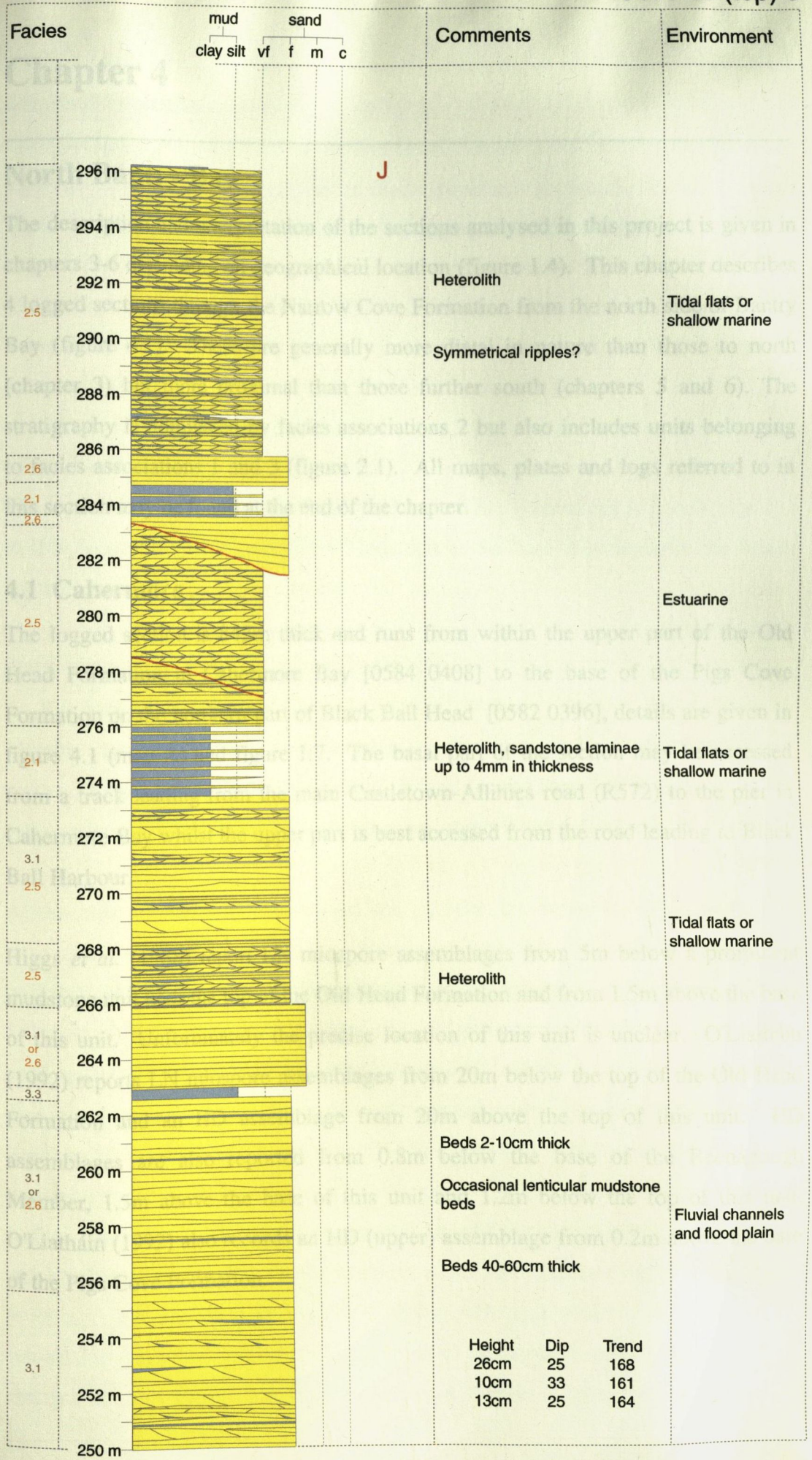
Facies	Comments	Environment
3.1	Height Dip Trend 30cm 20 304 35cm 18 280 80cm 15 270	Fluvial channels
3.3		
3.1	Beds 1-3cm thick	
3.3		
3.1		
3.3	Non-heterolithic unit	Flood plain
3.1	Cross-bed 60cm high, dips at 15 and trends to 148 Beds 5-40cm thick Cross-bed 45cm high trends to 255	Fluvial channels
2.5	Cross-beds up to 14cm high Mud flakes up to 5cm Steep lateral accretion surface up to 1.8m high dip at 30 and trend towards 253 Heterolith unit containing bi-directional sets and bundled up-building	Tidal flats or shallow marine
3.1	Beds 5-30cm thick	
3.3	Cross-beds Height Dip Trend 80cm 16 316 40cm 14 165	Fluvial channels
3.1		
3.3		
3.1		
3.3	Non-heterolithic laminated silt Height Dip Trend 35cm 15 304 70cm 23 134 16cm 14 162 22cm 30 343 26cm 22 147	Flood plain
3.1		
3.3		
3.1		
3.3	40cm 22 280 20cm 18 237 20cm 26 333 24cm 14 068 45cm 12 147 70cm 20 163	Fluvial channels
3.1	Lenticular beds around 1-10cm thick. Unit includes occasional lenticular mudstone up to 20cm thick	

No. 11

Collorus (top) 5



Comments	Environment
Cross-beds Height Dip Trend 10cm 30 299 12cm 16 159 16cm 18 152 50cm 18 186 35cm 11 193	Fluvial channels
Heterolithic unit	Estuarine
Cross-bed 28cm high, dips at 24 and trends to Height Dip Trend 14cm 28 163 35cm 25 157 13cm 12 347	Fluvial channels
Height Dip Trend 20cm 15 157 25cm 25 163 18cm 20 157 20cm 22 164	
Uni-directional ripples Height Dip Trend 20cm 25 179 39cm 15 165 19cm 15 157 18cm 22 161 15cm 18 178 26cm 18 168	Flood plain
13cm 20 169 13cm 15 184 23cm 28 148 35cm 30 157 35cm 30 171 70cm 07 162	Fluvial channels
Cross-beds Height Dip Trend 23cm 25 131 27cm 32 150	
Bi-directional ripples oriented to: 108, 141, 316	
Bi-directional ripples oriented to: 155, 163, 170, 148, 270, 255, 153	Tidal flats or shallow marine
	Fluvial channels


Facies
mud
clay silt
sand
vf f m c
Comments
Environment
J
296 m
294 m
292 m
290 m
288 m
286 m
284 m
282 m
280 m
278 m
276 m
274 m
272 m
270 m
268 m
266 m
264 m
262 m
260 m
258 m
256 m
254 m
252 m
250 m
2.5
2.6
2.1
2.6
2.5
2.1
3.1
2.5
2.5
3.1
or
2.6
3.3
3.1
or
2.6
3.1
Heterolith
Symmetrical ripples?
Tidal flats or shallow marine
Estuarine
Heterolith, sandstone laminae up to 4mm in thickness
Tidal flats or shallow marine
Tidal flats or shallow marine
Heterolith
Beds 2-10cm thick
Occasional lenticular mudstone beds
Fluvial channels and flood plain
Beds 40-60cm thick
Height Dip Trend
26cm 25 168
10cm 33 161
13cm 25 164

Chapter 4

North Bantry Bay

The description and interpretation of the sections analysed in this project is given in chapters 3-6 depending on geographical location (figure 1.4). This chapter describes 4 logged sections through the Narrow Cove Formation from the north side of Bantry Bay (figure 4.1). These are generally more distal in nature than those to north (chapter 3) but more proximal than those further south (chapters 5 and 6). The stratigraphy is dominated by facies associations 2 but also includes units belonging to facies associations 1 and 3 (figure 2.1). All maps, plates and logs referred to in this section may be found at the end of the chapter.

4.1 Cahermore

The logged section is 842m thick and runs from within the upper part of the Old Head Formation in Cahermore Bay [0584 0408] to the base of the Pigs Cove Formation on the northern part of Black Ball Head [0582 0396], details are given in figure 4.1 (map A) and figure 1.7. The basal part of the section may be accessed from a track leading from the main Castletown-Allihies road (R572) to the pier in Cahermore Bay whilst the upper part is best accessed from the road leading to Black Ball Harbour.

Higgs *et al.* (1988) report LN miospore assemblages from 5m below a prominent mudstone unit near the top of the Old Head Formation and from 1.5m above the base of this unit. Unfortunately the precise location of this unit is unclear. O'Liatháin (1992) reports LN miospore assemblages from 20m below the top of the Old Head Formation and an HD assemblage from 20m above the top of this unit. HD assemblages are also reported from 0.8m below the base of the Reenagough Member, 1.5m above the base of this unit and 1.2m below the top of this unit. O'Liatháin (1992) also records an HD (upper) assemblage from 0.2m above the base of the Pigs Cove Formation.

Old Head Formation

Only the upper portion (~7m) of the Old Head Formation is included in this study. This consists of a series of listric-fault (probably tectonic) bound packages dominated by laminated mudstone facies belonging to facies association 1 or 2. The lack of lithological change across these roughly strike parallel faults and the presence of similar facies at the top of the Old Head Formation in other sections exposed along the north side of Bantry Bay may indicate that these faults reflect little out of section displacement.

Castle Slate Formation

The transition between the Old Head and Castle Slate Formations is poorly exposed in this section but the Castle Slate Formation at the base may underlie the beach south of the small pier (6.4m - 14.4m).

Narrow Cove Formation

At the base of the Narrow Cove Formation (14.4m - 204.6m) the Ardaturrish Member is of comparable thickness (182m) to that measured from the Reenagough section (204m), the Ballycrovane section (171m) and the Bere Island section (184m) and consists of facies belonging to facies associations 2 and 3 (figure 2.1).

At the base of this unit between 14.4m - 29.5m the sequence is dominated by mudstone rich facies including sandstone laminae and symmetrical ripples and probably reflects deposition within a wave or storm influenced shelf setting. This is followed at 29.5m by an abrupt increase in sandstone content that persists up section until around 112m although the actual sandstone content does vary considerably. This sequence is dominated by small-scale symmetrical ripples with wavelengths of less than 5cm and crest-lines oriented NE-SW (plate 4.1). This interval also includes parallel lamination, desiccation cracks, asymmetric ripples, occasional down-cutting surfaces (80 - 85m) and a sandstone unit (57.5m - 62.0m) that displays south directed cross-beds and asymmetric ripples at its base and north directed asymmetric ripples at its top. The sequence as a whole probably reflects deposition within a shallow sub-tidal to inter-tidal setting whilst variation in sandstone content probably reflects changes in either coastal proximity or sediment supply. Although the cross-bedded

sandstone unit exposed between 57.5m - 62.0m may reflect deposition within a tidal channel these features are normally absent. This suggests that this extensive sequence of tidal flats resembled those of present day Inchon, Korea (Frey 1989) or the Gulf of California (Weimer *et al.* 1998) where tidal channels are also rare.

Overlying this between 102m - 204.6m the section is relatively poorly exposed but appears to consist of mudstone rich facies. The lower part of this sequence includes wavy bedded heterolithic facies that were probably deposited within a shallow shelf or mudstone rich near-shore setting but the central and upper parts are dominated by poorly sorted siltstone. Although similar packages exposed at this level within the Reenagough section (167.4m - 236.0m), the Ballycrovane section (141.2m - 181.3m) and the Bere Island section (139m - 183.7m) are interpreted to reflect deposition within a coastal plain setting the poor exposure of this section makes interpretation difficult. However, a thick sandstone unit exposed within this package (153.8m - 161m) is dominated by SW directed bedforms and is likely to have been deposited within a fluvial setting.

Above 204.6m the sequence displays a higher sandstone content than the sequence below and has been taken as the base of the Reenagough Member by Pracht (1994). However both McAfee (1992) and O'Liatháin (1992) place the base of this unit higher in the section where the sequence becomes sandstone dominant (293.7m). Although Pracht (1994) proposes that these points lie at the same level in the section but are displaced by faulting, logging of both areas indicate that the sequences are clearly different. Although good arguments may be made for taking either level as the base of the Reenagough Member the lower surface at 204.6m is preferred. The main benefits of this are that the Ardaturrish Member is of comparable thickness to that found in other sections and that the base of the Reenagough Member overlies a thick, poorly sorted sequence as in all adjacent sections. Although this means that the base of the Reenagough Member in this section (204.6m - 293.7m) is relatively mudstone rich this is also the case in the Reenagough Point section (236m -294m). It is also likely that some of the intervening sequence (204.6m - 293.7m) has been duplicated by the small faults exposed along the north side of White Ball Head.

The Reenagough Member exposed between 204.6m - 622m is thicker than that measured elsewhere in the South Munster Basin but this is probably mainly because other sections in the western part of the basin are incomplete.

At the base of the Reenagough Member between 204.6m - 216m a series of down-cutting surfaces overlain by heterolithic units (plate 4.2) probably reflect deposition within an estuarine or tide influenced deltaic setting. This is overlain (216 - 293.7m) by a wavy bedded rippled heterolithic package dominated by small scale symmetric and asymmetric ripples that were probably deposited within a coastal setting although some of the more mudstone rich packages may have been deposited within a shallow shelf setting.

This is overlain between 293.7m - 622m by a sequence that is almost entirely dominated by sandstone and includes a number of distinctive elements. These include a high sandstone content, homogenous mudstone units containing sand-balls, abundant down-cutting surfaces and a low level of bioturbation. The sequence may be roughly divided into two facies associations. The first includes parts of the section dominated by down-cutting surfaces (plate 4.3), parallel lamination, cross-beds, asymmetric ripples and homogenous mudstone units containing sand balls (plate 4.4). These features indicate high rates of deposition and possibly reflect a tide influenced deltaic setting. The second facies association is more tabular bedded and includes symmetrical ripples, asymmetric ripples and parallel lamination (plate 4.5). These probably reflect deposition within an inner-shelf to coastal setting. Changes between these depositional styles probably reflect changes in coastal proximity but may also have been generated by migration of distributary point sources. Unfortunately the portion of the sequence underlying Black Ball Harbour (622m - 700m) is not exposed.

The Black Ball Member situated at the top of the Narrow Cove Formation is composed of facies belonging to facies associations 1 and 2. At the base of this unit between 700m - 781.4 the sequence is dominated by laminated and wavy bedded mudstone containing occasional nodules, poorly developed graded beds and occasional gutter casts (plate 4.6). This package marks a dramatic reduction in sandstone content relative to the underlying Reenagough Member. However, this

package also includes several sandstone rich intervals (700m - 708m, 732m - 748m, 754m - 765m, 774m - 778m) that are dominated by symmetrical ripples but which sometimes also include asymmetric ripples, cross-bedding and possibly SCS. This sequence was probably deposited within a shelf setting whilst variation in sandstone content probably reflects varying proximity to the coastline. This relatively mudstone rich part of the sequence probably correlates with similar packages developed at this level within the Ballycrovane (398m - 548m) and Dunworly sections (212m - 299m) which also include repeated changes in sandstone content.

At 781.5m an erosive based sandstone unit incises into the underlying mudstone rich shelf succession and marks a dramatic increase in sandstone content which continues until the top of Narrow Cove Formation at 882.2m. However, it should be noted that 35m of this thickness consists of basaltic sills. Within this sequence sandstone packages contain parallel lamination, cross-beds and asymmetric ripples and are commonly underlain by down-cutting surfaces. These features probably reflect deposition within a coastal setting although the upper part of this sequence which is more tabular bedded and includes ripples (plate 4.7) may have been deposited within an inner-shelf setting. These sandstone units are separated by laminated or wavy bedded mudstone units that may reflect deposition within shelf or inter-tidal settings. The presence of these predominantly coastal sediments enclosed by shelf mudstone (above and below) suggest that this interval was generated during a low-stand of relative sea-level.

Pigs Cove Formation

At 882.2m the sequence exhibits a rapid transition from the sandstone rich facies of the Narrow Cove Formation to mudstone rich facies belonging to the Pigs Cove Formation and was accompanied by an increase in storm influenced facies (facies association 1). This change indicates a pronounced landward shift of facies belts that probably occurred in response to a phase of relative sea-level rise and associated drowning of the northern basin margin.

4.2 Fair Head

The logged section is 233m thick and runs through part of the Reenagough Member. The section stretches from the core of the anticline exposed in the cliffs south of Disert Hill [0653 0422] to a position on the north side of Fair Head [0658 0421], details are given in figure 4.1 (map B) and figure 1.7. Much of the section is exposed within precipitous cliffs and was difficult to study in detail. The section may be accessed from the road leading from Dunboy towards Piper's Point.

Although no palynological data is available for the measured section Pracht (1994) reports an HD miospore assemblage from the sequence underlying the base of this section. Considering this and the fact that the package is dominated by sandstone it seems likely that the measured section lies within part of the Reenagough Member.

Narrow Cove Formation

Between 0m - 13.2m the sequence is dominated by rippled and often flaser bedded sandstone but also includes a small north directed cross-bed. Although the exposure is rather poor at this level it seems likely that the package reflects deposition within an inner-shelf or coastal setting. Poor exposure continues into the overlying sequence (13.2m - 19.7m) which appears to be more mudstone rich than the package below but it is not clear whether this indicates a basinward shift in facies belts or simply a change in setting within the near-shore zone.

Although the exposure improves between 19.2m - 111.2m much of the section is exposed within precipitous cliffs and is largely inaccessible. However, the package appears to be dominated by wavy and flaser bedded rippled heterolith (with bi-modal palaeoflow patterns) but also includes parallel lamination and a series of prominent down-cutting surfaces. These features probably reflect deposition within an inner-shelf to coastal setting.

Overlying this between 111.2m - 156.8m the sequence includes several thick parallel laminated and cross-bedded fine sandstone units interspersed with wavy and flaser bedded rippled heteroliths. The increased prevalence of parallel lamination and cross-bedding and a modest increase in grain size relative to the underlying sequence

suggests an increase in tidal current velocity and possibly increased coastal proximity.

Between 156.8m - 202m the sequence is dominated by wavy and flaser bedded rippled heterolith and to a lesser extent by parallel lamination and was probably deposited within an inner-shelf to coastal setting. This is overlain by a mudstone dominated wavy and lenticular bedded heterolithic package that includes several prominent down-cutting surfaces (202m - 216.4m) that probably reflects deposition within an estuarine or tide influenced deltaic setting. The section culminates in a flaser bedded rippled sandstone unit probably deposited within an inner-shelf or coastal setting and therefore reflects a land-wards shift in facies relative to the underlying package.

4.3 Bere Island

The logged section is 373m thick and runs from the lower part of the Ardaturrish Member south-west of Lonehort Point [0765 0451] to within the Reenagough Member on the eastern side of Coosnafeagh Bay [0761 0445], details are given in figure 4.1 (map C) and figure 1.7. The section may be accessed from the old military batteries north of Coosnafeagh Bay. Unfortunately no palynological data is available for this section.

Narrow Cove Formation

The base of the measured section lies within the Ardaturrish Member 184m below the base of the Reenagough Member. Interestingly, this is comparable to the thickness of the Ardaturrish Member in the Reenagough section (204m), the Ballycrovane section (171m) and the Cahermore section (182m). Furthermore, considering the presence of laminated mudstone facies at the base of the measured section it seems likely that this section commences immediately overlying the Castle Slate Formation. The Ardaturrish Member consists of units belonging to facies associations 2 and 3 (figure 2.1).

The laminated mudstone unit at the base of the section probably reflects deposition within a relatively distal shelf setting. This is overlain by a wavy bedded heterolithic

package that includes ripples and occasional lenticular cross-beds (7.8m - 10.8m) and is in turn overlain by a sandstone rich package containing cross-beds, parallel lamination and asymmetric ripples (10.8m - 14.2m). This probably reflects increasing coastal proximity and a transition from shelf to coastal settings. The staggered rather than gradual increases in sandstone content suggest that these basin-ward shifts in facies were achieved during phases of forced rather than normal regression (Posamentier *et al.* 1992).

Between 14.2m - 110.6m the sequence is dominated by alternating mudstone and sandstone rich packages. Mudstone rich packages are wavy or lenticular bedded and may contain non-graded sandstone laminae and both symmetric and asymmetric ripples. Sandstone rich packages are typically dominated by both symmetrical and asymmetric ripples but may also include parallel lamination and a prominent down-cutting surface is developed at 63m suggesting deposition within a fairly proximal setting. Mudstone rich packages may reflect deposition within a shelf setting. Variation between these may have been generated by fluctuation in relative sea-level or autocyclic variation between a variety of coastal settings.

Between 110.6m - 139m the sequence is dominated by sandstone and includes a series of west directed asymmetric ripples, variably oriented lateral accretion surfaces, small-scale symmetric ripples and desiccation cracks. These features probably reflect deposition within a coastal or fluvial setting.

The overlying sequence between 139m - 183.7m is dominated by relatively poorly sorted siltstone but includes sandstone rich heterolithic units near the base of the sequence. The poorly sorted siltstone that dominates this sequence typically includes poorly defined sandstone linsen and may contain desiccation cracks and mottling whilst intermittent sandstone rich packages are dominated by symmetrical ripples. Considering the poor grain-size separation and presence of both desiccation surfaces and mottling it is likely that this sequence reflects deposition within a coastal plain setting although the degree of marine influence is unclear. The package probably correlates with similar packages at this level in the Reenagough section (167.4m - 236.0m), the Ballycrovane section (141.2m - 181.3m) and the Cahermore section (161m - 204m).

Overlying this from 183.7m until the top of the section at 373m the Reenagough Member consists of a variety of sandstone rich facies belonging to facies associations 2 and 3. The sequence commences between 183.7m - 196.6m with a series of erosive based sandstone packages separated by laminated or wavy bedded mudstone which was probably deposited within a shelf setting. The lowermost sandstone unit (183.7m - 184.9m) overlies a planar erosion which is probably a wave ravinement surface generated as the coastline migrated landward. The sandstone unit between 187.4m- 190m includes several down-cutting surfaces and evidence of tidal influence and therefore probably reflects deposition within a coastal setting. The sharp basal and upper surfaces of this package suggest deposition progressed during a lowstand of relative sea-level.

A further basin-wards shift in facies is recorded at 196.6m and from this level until about 254.4m the sequence is dominated by bedforms that suggest palaeo-flow to the east and south-east although rippled sandstone packages that include mud drapes and bi-modal palaeo-current patterns also occur. The basal and upper portions of this sequence are sandstone rich and include cross-bedding and asymmetric ripples whilst the central portion is dominated by poorly sorted siltstone. This includes disparate sandstone stringers but does not resemble typical marine generated heterolith and therefore probably reflects deposition within a coastal plain setting. Variation between sandstone and mudstone rich packages may reflect changes in accommodation or in the location of distributary channels.

From 254.4m until the top of the section at 340.5m the section consists of sandstone rich and often heterolithic facies inter-bedded with relatively thin packages of wavy bedded mudstone. Sandstone rich packages are dominated by symmetrical ripples and to a lesser extent by asymmetric ripples but also include parallel lamination, convolute bedding (plate 4.8) and cross-beds. Mudstone rich packages include symmetric and asymmetric ripples and sometimes include sand-balls. The package also includes down-cutting surfaces and in one instance there is possibly evidence for the development of tidal sand-waves (figure 2.7). Sandstone rich parts of this sequence probably reflect deposition within an inner-shelf to coastal setting.

Intervening mudstone rich packages may reflect deposition within coastal and/or a shallow shelf setting.

4.4 Reenagough Point

The logged section is 509m thick and runs from within the upper part of the Old Head Formation on the southern side of Ardaturrish Point [0960 0530] to within the upper part of the Reenagough Member (Narrow Cove Formation) on the western side of Reenagough Point [0966 0526], details are given in figure 4.1 (map D) and figure 1.7. The section may be accessed from a number of tracks leading towards the coast from the main Bantry - Glengarriff road.

O'Liatháin (1992) reports an LN miospore assemblage from 0.5m below the top of the Old Head Formation in this section and VI assemblages from 0.5m above the base of the Castle Slate Formation and from 0.1m below the top of this unit. However, the presence of VI miospore assemblages within the base of the Castle Slate Formation is in disagreement with the findings of Van der Zwan (1980) who reports an LN assemblage from 7.5m above the base of the Castle Slate Formation. However, considering the mudstone rich nature of the upper part of the Old Head Formation it is possible that Van der Zwan (1980) mis-located the Castle Slate Formation in his study. O'Liatháin (1992) also records HD assemblages from 0.5m above the top of the Castle Slate Formation, from 3.3m below the base of the Reenagough Member, from 10m above the base of this unit and from 33.5m below the top of the section. An HD assemblage is also recorded from 0.1m below the base of the Pigs Cove Formation on the far side of the fault lying to the east of Reenagough Point (figure 4.1 - map D).

Old Head Formation

Only the upper 24m of the Old Head Formation is included in this study. This sequence varies between symmetric or asymmetric rippled units and laminated mudstone rich facies dominated by graded beds and gutter casts (plate 4.9). Bioturbation and nodules are common throughout. The sequence probably reflects deposition within a wave and storm influenced shelf setting whilst the variation in

sandstone content throughout the unit probably results from fluctuation of relative sea-level.

Castle Slate Formation

Between 24.0m - 32.0m the Castle Slate Formation consists of dark grey homogenous mudstone although this is poorly exposed and only seen at low tide. The thickness of this (~9m) is comparable to that found on the south side of Bantry Bay (~9m) and the north side of Dunmanus Bay (~7m). The Castle Slate Formation was probably deposited with a distal shelf setting during a phase of relative sea level rise.

Narrow Cove Formation

At the base of the Narrow Cove Formation (32.0m - 236m) the Ardaturrish Member is of comparable thickness (204m) to that measured from the Ballycrovane section (171m), the Cahermore section (182m) and the Bere Island section (184m) and consists of facies belonging to facies associations 2 and 3 (figure 2.1).

The base of this unit between 32.0m - 37.7m consists of mudstone rich facies that contain an upward increase of siltstone and sandstone laminae probably indicating increased coastal proximity. At 37.7m the sequence then exhibits a dramatic increase in sandstone content (although this then fluctuates) and is dominated by wavy bedded rippled heterolith (plate 2.18). This sequence probably reflects deposition within a shallow shelf setting whilst the variation in sandstone content probably reflects small-scale variation in relative sea-level or changes in sediment supply. The sharp transition between this package and the more mudstone rich sequence below probably reflects a drop in relative sea-level.

Between 79.2m - 167.4m the sequence is dominated by sandstone rich symmetrical rippled heterolithic units but also includes a sandstone unit containing asymmetric ripples and cross-beds oriented towards the SE (34.5m - 39.0m). Analysis of a symmetrical ripple from the upper portion of this sequence (146m) indicates that the generative surface wave was of limited fetch and that deposition progressed within a fairly shallow water setting (< 5m). It therefore seems likely that the sequence developed within an inner-shelf or coastal setting. The cross-bedded and asymmetric

rippled sandstone unit (34.5m - 39.0m) may reflect deposition within a fluvial or tidal setting.

Between 167.4m - 236m the sequence is dominated by relatively poorly sorted siltstone. This probably correlates with similar units (directly underlying the Reenagough Member) in the Ballycrovane section (141.2m - 181.3m), the Bere Island section (139m - 182.7m) and the Cahermore section (102m -204.6m). The siltstone that dominates this sequence typically includes poorly defined sandstone linsen whilst intermittent sandstone rich packages (173.3m - 183.2m, 202.7 - 204.2m and 229.0m - 232.7m) are dominated by symmetric and asymmetric ripples (plate 4.10). Analysis of three symmetrical ripples from the highest of these sandstone rich levels suggests that the generative surface waves were of limited fetch and that deposition progressed within a very shallow water setting (< 2.5m). The poor grain size separation developed in this unit and the low calculated water depth suggest that deposition progressed within a fluvial plain setting.

From 236.0m until the top the logged section at 533.2m the Reenagough Member is dominated by sandstone and sandstone rich heterolithic units mainly belonging to facies association 2 (figure 2.1). This sequence may be divided into three facies groupings;

(1) Parallel laminated and cross-bedded sandstone packages often associated with down-cutting surfaces.
(2) Tabular, wavy and flaser bedded heterolithic packages of varying sandstone content.
(3) Mudstone rich wavy bedded heterolithic packages associated with down-cutting surfaces and asymmetric ripples.

Parts of the Reenagough Member composed of parallel laminated, cross-bedded and rippled (plate 4.11) sandstone are commonly associated with relatively small scale down-cutting surfaces (plate 4.12). These rarely exceed 1m in depth and are often only a few metres or 10's of metres in width. Palaeoflow patterns determined from cross-bedding and asymmetric ripples are generally bi-modal and suggest tidal influence. Considering the lack of mudstone, the presence of down-cutting surfaces

and prominence of high flow velocity bedforms within these parts of the section it seems likely that they were deposited within coastal settings.

Parts of the Reenagough Member composed of tabular, wavy and flaser bedded heterolithic units dominate this section. These units contain symmetric and asymmetric ripples and are often intimately inter-bedded with thin parallel laminated sandstone beds. Measurement of ripple fore-set orientation from several horizons throughout the sequence suggests a bimodal pattern oriented roughly north-south although the majority of foresets are oriented to the north. This pattern may reflect both tidal and shoaling oscillatory components. Considering the lack of down-cutting surfaces but clear marine origin of these units it seems likely that they reflect deposition within an inner-shelf setting.

Finally, parts of the Reenagough Member composed of mudstone rich heterolithic units are commonly associated with large scale down-cutting surfaces. Although these may have depths of up to 4.3m their true scale (depth and width) is sometimes limited by exposure. Considering the scale of these channels and their association with current generated bedforms it seems likely that this sequence reflects deposition within an estuarine or tidal delta setting. The relationship between these units and those dominated by parallel lamination and cross-beds is interesting as these facies associations appear to reflect different styles of coastal setting. This may have arisen either in response to differences of relative sea-level (rising or falling) or variation between inter-distributary and delta front settings.

Both O'Liatháin (1992) and McAfee (1992) suggest that the top of the logged section lies close to the top of the Reenagough Member. However, this would mean that the Reenagough Member is considerably thinner in this section (~300m) than in the Cahermore section (~ 600m) and the Ballycrovane section (> 450m?). In addition, in each of the sections where the upper part of the Narrow Cove Formation is exposed (Cahermore, Ballycrovane and Dunworly) this part of the stratigraphy is dominated by mudstone (Black Ball Member) yet this is not the case at Reenagough Point. Together, these features tend to suggest that the top of the measured section lies substantially below the top of the Narrow Cove Formation (200-300m).

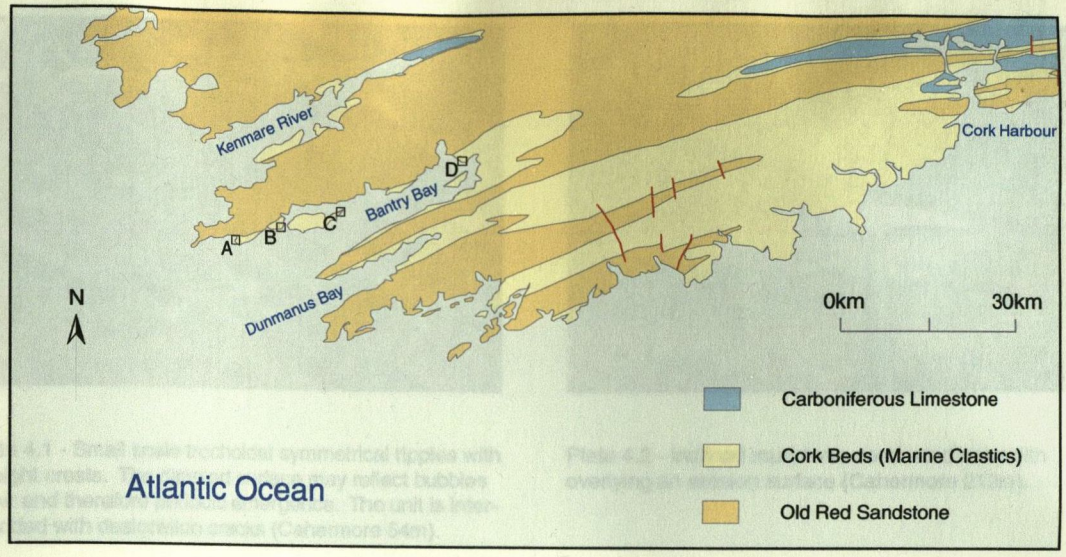
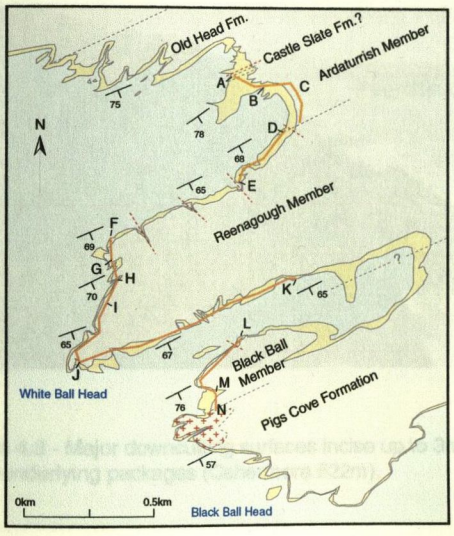
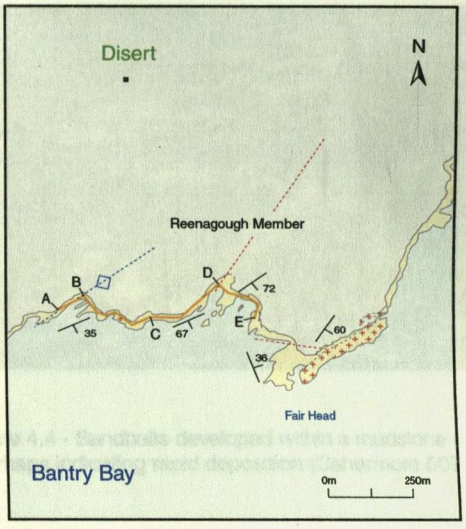


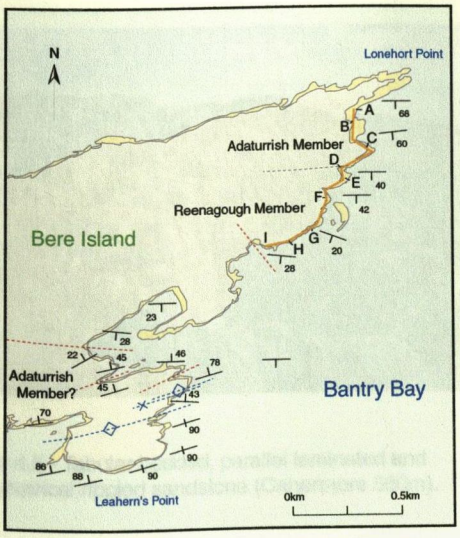
Figure 4.1 - Location of logged sections from the north of Bantry Bay.



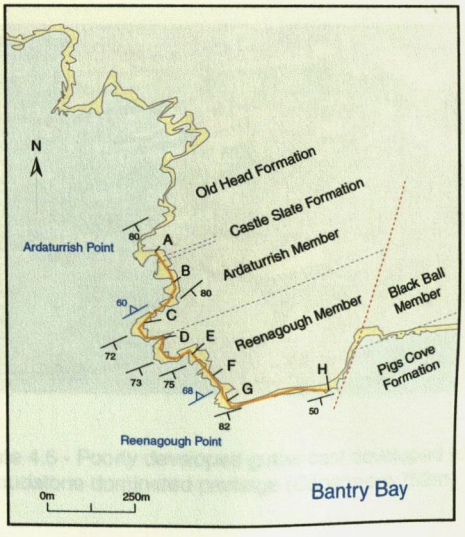
Map A - Cahermore, Bantry Bay.



Map B - Fair Head, Bantry Bay. Modified from Pracht (1994).



Map C - Bere Island, Bantry Bay.



Map D - Reenagough Point, Bantry Bay.



Plate 4.1 - Small scale trochoidal symmetrical ripples with straight crests. The dimpled surface may reflect bubbles of air and therefore periodic emergence. The unit is inter--bedded with desiccation cracks (Cahermore 54m).



Plate 4.2 - Inclined mudstone dominated heterolith overlying an erosion surface (Cahermore 212m).



Plate 4.3 - Major downcutting surfaces incise up to 3m into underlying packages (Cahermore 522m).



Plate 4.4 - Sandballs developed within a mudstone unit perhaps indicating rapid deposition (Cahermore 507m).

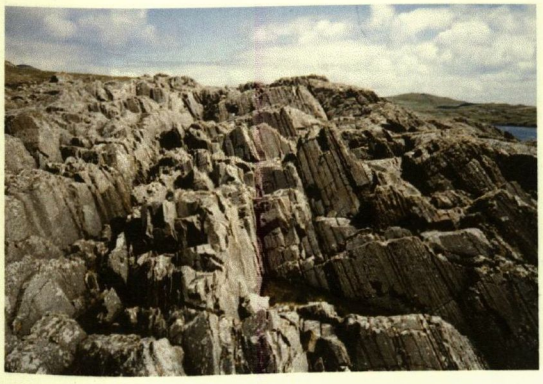


Plate 4.5 - Tabular bedded, parallel laminated and symmetrical rippled sandstone (Cahermore 560m).

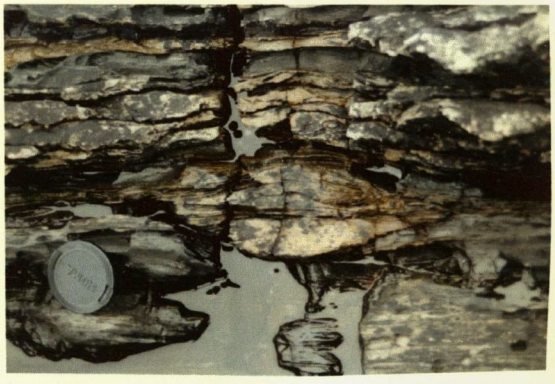


Plate 4.6 - Poorly developed gutter cast developed within a mudstone dominated package (Cahermore 752m).



Plate 4.7 - Herring bone patterns within a rippled unit. These vary from laterally continuous to bundled and illustrate the difficulty in distinguishing symmetric and asymmetric ripples in section (Cahermore 854m).

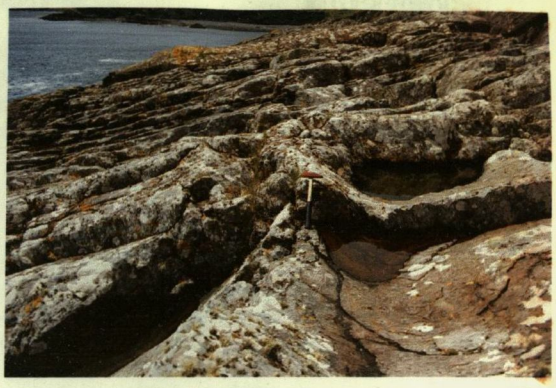


Plate 4.8 - Convolute bedding forming folds up to 70cm in height. These are truncated by overlying beds (Bere Island 344m).



Plate 4.9 - Wavy bedded unit underlying the Castle Slate Formation. This includes a shallow gutter cast and some symmetrical ripples. The orange colouration may reflect decalcification (Reenagough Point 15m).



Plate 4.10 - Asymmetrical ripples developed within a sand--stone unit. Ripples suggest dominant palaeoflow to the north with a subordinate southerly directed flow. This package probably reflects tidal influence (Reenagough Point 180).

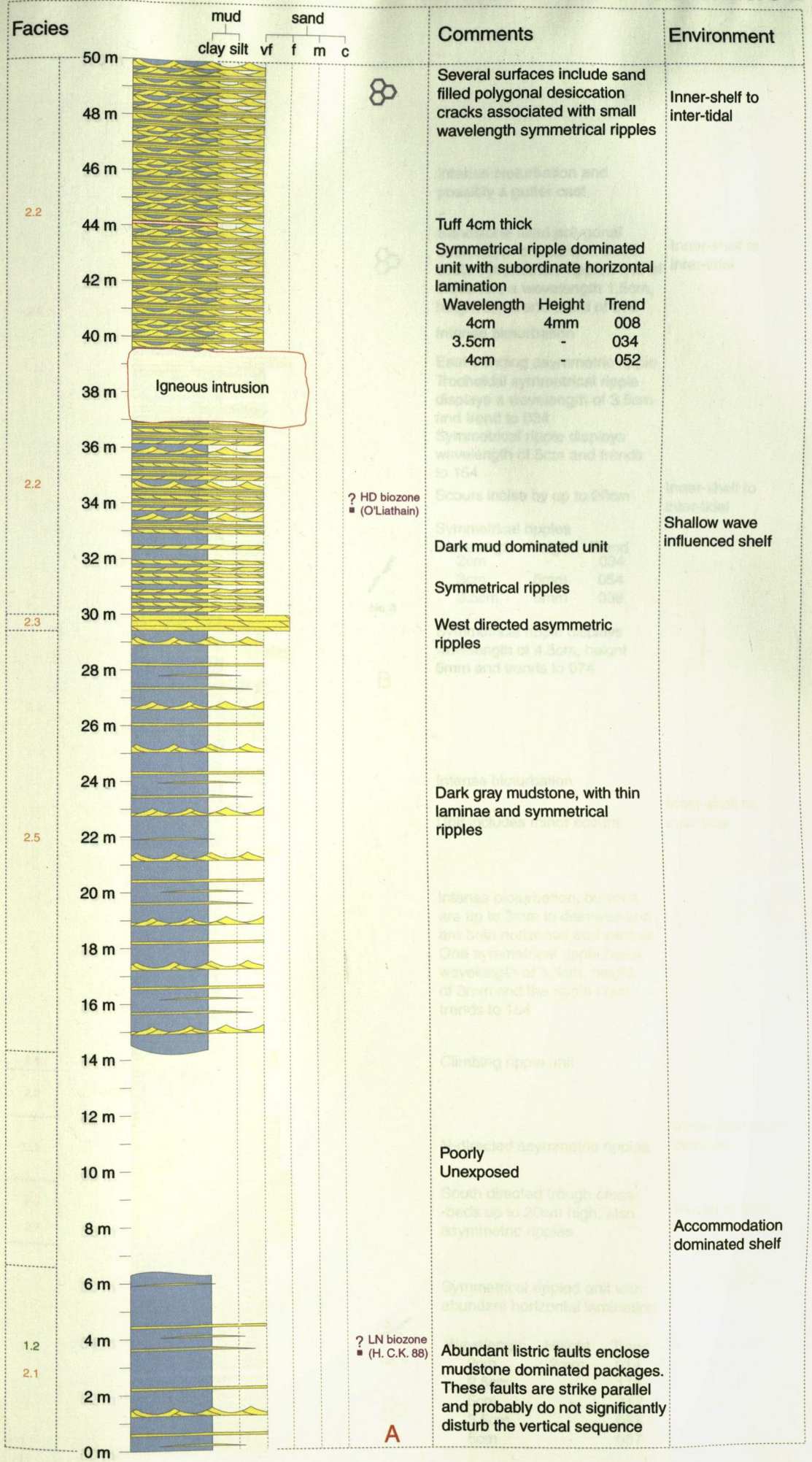


Plate 4.11 - Climbing ripples exposed at the base of an erosive based sandstone unit (2.5m thick). These are oriented to the SW and may reflect tide and / or storm generated currents (Reenagough Point 328m).

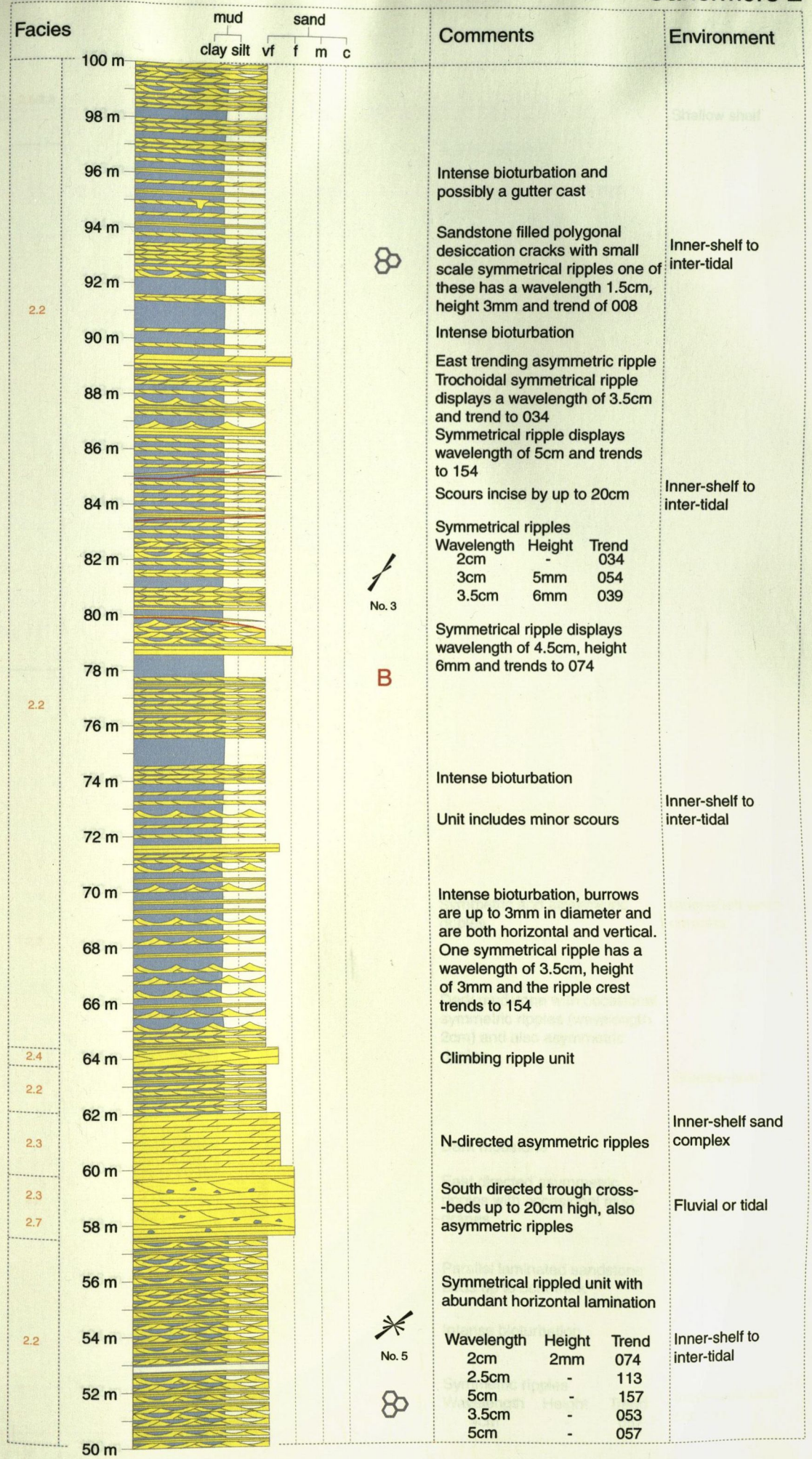


Plate 4.12 - Tide or storm generated incisional feature probably formed within a sandstone rich nearshore setting (Reenagough Point 542m).

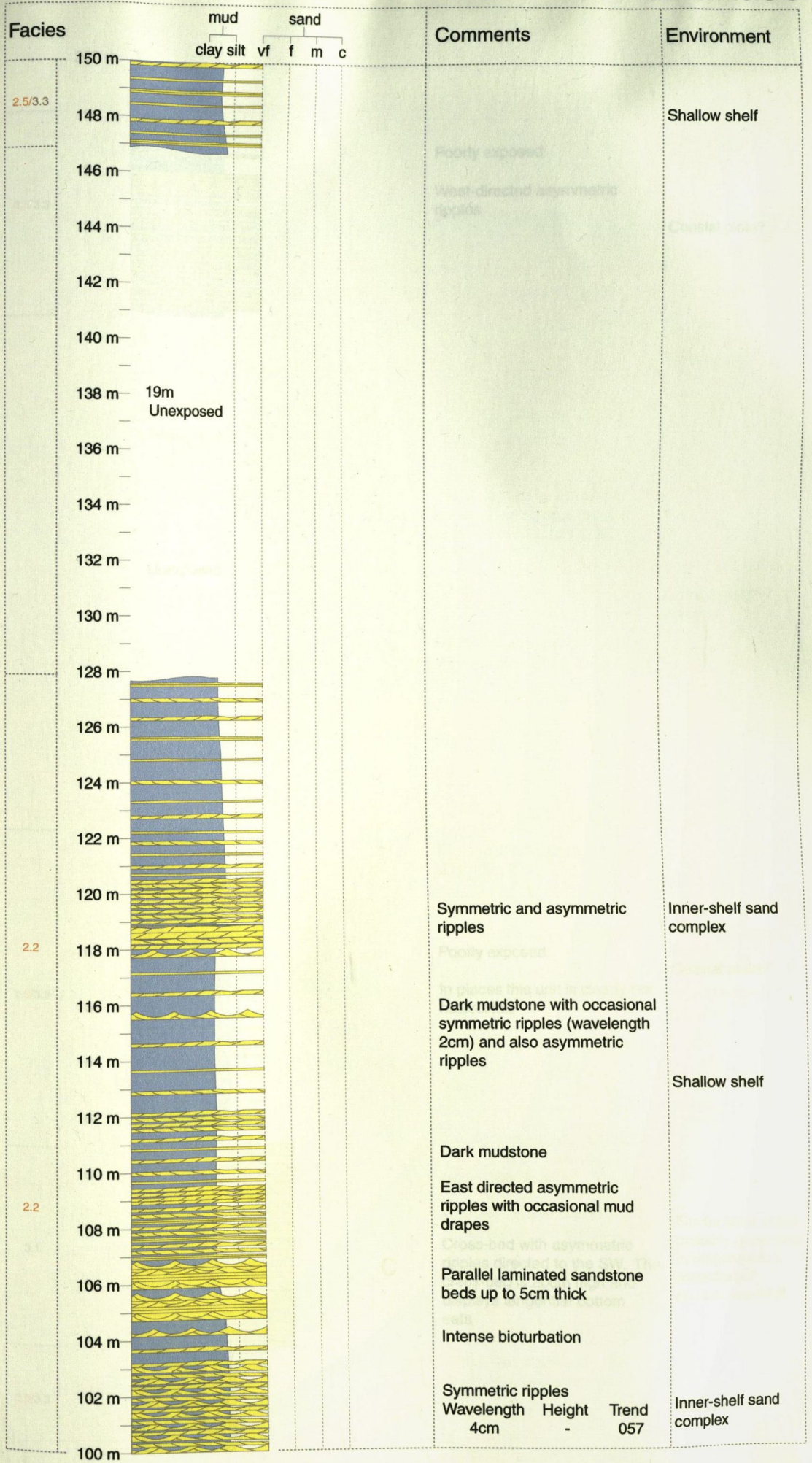
Cahermore 1


Facies
mud
clay silt
sand
vf f m c
50 m
48 m
46 m
44 m
42 m
40 m
38 m
36 m
34 m
32 m
30 m
28 m
26 m
24 m
22 m
20 m
18 m
16 m
14 m
12 m
10 m
8 m
6 m
4 m
2 m
0 m
2.2
2.2
2.3
2.5
1.2
2.1
Igneous intrusion
? HD biozone
(O'Liathain)
? LN biozone
(H. C.K. 88)
A
Comments
Several surfaces include sand filled polygonal desiccation cracks associated with small wavelength symmetrical ripples
Tuff 4cm thick
Symmetrical ripple dominated unit with subordinate horizontal lamination
Wavelength Height Trend
4cm 4mm 008
3.5cm - 034
4cm - 052
Dark mud dominated unit
Symmetrical ripples
West directed asymmetric ripples
Dark gray mudstone, with thin laminae and symmetrical ripples
Poorly Unexposed
Abundant listric faults enclose mudstone dominated packages. These faults are strike parallel and probably do not significantly disturb the vertical sequence
Environment
Inner-shelf to inter-tidal
Shallow wave influenced shelf
Accommodation dominated shelf

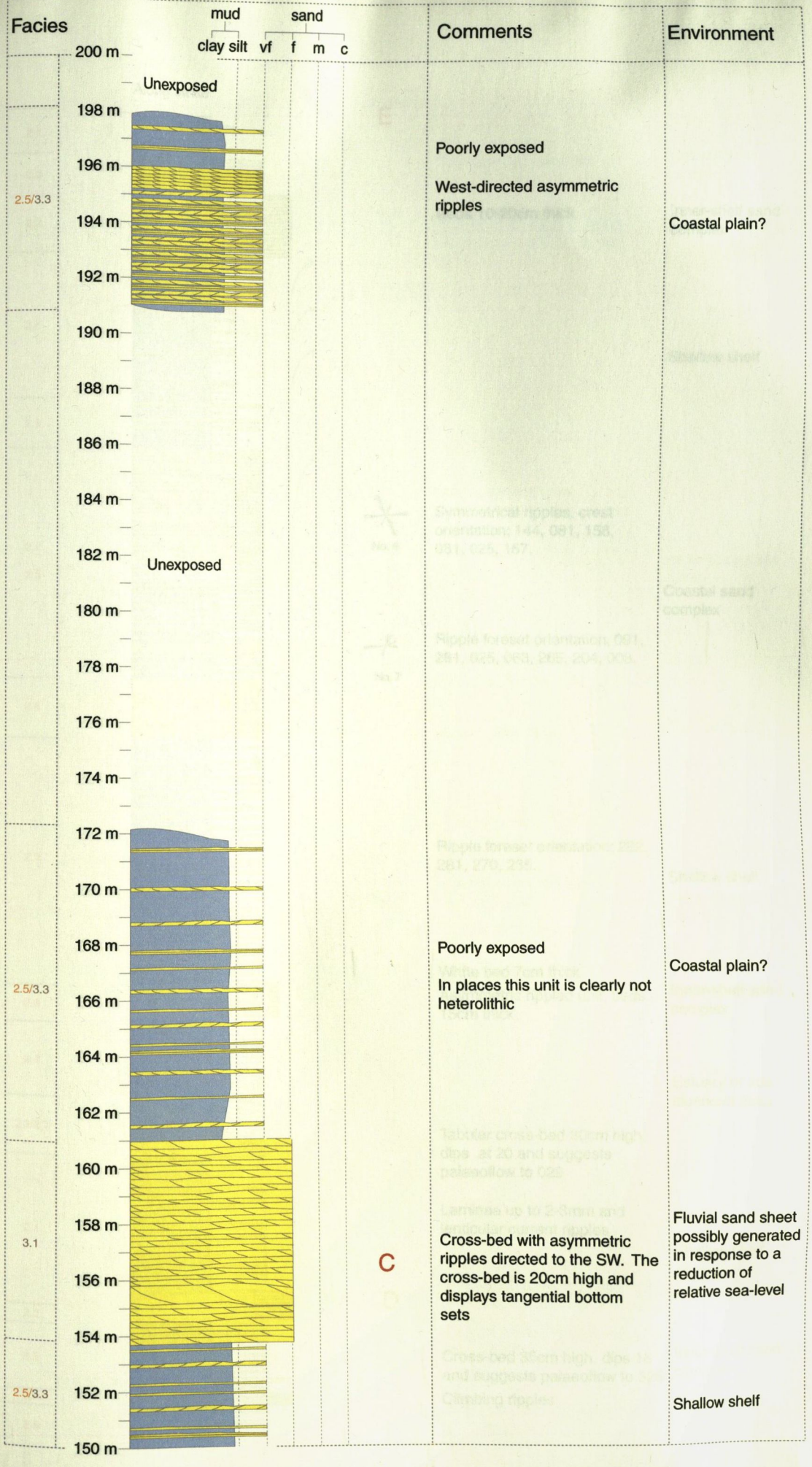
Cahermore 2


Facies
mud
clay silt
sand
vf
f
m
c
100 m
98 m
96 m
94 m
92 m
90 m
88 m
86 m
84 m
82 m
80 m
78 m
76 m
74 m
72 m
70 m
68 m
66 m
64 m
62 m
60 m
58 m
56 m
54 m
52 m
50 m
2.2
2.2
2.4
2.2
2.3
2.3
2.7
2.2
No. 3
B
No. 5
Comments
Intense bioturbation and possibly a gutter cast
Sandstone filled polygonal desiccation cracks with small scale symmetrical ripples one of these has a wavelength 1.5cm, height 3mm and trend of 008
Intense bioturbation
East trending asymmetric ripple
Trochoidal symmetrical ripple displays a wavelength of 3.5cm and trend to 034
Symmetrical ripple displays wavelength of 5cm and trends to 154
Scours incise by up to 20cm
Symmetrical ripples
Wavelength Height Trend
2cm - 034
3cm 5mm 054
3.5cm 6mm 039
Symmetrical ripple displays wavelength of 4.5cm, height 6mm and trends to 074
Intense bioturbation
Unit includes minor scours
Intense bioturbation, burrows are up to 3mm in diameter and are both horizontal and vertical. One symmetrical ripple has a wavelength of 3.5cm, height of 3mm and the ripple crest trends to 154
Climbing ripple unit
N-directed asymmetric ripples
South directed trough cross--beds up to 20cm high, also asymmetric ripples
Symmetrical rippled unit with abundant horizontal lamination
Wavelength Height Trend
2cm 2mm 074
2.5cm - 113
5cm - 157
3.5cm - 053
5cm - 057
Environment
Inner-shelf to inter-tidal
Inner-shelf to inter-tidal
Inner-shelf to inter-tidal
Inner-shelf sand complex
Fluvial or tidal
Inner-shelf to inter-tidal

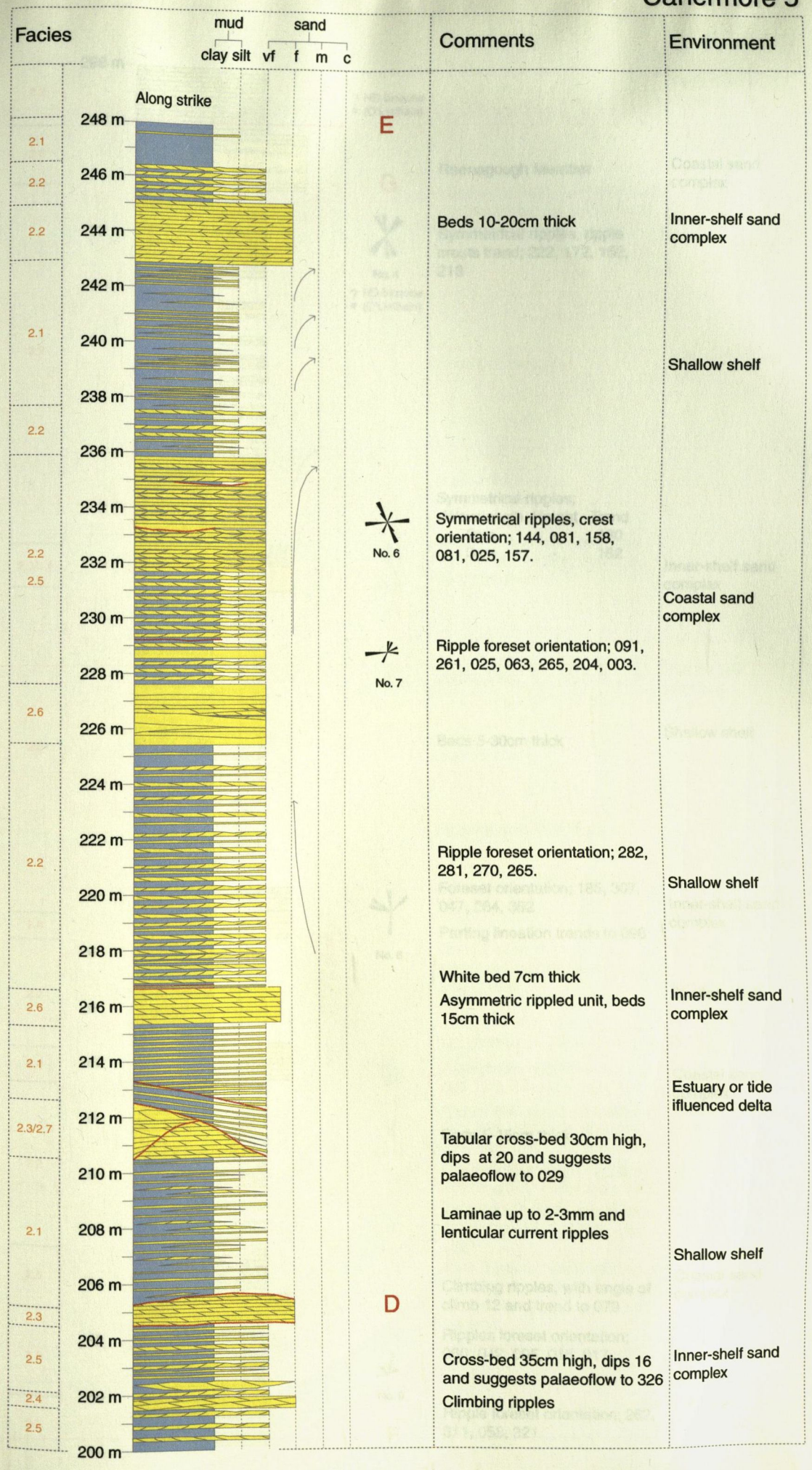
Cahermore 3


Facies
mud
clay silt
sand
vf f m c
Comments
Environment
150 m
148 m
146 m
144 m
142 m
140 m
138 m
136 m
134 m
132 m
130 m
128 m
126 m
124 m
122 m
120 m
118 m
116 m
114 m
112 m
110 m
108 m
106 m
104 m
102 m
100 m
2.5/3.3
2.2
2.2
19m
Unexposed
Shallow shelf
Symmetric and asymmetric ripples
Inner-shelf sand complex
Dark mudstone with occasional symmetric ripples (wavelength 2cm) and also asymmetric ripples
Shallow shelf
Dark mudstone
East directed asymmetric ripples with occasional mud drapes
Parallel laminated sandstone beds up to 5cm thick
Intense bioturbation
Symmetric ripples
Wavelength Height Trend
4cm - 057
Inner-shelf sand complex

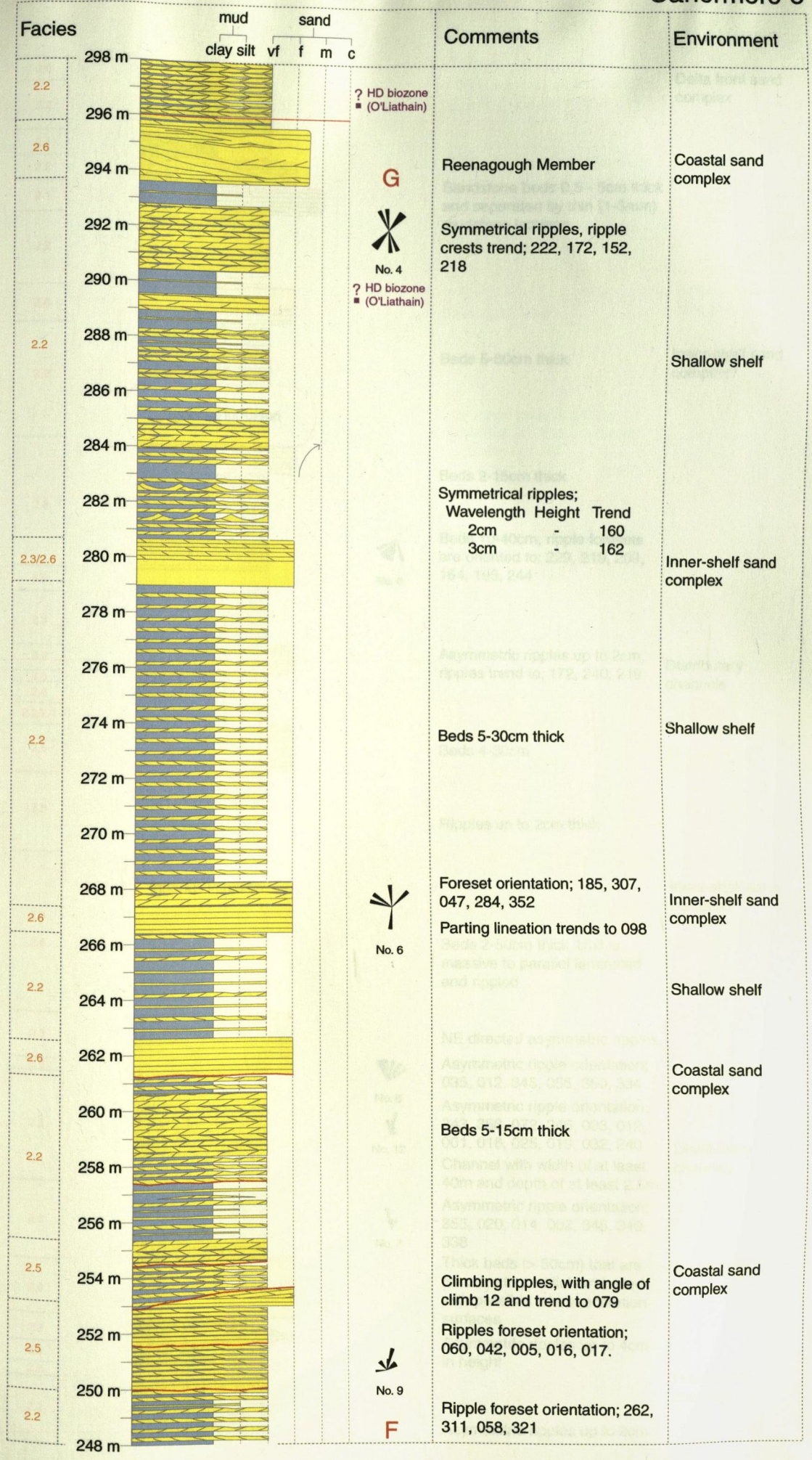
Cahermore 4


Facies
mud
clay silt
sand
vf f m c
Comments
Environment
200 m
Unexposed
198 m
196 m
194 m
192 m
190 m
188 m
186 m
184 m
182 m
Unexposed
180 m
178 m
176 m
174 m
172 m
170 m
168 m
166 m
164 m
162 m
160 m
158 m
156 m
154 m
152 m
150 m
2.5/3.3
2.5/3.3
3.1
2.5/3.3
Poorly exposed
West-directed asymmetric ripples
Coastal plain?
Poorly exposed
In places this unit is clearly not heterolithic
Coastal plain?
C
Cross-bed with asymmetric ripples directed to the SW. The cross-bed is 20cm high and displays tangential bottom sets
Fluvial sand sheet possibly generated in response to a reduction of relative sea-level
Shallow shelf

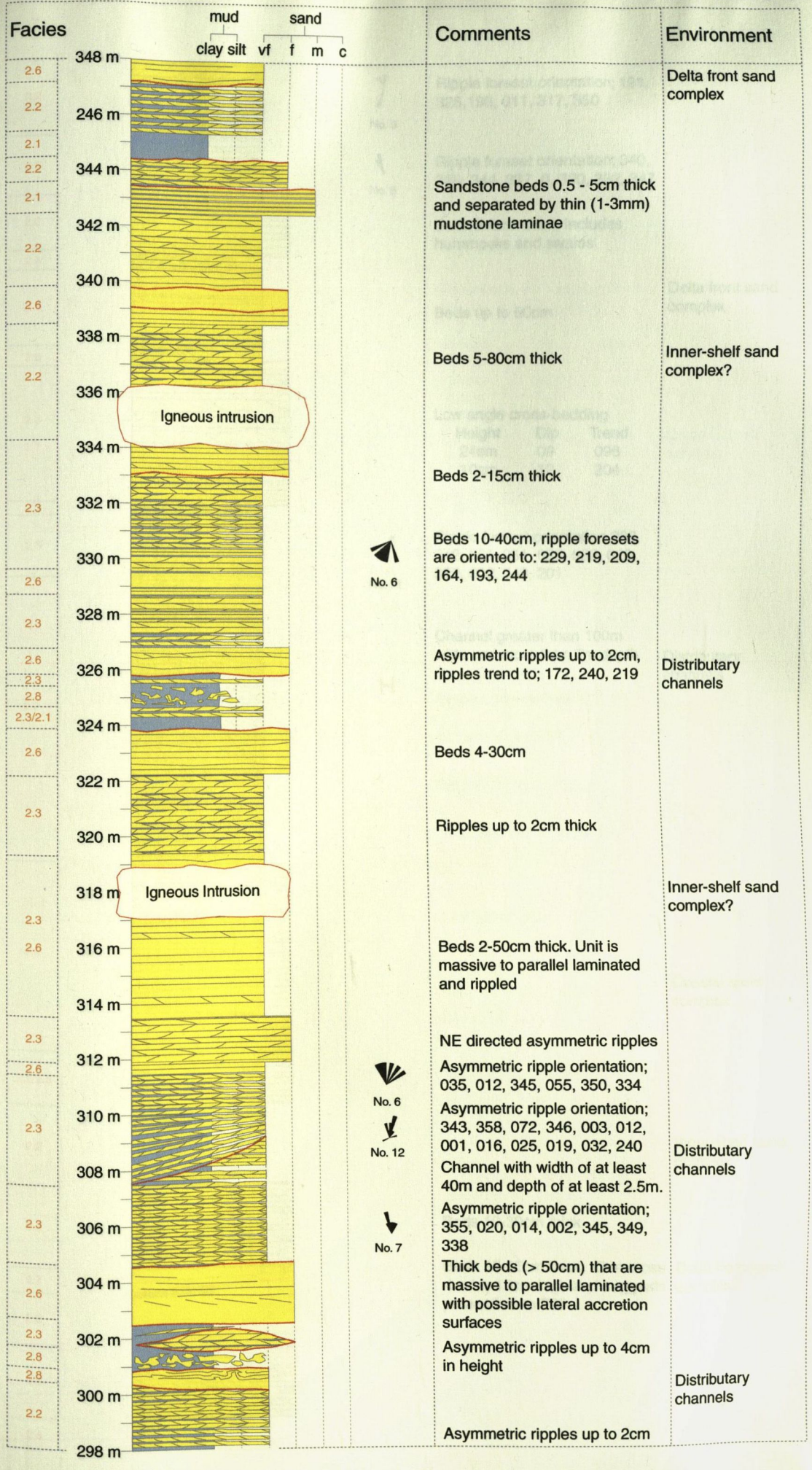
Cahermore 5


Facies
mud
clay silt
sand
vf f m c
Comments
Environment
Along strike
248 m
246 m
244 m
242 m
240 m
238 m
236 m
234 m
232 m
230 m
228 m
226 m
224 m
222 m
220 m
218 m
216 m
214 m
212 m
210 m
208 m
206 m
204 m
202 m
200 m
2.1
2.2
2.2
2.1
2.2
2.2
2.5
2.6
2.2
2.6
2.1
2.3/2.7
2.1
2.3
2.5
2.4
2.5
E
D
No. 6
No. 7
Beds 10-20cm thick
Inner-shelf sand complex
Shallow shelf
Symmetrical ripples, crest orientation; 144, 081, 158, 081, 025, 157.
Coastal sand complex
Ripple foreset orientation; 091, 261, 025, 063, 265, 204, 003.
Ripple foreset orientation; 282, 281, 270, 265.
Shallow shelf
White bed 7cm thick
Asymmetric rippled unit, beds 15cm thick
Inner-shelf sand complex
Estuary or tide ifluenced delta
Tabular cross-bed 30cm high, dips at 20 and suggests palaeoflow to 029
Laminae up to 2-3mm and lenticular current ripples
Shallow shelf
Cross-bed 35cm high, dips 16 and suggests palaeoflow to 326
Climbing ripples
Inner-shelf sand complex

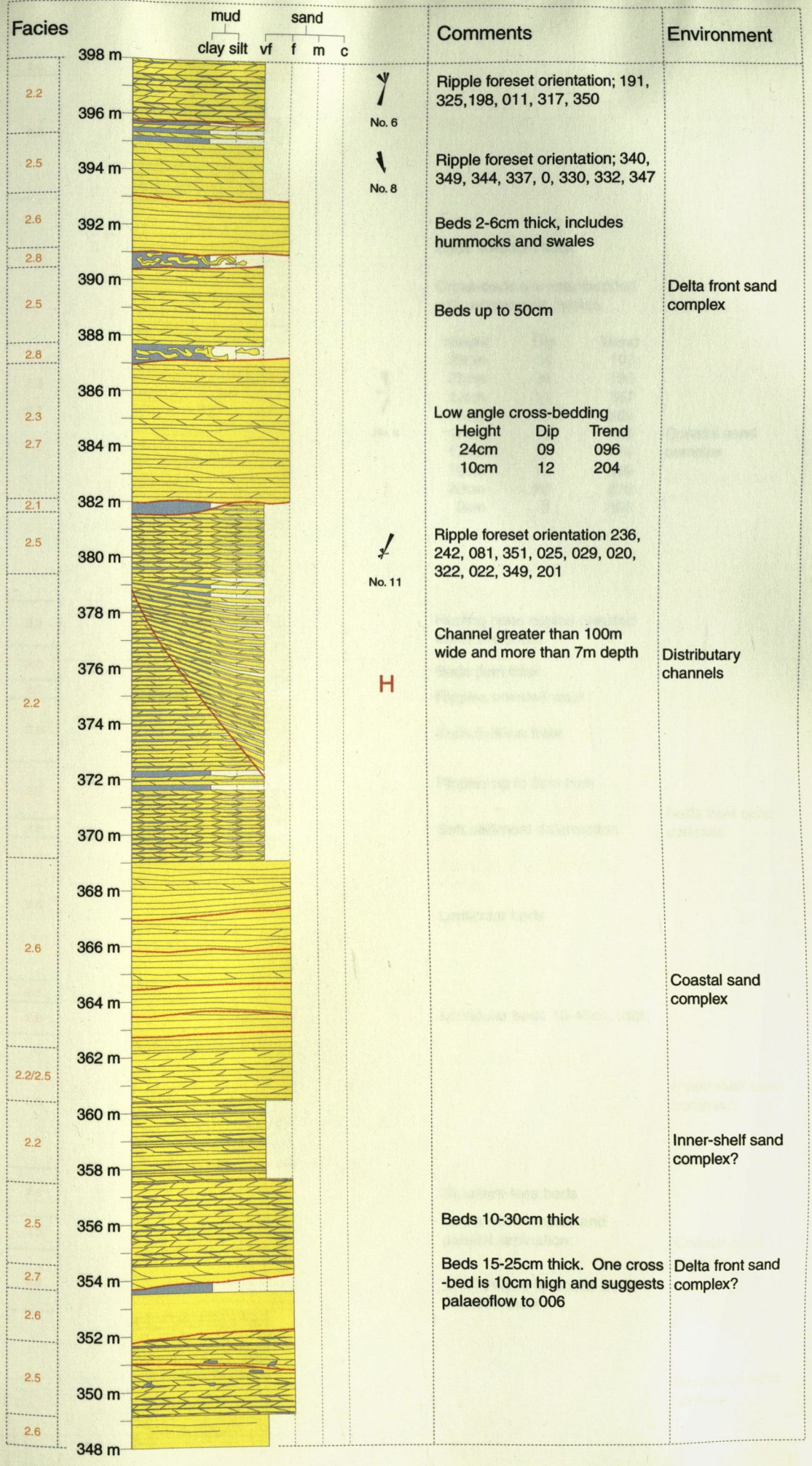
Cahermore 6


Facies
mud
clay silt
sand
vf
f
m
c
Comments
Environment
298 m
296 m
294 m
292 m
290 m
288 m
286 m
284 m
282 m
280 m
278 m
276 m
274 m
272 m
270 m
268 m
266 m
264 m
262 m
260 m
258 m
256 m
254 m
252 m
250 m
248 m
2.2
2.6
2.2
2.3/2.6
2.2
2.6
2.2
2.6
2.2
2.5
2.5
2.2
? HD biozone
(O'Liathain)
G
No. 4
? HD biozone
(O'Liathain)
No. 6
No. 9
F
Reenagough Member
Symmetrical ripples, ripple crests trend; 222, 172, 152, 218
Symmetrical ripples;
Wavelength Height Trend
2cm - 160
3cm - 162
Beds 5-30cm thick
Foreset orientation; 185, 307, 047, 284, 352
Parting lineation trends to 098
Beds 5-15cm thick
Climbing ripples, with angle of climb 12 and trend to 079
Ripples foreset orientation; 060, 042, 005, 016, 017.
Ripple foreset orientation; 262, 311, 058, 321
Coastal sand complex
Shallow shelf
Inner-shelf sand complex
Shallow shelf
Inner-shelf sand complex
Shallow shelf
Coastal sand complex
Coastal sand complex

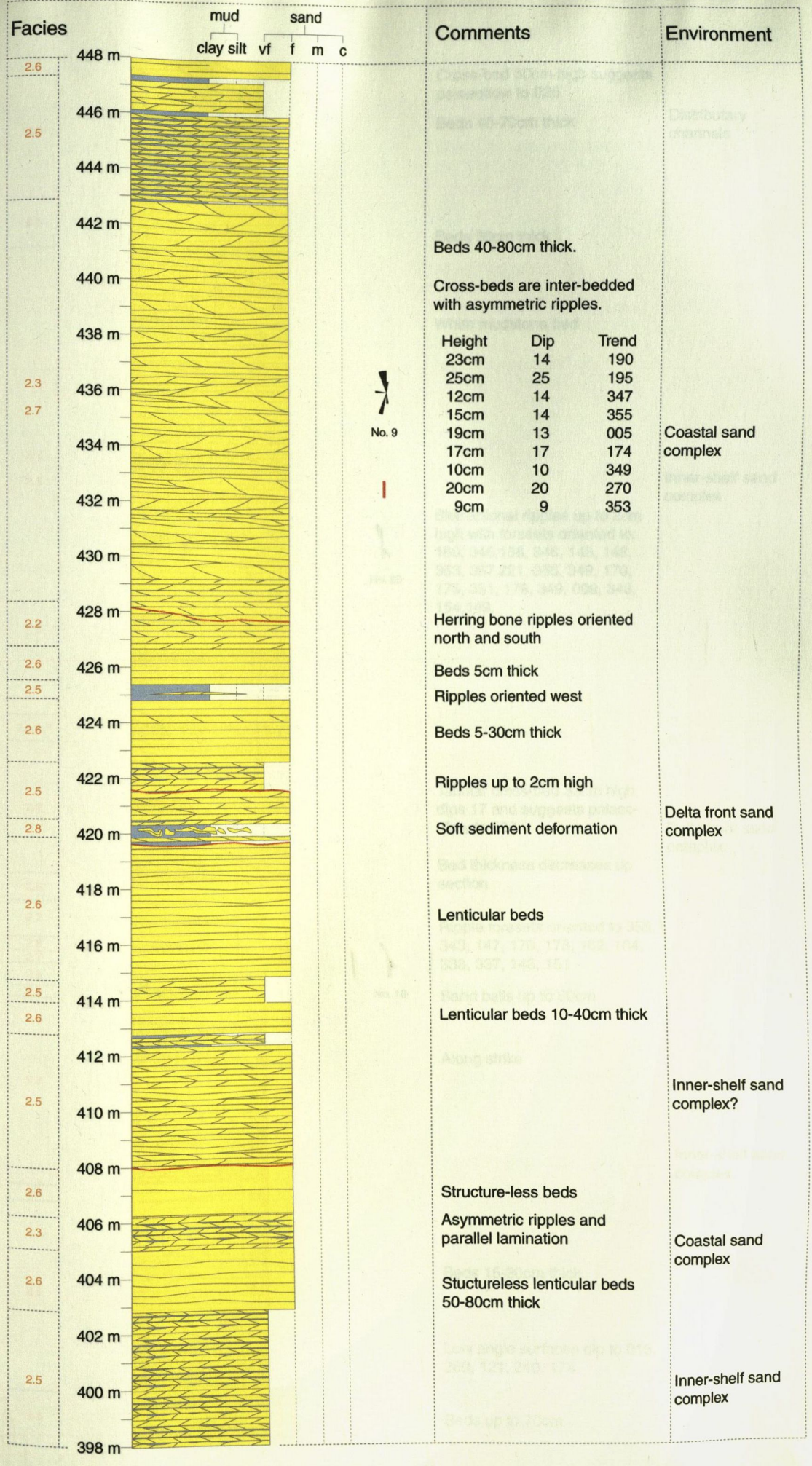
Cahermore 7


Facies
mud
clay silt
sand
vf f m c
Comments
Environment
348 m
246 m
344 m
342 m
340 m
338 m
336 m
334 m
332 m
330 m
328 m
326 m
324 m
322 m
320 m
318 m
316 m
314 m
312 m
310 m
308 m
306 m
304 m
302 m
300 m
298 m
2.6
2.2
2.1
2.2
2.1
2.2
2.6
2.2
2.3
2.6
2.3
2.6
2.3
2.8
2.3/2.1
2.6
2.3
2.3
2.6
2.3
2.6
2.3
2.3
2.6
2.3
2.8
2.8
2.2
Igneous intrusion
Igneous Intrusion
No. 6
No. 6
No. 12
No. 7
Delta front sand complex
Sandstone beds 0.5 - 5cm thick and separated by thin (1-3mm) mudstone laminae
Beds 5-80cm thick
Inner-shelf sand complex?
Beds 2-15cm thick
Beds 10-40cm, ripple foresets are oriented to: 229, 219, 209, 164, 193, 244
Asymmetric ripples up to 2cm, ripples trend to; 172, 240, 219
Distributary channels
Beds 4-30cm
Ripples up to 2cm thick
Inner-shelf sand complex?
Beds 2-50cm thick. Unit is massive to parallel laminated and rippled
NE directed asymmetric ripples
Asymmetric ripple orientation; 035, 012, 345, 055, 350, 334
Asymmetric ripple orientation; 343, 358, 072, 346, 003, 012, 001, 016, 025, 019, 032, 240
Channel with width of at least 40m and depth of at least 2.5m.
Asymmetric ripple orientation; 355, 020, 014, 002, 345, 349, 338
Thick beds (> 50cm) that are massive to parallel laminated with possible lateral accretion surfaces
Distributary channels
Asymmetric ripples up to 4cm in height
Distributary channels
Asymmetric ripples up to 2cm

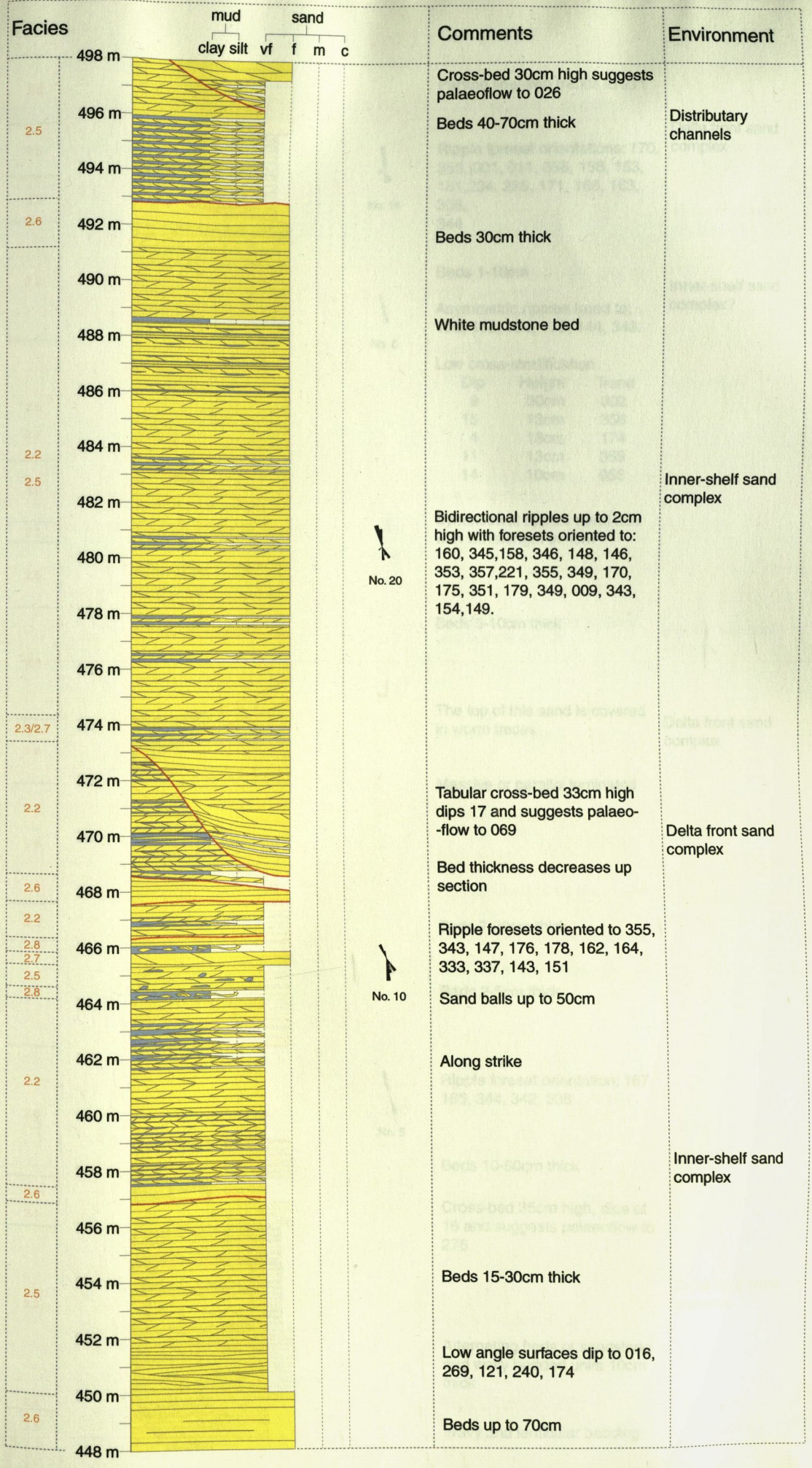
Cahermore 8


Facies
mud
clay silt
sand
vf
f
m
c
398 m
396 m
394 m
392 m
390 m
388 m
386 m
384 m
382 m
380 m
378 m
376 m
374 m
372 m
370 m
368 m
366 m
364 m
362 m
360 m
358 m
356 m
354 m
352 m
350 m
348 m
2.2
2.5
2.6
2.8
2.5
2.8
2.3
2.7
2.1
2.5
2.2
2.6
2.2/2.5
2.2
2.5
2.7
2.6
2.5
2.6
No. 6
No. 8
No. 11
H
Comments
Ripple foreset orientation; 191, 325,198, 011, 317, 350
Ripple foreset orientation; 340, 349, 344, 337, 0, 330, 332, 347
Beds 2-6cm thick, includes hummocks and swales
Beds up to 50cm
Low angle cross-bedding
Height Dip Trend
24cm 09 096
10cm 12 204
Ripple foreset orientation 236, 242, 081, 351, 025, 029, 020, 322, 022, 349, 201
Channel greater than 100m wide and more than 7m depth
Beds 10-30cm thick
Beds 15-25cm thick. One cross -bed is 10cm high and suggests palaeoflow to 006
Environment
Delta front sand complex
Distributary channels
Coastal sand complex
Inner-shelf sand complex?
Delta front sand complex?

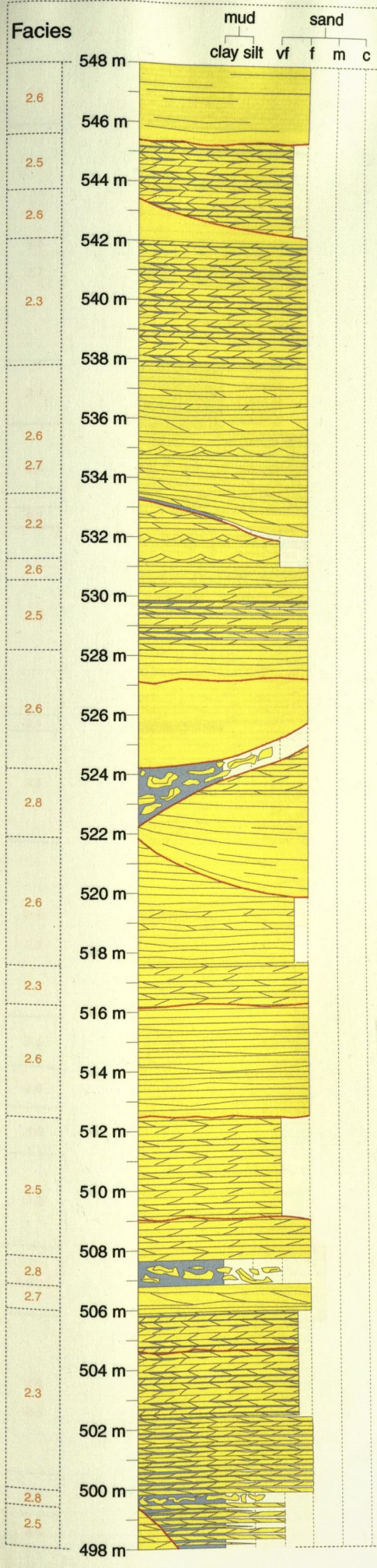
Cahermore 9


Facies
mud
clay silt
sand
vf f m c
448 m
446 m
444 m
442 m
440 m
438 m
436 m
434 m
432 m
430 m
428 m
426 m
424 m
422 m
420 m
418 m
416 m
414 m
412 m
410 m
408 m
406 m
404 m
402 m
400 m
398 m
2.6
2.5
2.3
2.7
2.2
2.6
2.5
2.6
2.5
2.8
2.6
2.5
2.6
2.5
2.6
2.3
2.6
2.5
No. 9
Comments
Beds 40-80cm thick.
Cross-beds are inter-bedded with asymmetric ripples.
Height Dip Trend
23cm 14 190
25cm 25 195
12cm 14 347
15cm 14 355
19cm 13 005
17cm 17 174
10cm 10 349
20cm 20 270
9cm 9 353
Herring bone ripples oriented north and south
Beds 5cm thick
Ripples oriented west
Beds 5-30cm thick
Ripples up to 2cm high
Soft sediment deformation
Lenticular beds
Lenticular beds 10-40cm thick
Structure-less beds
Asymmetric ripples and parallel lamination
Stuctureless lenticular beds 50-80cm thick
Environment
Coastal sand complex
Delta front sand complex
Inner-shelf sand complex?
Coastal sand complex
Inner-shelf sand complex

Cahermore 10



Cahermore 11



No. 15

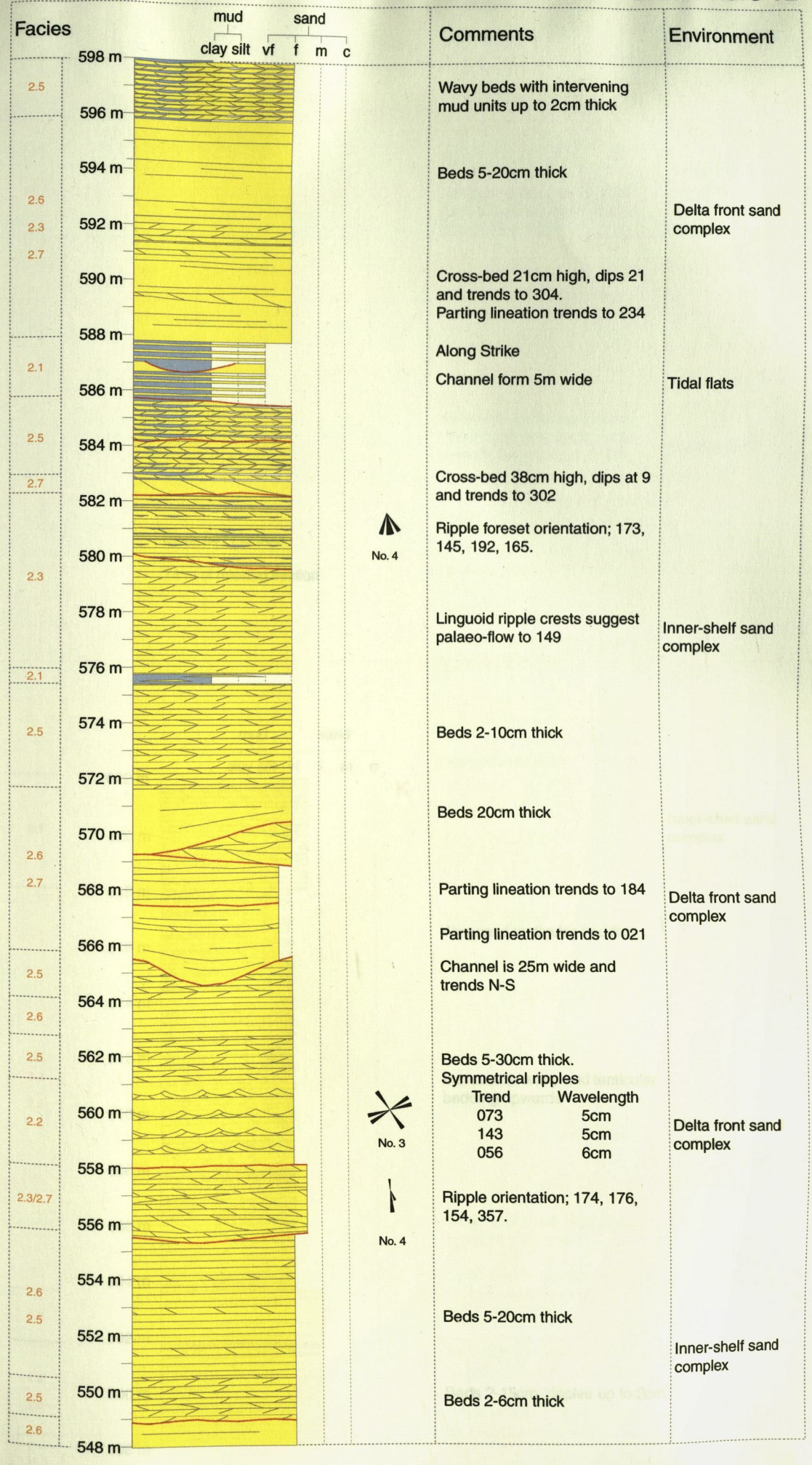
No. 6

J

No. 5

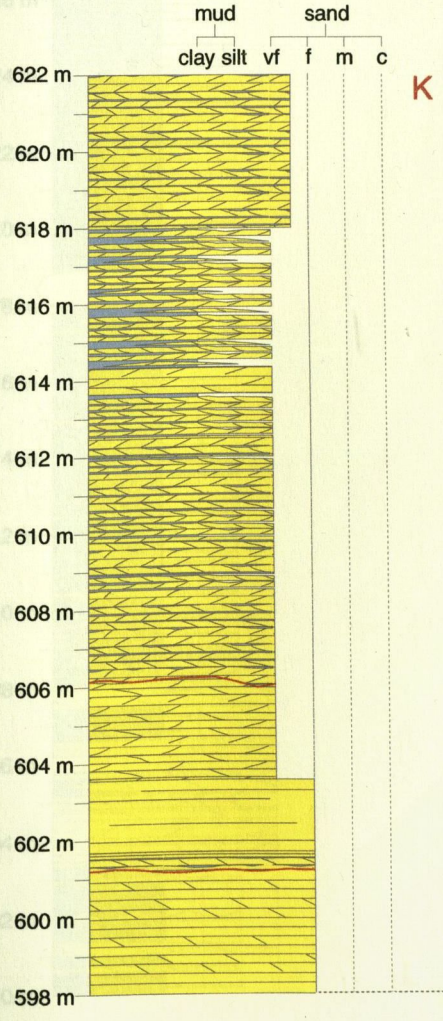
Comments	Environment
Parting lineation trends to 211	
Ripple foreset orientations; 170, 355, 001, 011, 358, 158, 153, 181,234, 226, 171, 168, 163, 358, 344	Delta front sand complex
Beds 1-10cm	
Asymmetric ripples trend to; 165, 166, 168, 176, 144, 343.	Inner-shelf sand complex?
Low cross-stratification Dip 9, Height 30cm, Trend 002 Dip 15, Height 13cm, Trend 356 Dip 4, Height 18cm, Trend 174 Dip 11, Height 13cm, Trend 359 Dip 14, Height 10cm, Trend 056	
Symmetrical ripples trend 233 with wavelength of 4cm	
Beds 5-10cm thick	
The top of this sand is covered in worm traces	Delta front sand complex
Massive or parallel laminated	
Beds 7-20cm thick	
Beds 2-5cm thick	
Ripple foreset orientation; 167, 165, 344, 342, 336	
Beds 10-50cm thick	
Cross-bed 35cm high, dips at 16 and suggests palaeoflow to 276	
Alternating beds of sandstone and wavy bedded units 10cm thick	Delta front sand complex
Wavy and lenticular bedding	

Cahermore 12

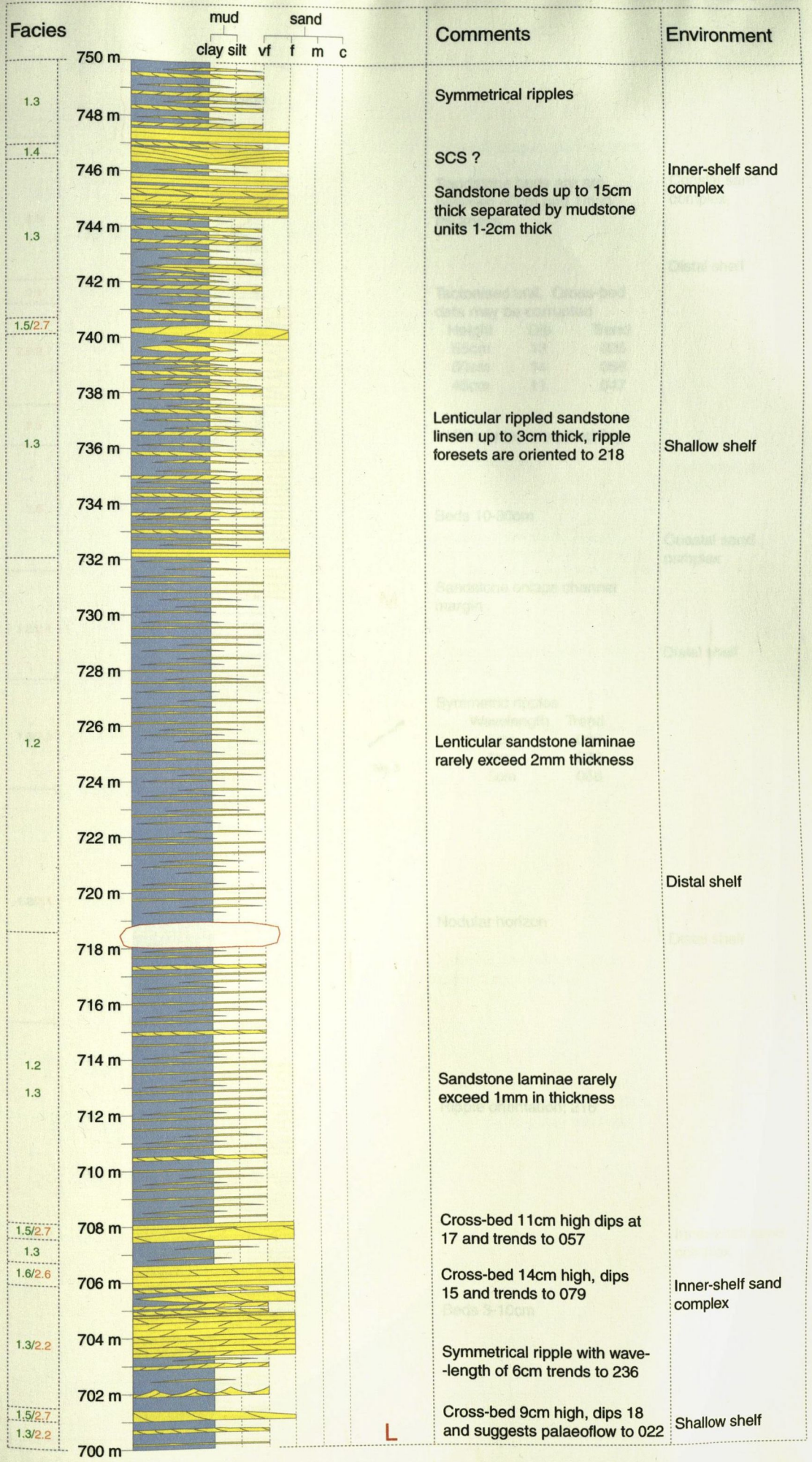


Cahermore 13

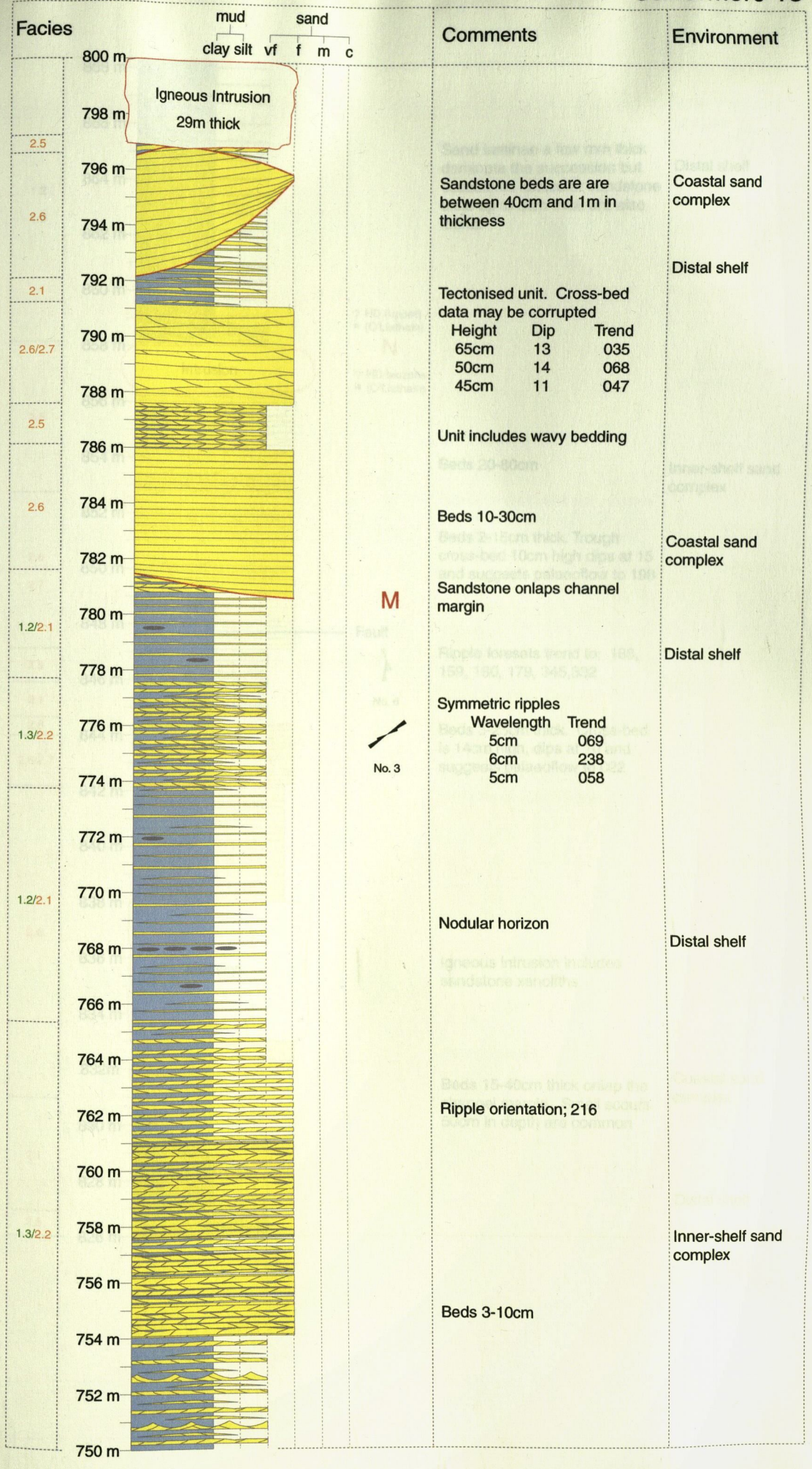
Facies	Comments	Environment
	Black Ball Harbour 78 m of missing section	
2.5		Inner-shelf sand complex
	Wavy and lenticular bedding	
2.2 2.5	Increase in wavy and lenticular bedding upwards	Inner-shelf sand complex
2.6		
2.3 2.6	Beds 2-15cm, ripples up to 2cm	



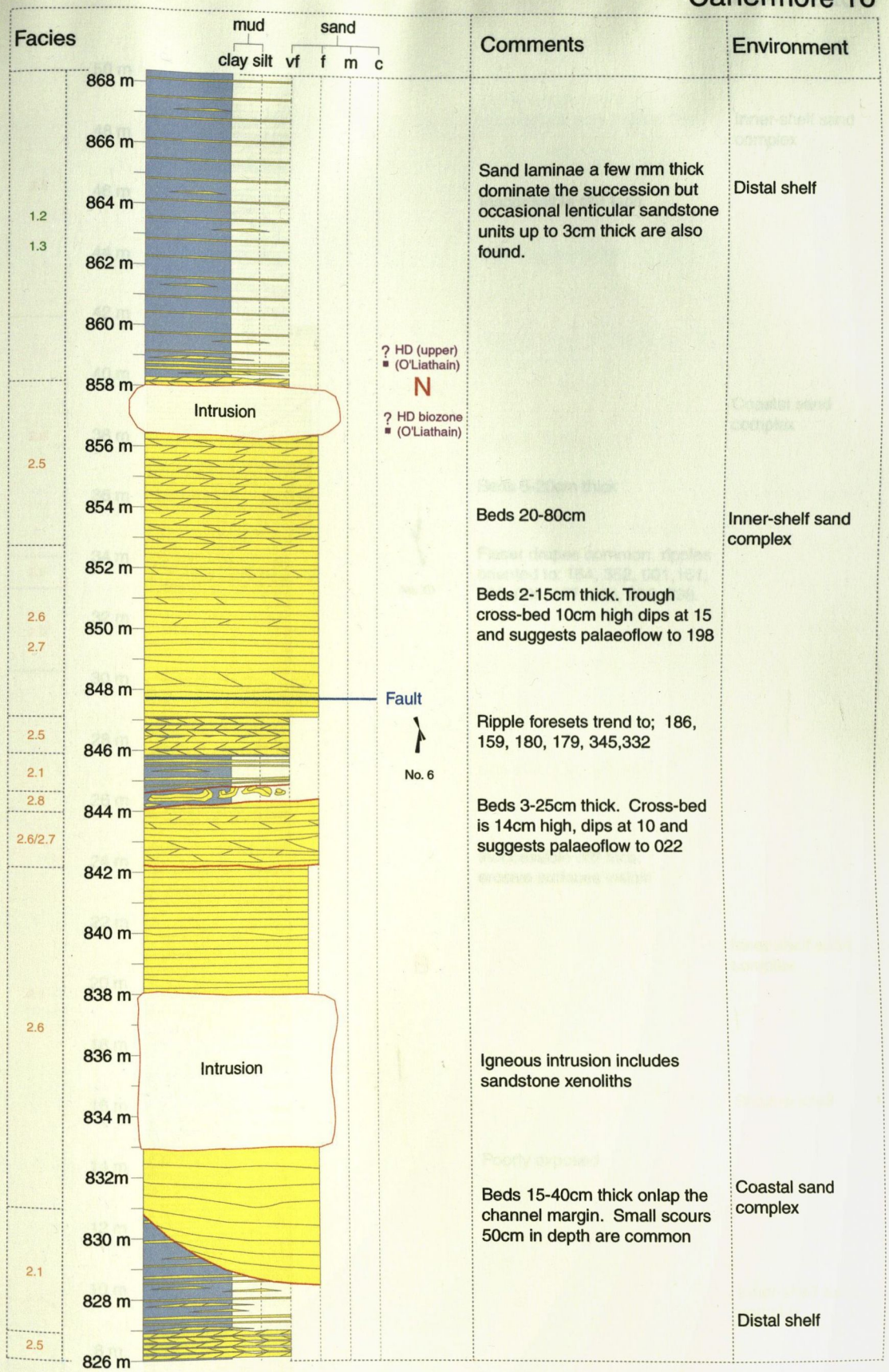
Cahermore 14



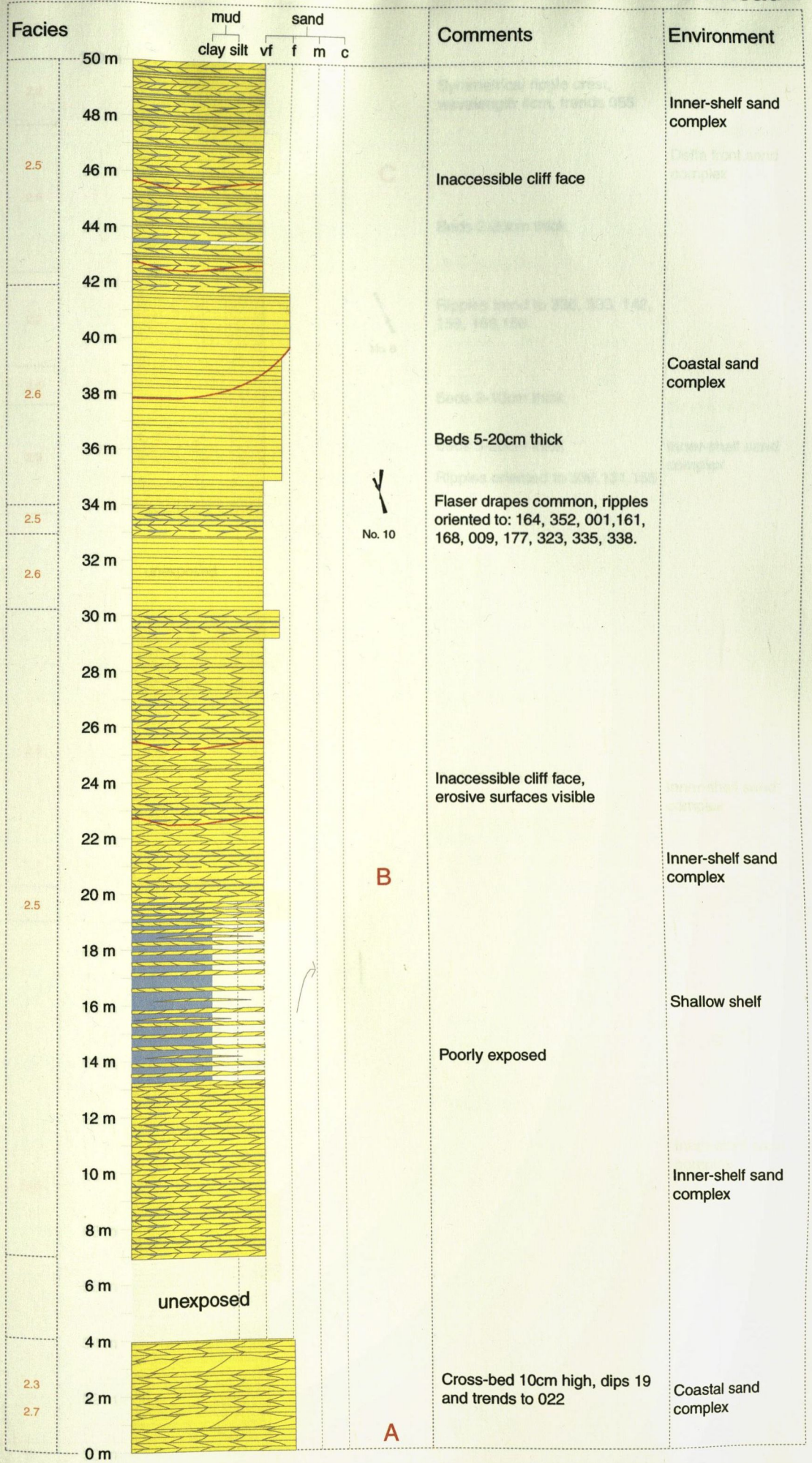
Cahermore 15



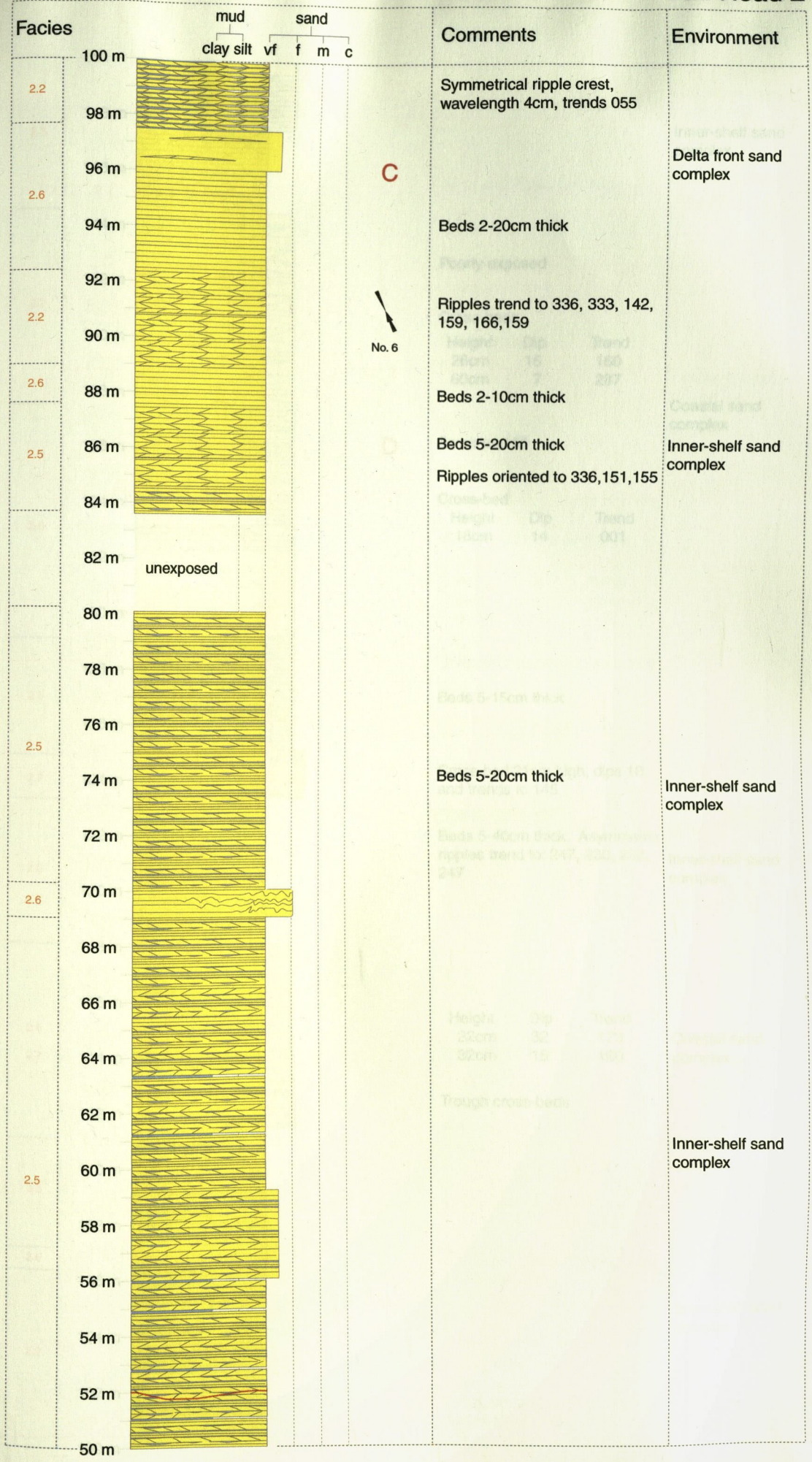
Cahermore 16



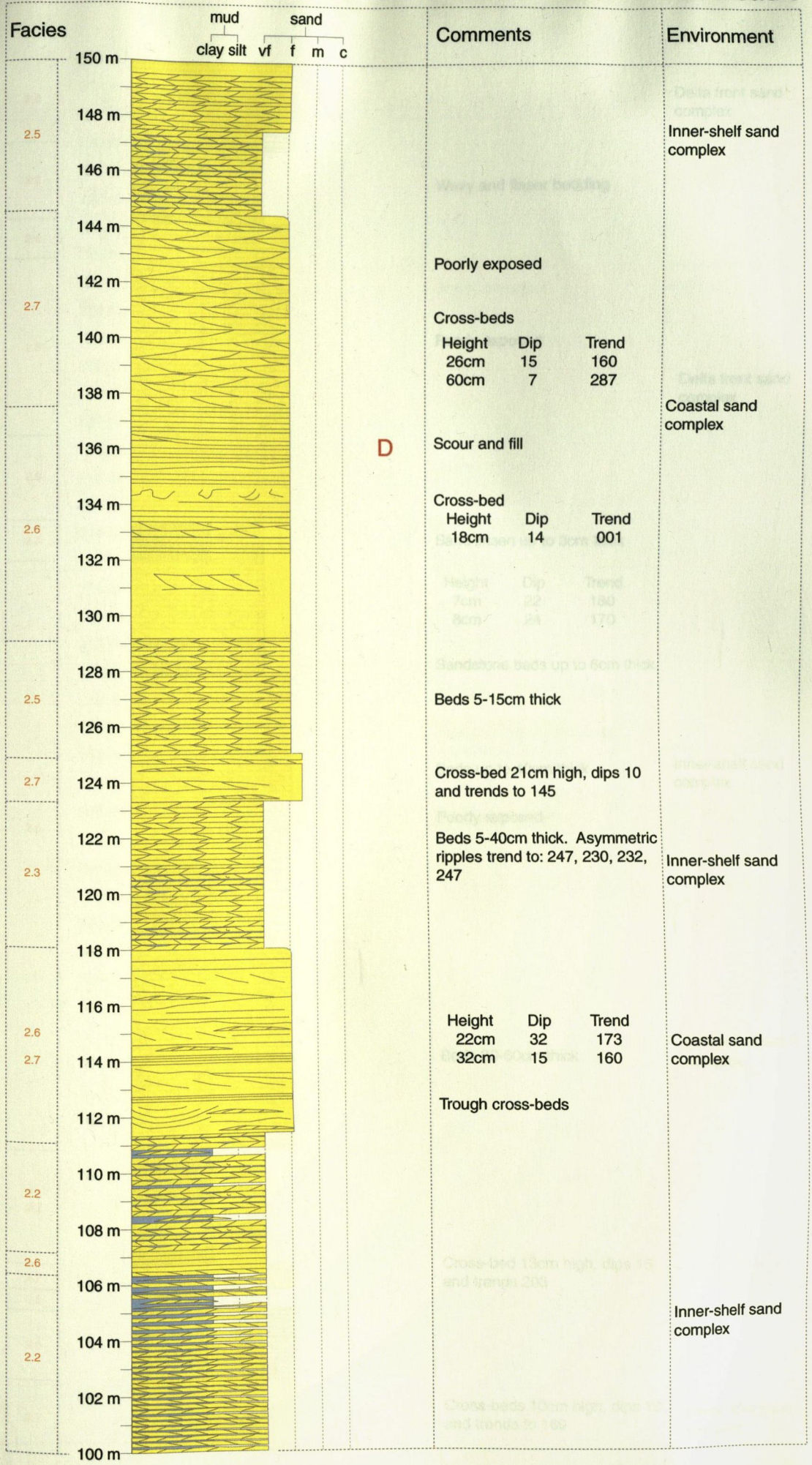
Fair Head 1


Facies
mud
clay silt
sand
vf f m c
Comments
Environment
50 m
48 m
46 m
44 m
42 m
40 m
38 m
36 m
34 m
32 m
30 m
28 m
26 m
24 m
22 m
20 m
18 m
16 m
14 m
12 m
10 m
8 m
6 m
4 m
2 m
0 m
2.5
2.6
2.5
2.6
2.5
2.3
2.7
unexposed
No. 10
C
B
A
Inaccessible cliff face
Beds 5-20cm thick
Flaser drapes common, ripples oriented to: 164, 352, 001,161, 168, 009, 177, 323, 335, 338.
Inaccessible cliff face, erosive surfaces visible
Poorly exposed
Cross-bed 10cm high, dips 19 and trends to 022
Inner-shelf sand complex
Coastal sand complex
Inner-shelf sand complex
Shallow shelf
Inner-shelf sand complex
Coastal sand complex

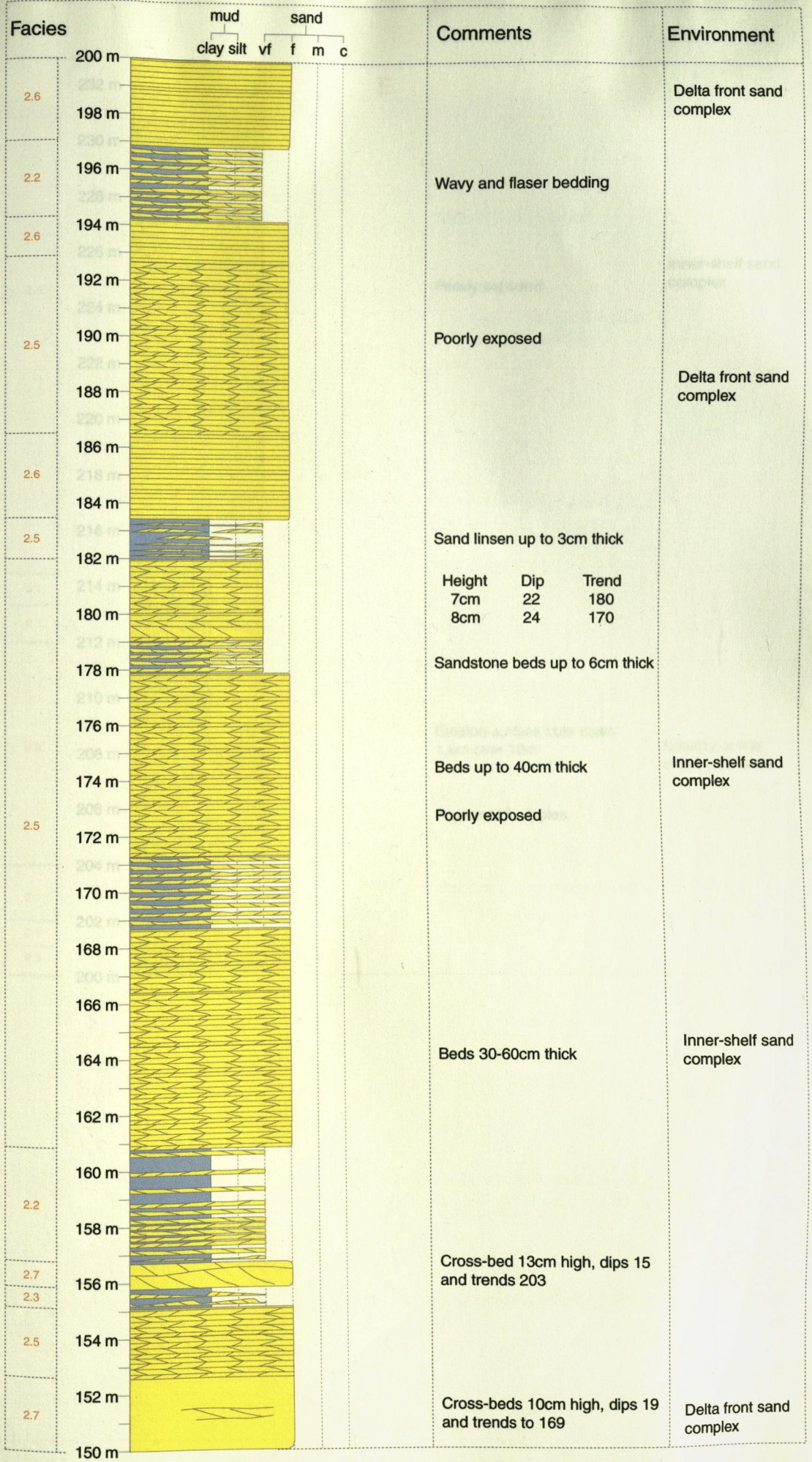
Fair Head 2


Facies
mud
clay silt
sand
vf f m c
Comments
Environment
100 m
98 m
96 m
94 m
92 m
90 m
88 m
86 m
84 m
82 m
80 m
78 m
76 m
74 m
72 m
70 m
68 m
66 m
64 m
62 m
60 m
58 m
56 m
54 m
52 m
50 m
2.2
2.6
2.2
2.6
2.5
2.5
2.6
2.5
C
No. 6
unexposed
Symmetrical ripple crest, wavelength 4cm, trends 055
Beds 2-20cm thick
Ripples trend to 336, 333, 142, 159, 166,159
Beds 2-10cm thick
Beds 5-20cm thick
Ripples oriented to 336,151,155
Beds 5-20cm thick
Delta front sand complex
Inner-shelf sand complex
Inner-shelf sand complex
Inner-shelf sand complex

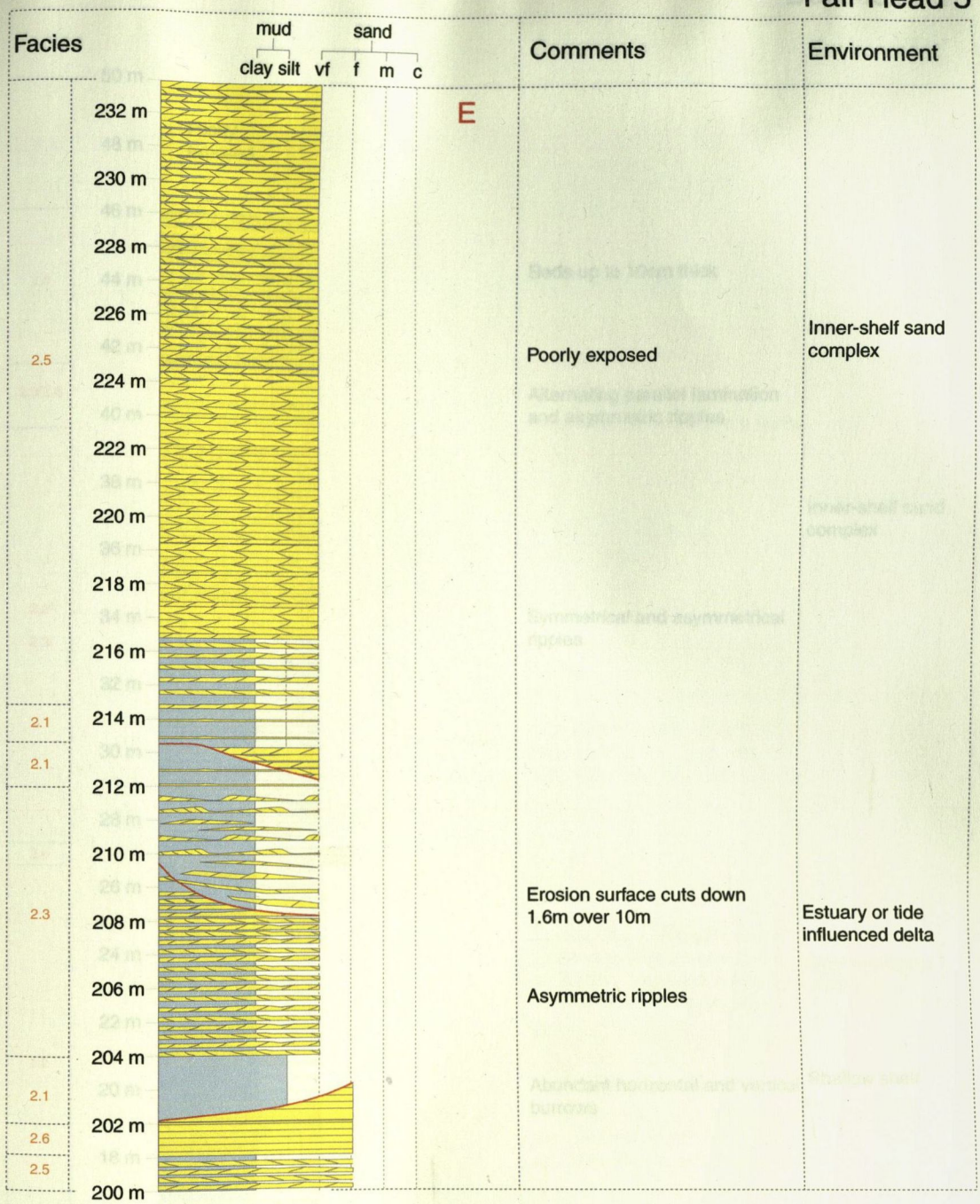
Fair Head 3


Facies
mud
clay silt
sand
vf f m c
150 m
148 m
146 m
144 m
142 m
140 m
138 m
136 m
134 m
132 m
130 m
128 m
126 m
124 m
122 m
120 m
118 m
116 m
114 m
112 m
110 m
108 m
106 m
104 m
102 m
100 m
2.5
2.7
2.6
2.5
2.7
2.3
2.6
2.7
2.2
2.6
2.2
Comments
Environment
Poorly exposed
Cross-beds
Height Dip Trend
26cm 15 160
60cm 7 287
Coastal sand complex
D
Scour and fill
Cross-bed
Height Dip Trend
18cm 14 001
Beds 5-15cm thick
Cross-bed 21cm high, dips 10 and trends to 145
Beds 5-40cm thick. Asymmetric ripples trend to: 247, 230, 232, 247
Inner-shelf sand complex
Height Dip Trend
22cm 32 173
32cm 15 160
Coastal sand complex
Trough cross-beds
Inner-shelf sand complex

Fair Head 4


Facies
mud
clay silt
sand
vf f m c
Comments
Environment
200 m
198 m
196 m
194 m
192 m
190 m
188 m
186 m
184 m
182 m
180 m
178 m
176 m
174 m
172 m
170 m
168 m
166 m
164 m
162 m
160 m
158 m
156 m
154 m
152 m
150 m
2.6
2.2
2.6
2.5
2.6
2.5
2.5
2.2
2.7
2.3
2.5
2.7
Delta front sand complex
Wavy and flaser bedding
Poorly exposed
Delta front sand complex
Sand linsen up to 3cm thick
Height Dip Trend
7cm 22 180
8cm 24 170
Sandstone beds up to 6cm thick
Beds up to 40cm thick
Inner-shelf sand complex
Poorly exposed
Beds 30-60cm thick
Inner-shelf sand complex
Cross-bed 13cm high, dips 15 and trends 203
Cross-beds 10cm high, dips 19 and trends to 169
Delta front sand complex

Fair Head 5


Facies
mud
clay silt
sand
vf f m c
Comments
Environment
E
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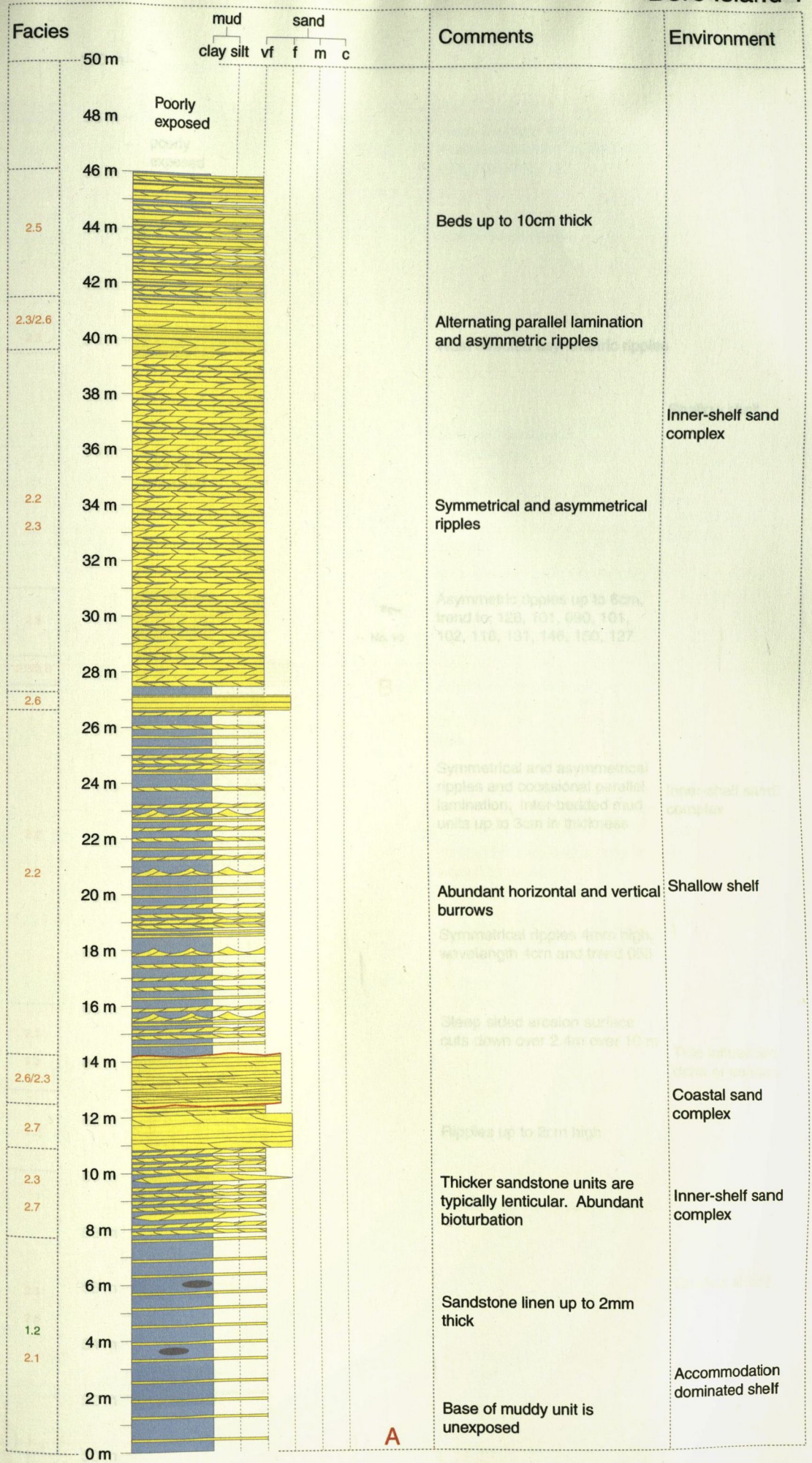
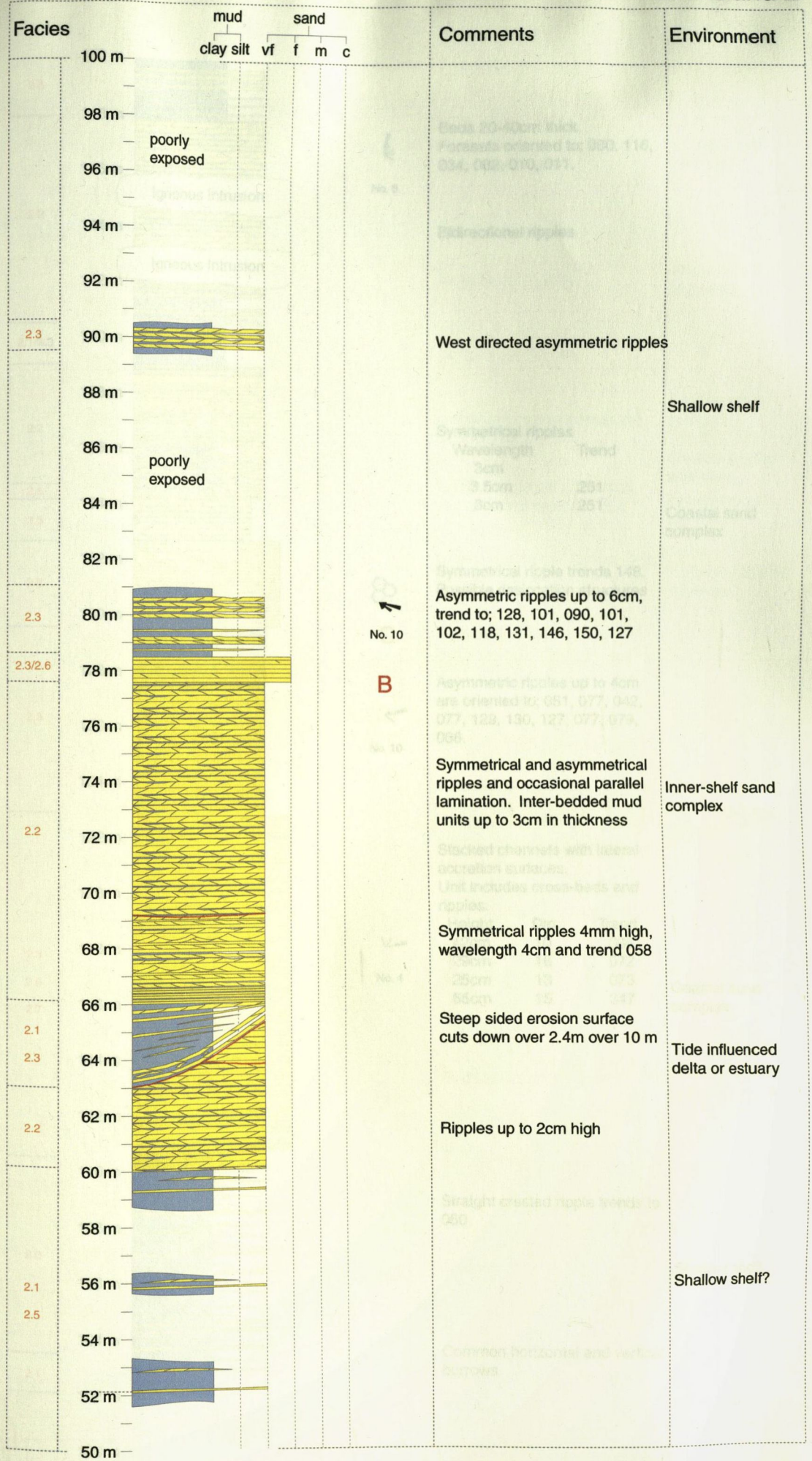
230 m
228 m
226 m
224 m
222 m
220 m
218 m
216 m
214 m
212 m
210 m
208 m
206 m
204 m
202 m
200 m
2.5
2.1
2.1
2.3
2.1
2.6
2.5
Poorly exposed
Erosion surface cuts down 1.6m over 10m
Asymmetric ripples
Inner-shelf sand complex
Estuary or tide influenced delta

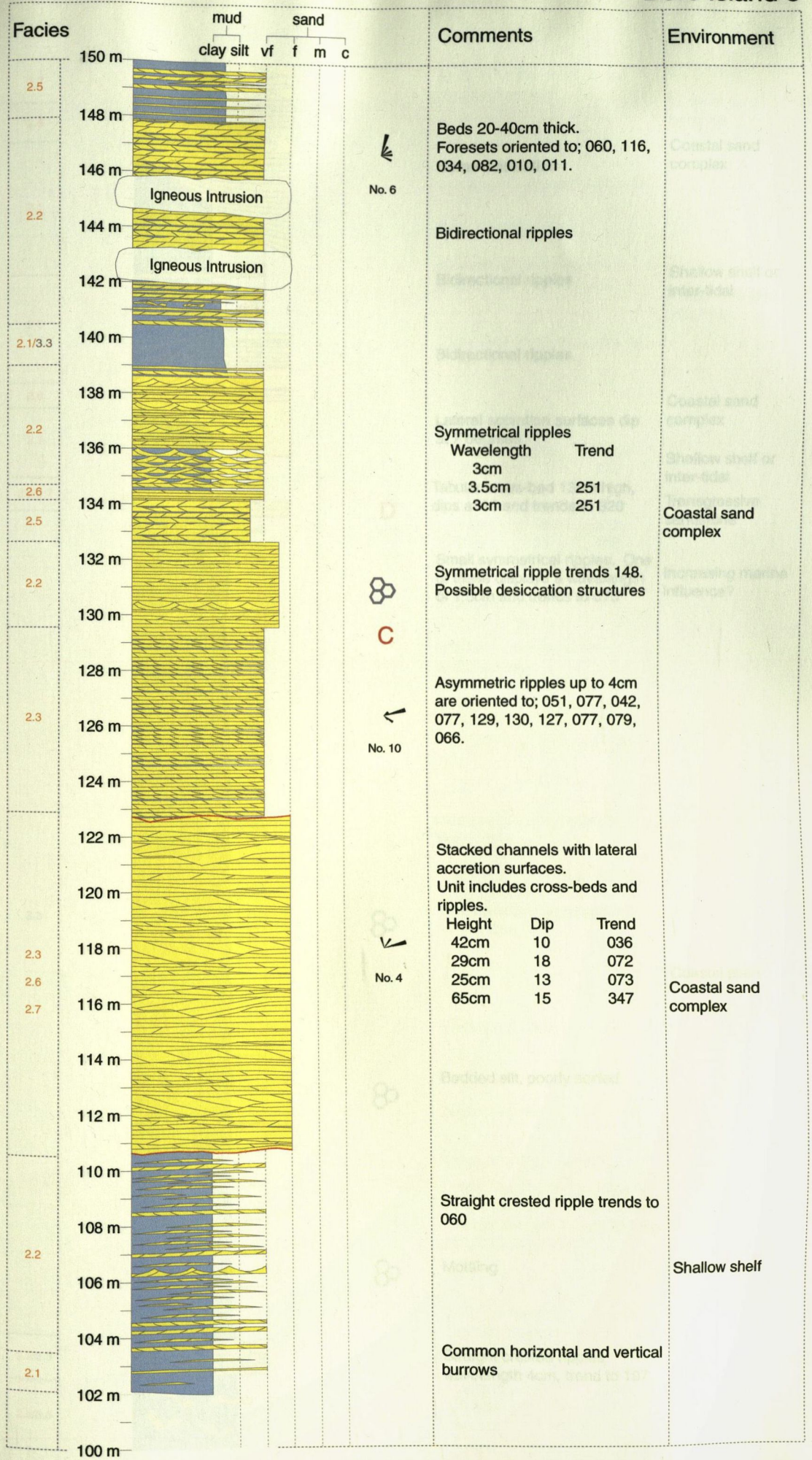
Bere Island 1



Bere Island 2



Bere Island 3



Comments

Beds 20-40cm thick.
Foresets oriented to; 060, 116, 034, 082, 010, 011.

Bidirectional ripples

Symmetrical ripples

Wavelength	Trend
3cm	
3.5cm	251
3cm	251

Symmetrical ripple trends 148.
Possible desiccation structures

Asymmetric ripples up to 4cm are oriented to; 051, 077, 042, 077, 129, 130, 127, 077, 079, 066.

Stacked channels with lateral accretion surfaces.
Unit includes cross-beds and ripples.

Height	Dip	Trend
42cm	10	036
29cm	18	072
25cm	13	073
65cm	15	347

Straight crested ripple trends to 060

Common horizontal and vertical burrows

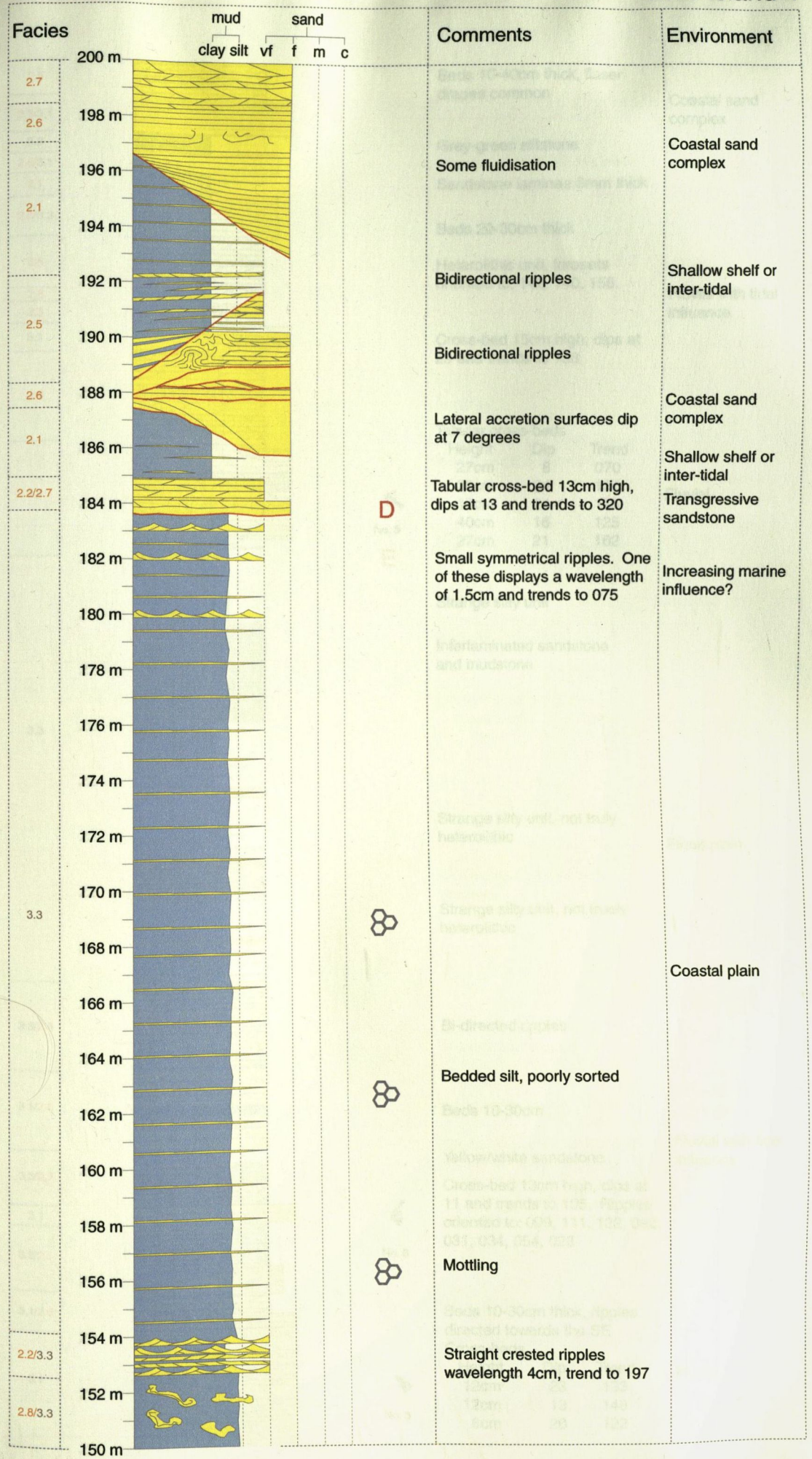
Environment

Coastal sand complex

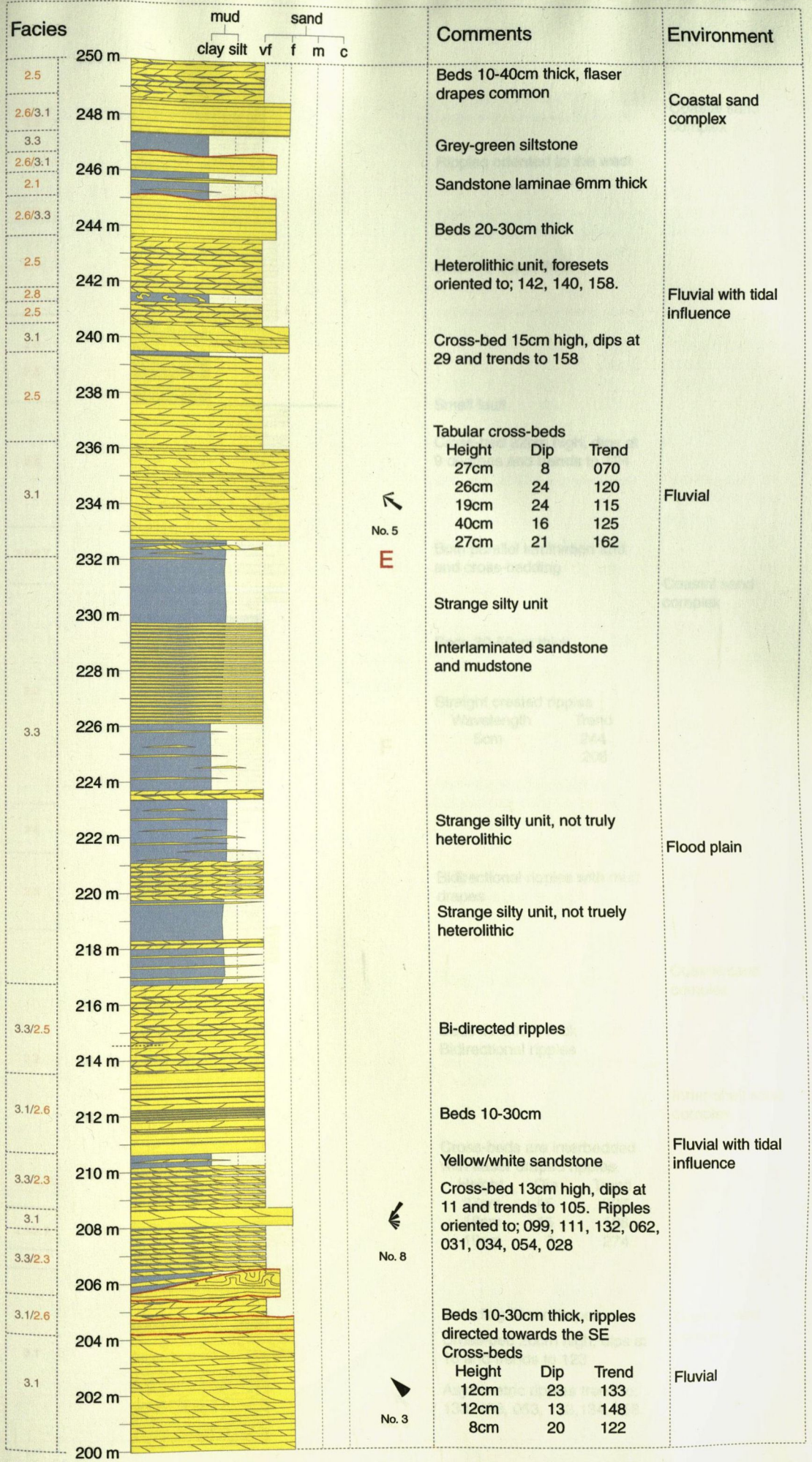
Coastal sand complex

Shallow shelf

Bere Island 4

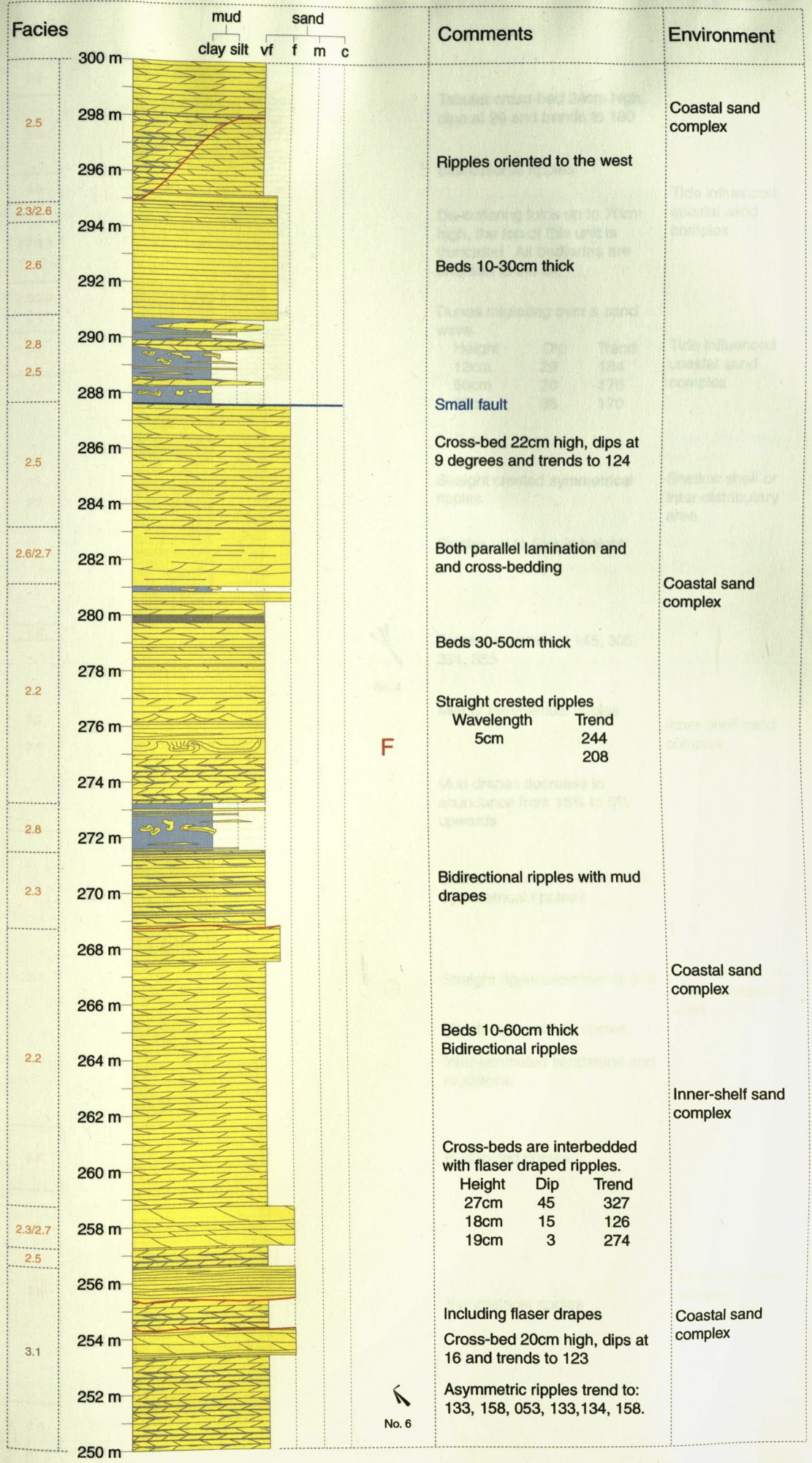


Bere Island 5

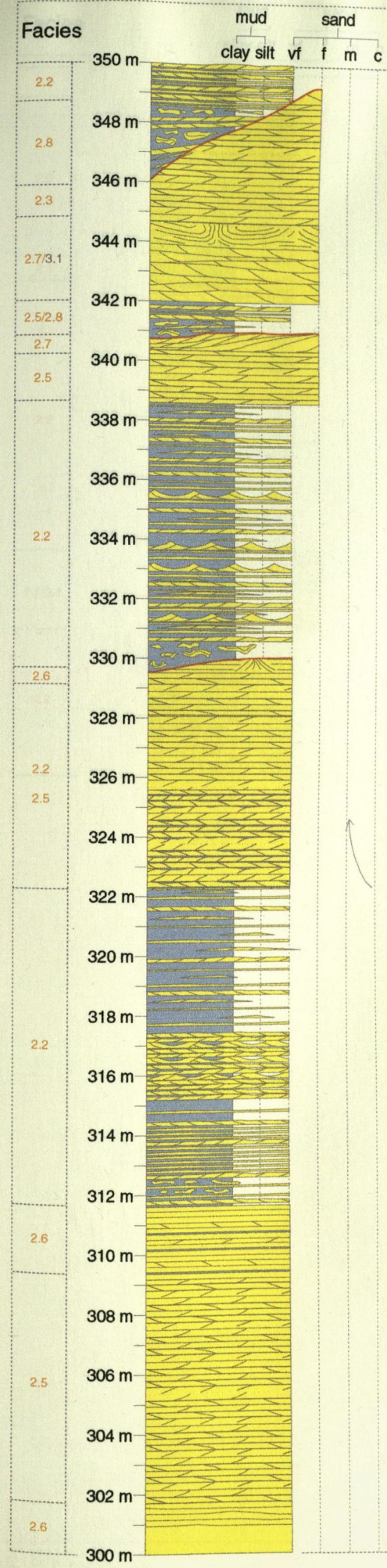


Comments	Environment
Beds 10-40cm thick, flaser drapes common	Coastal sand complex
Grey-green siltstone	
Sandstone laminae 6mm thick	
Beds 20-30cm thick	
Heterolithic unit, foresets oriented to; 142, 140, 158.	Fluvial with tidal influence
Cross-bed 15cm high, dips at 29 and trends to 158	
Tabular cross-beds Height Dip Trend 27cm 8 070 26cm 24 120 19cm 24 115 40cm 16 125 27cm 21 162	Fluvial
Strange silty unit	
Interlaminated sandstone and mudstone	
Strange silty unit, not truly heterolithic	Flood plain
Strange silty unit, not truely heterolithic	
Bi-directed ripples	
Beds 10-30cm	Fluvial with tidal influence
Yellow/white sandstone	
Cross-bed 13cm high, dips at 11 and trends to 105. Ripples oriented to; 099, 111, 132, 062, 031, 034, 054, 028	
Beds 10-30cm thick, ripples directed towards the SE Cross-beds Height Dip Trend 12cm 23 133 12cm 13 148 8cm 20 122	Fluvial

Bere Island 6

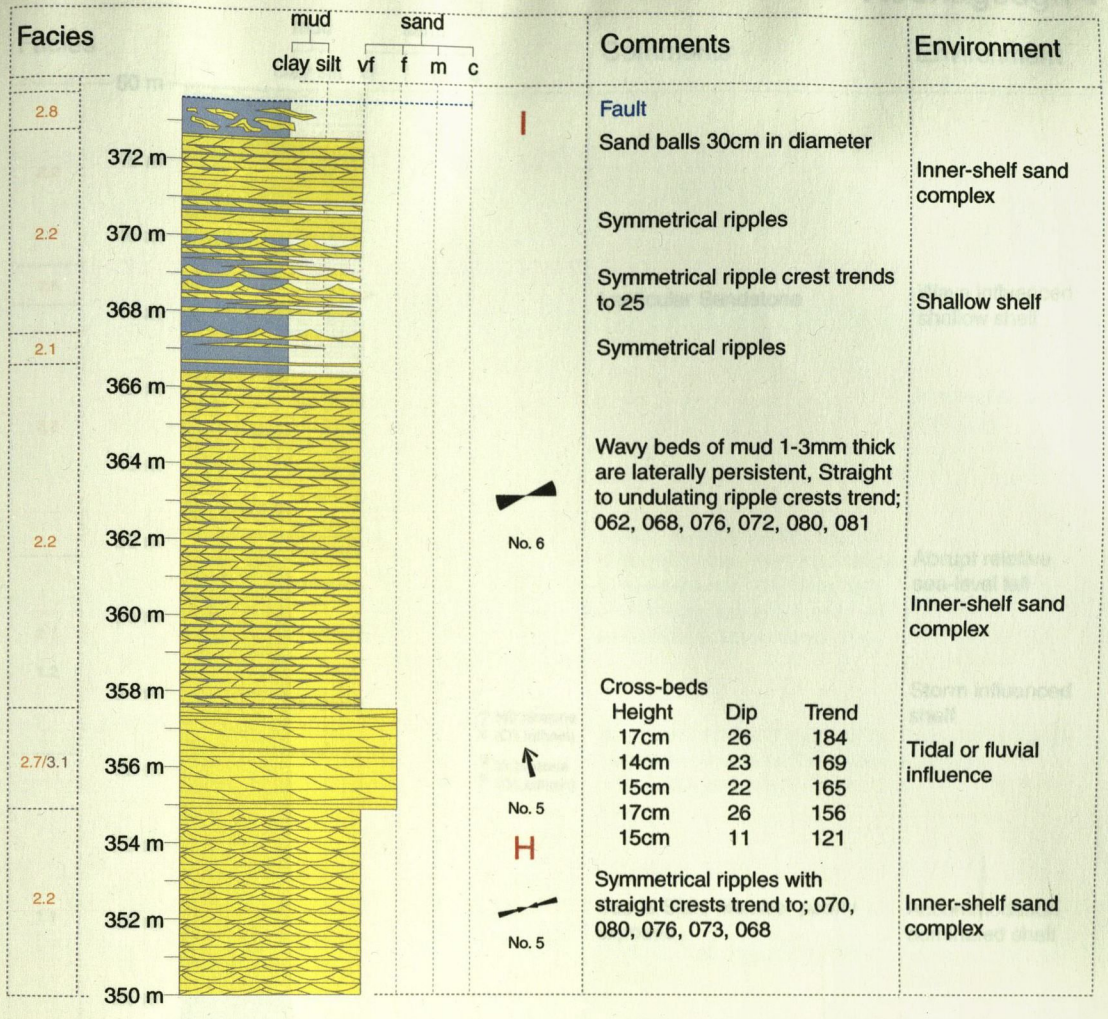


Bere Island 7

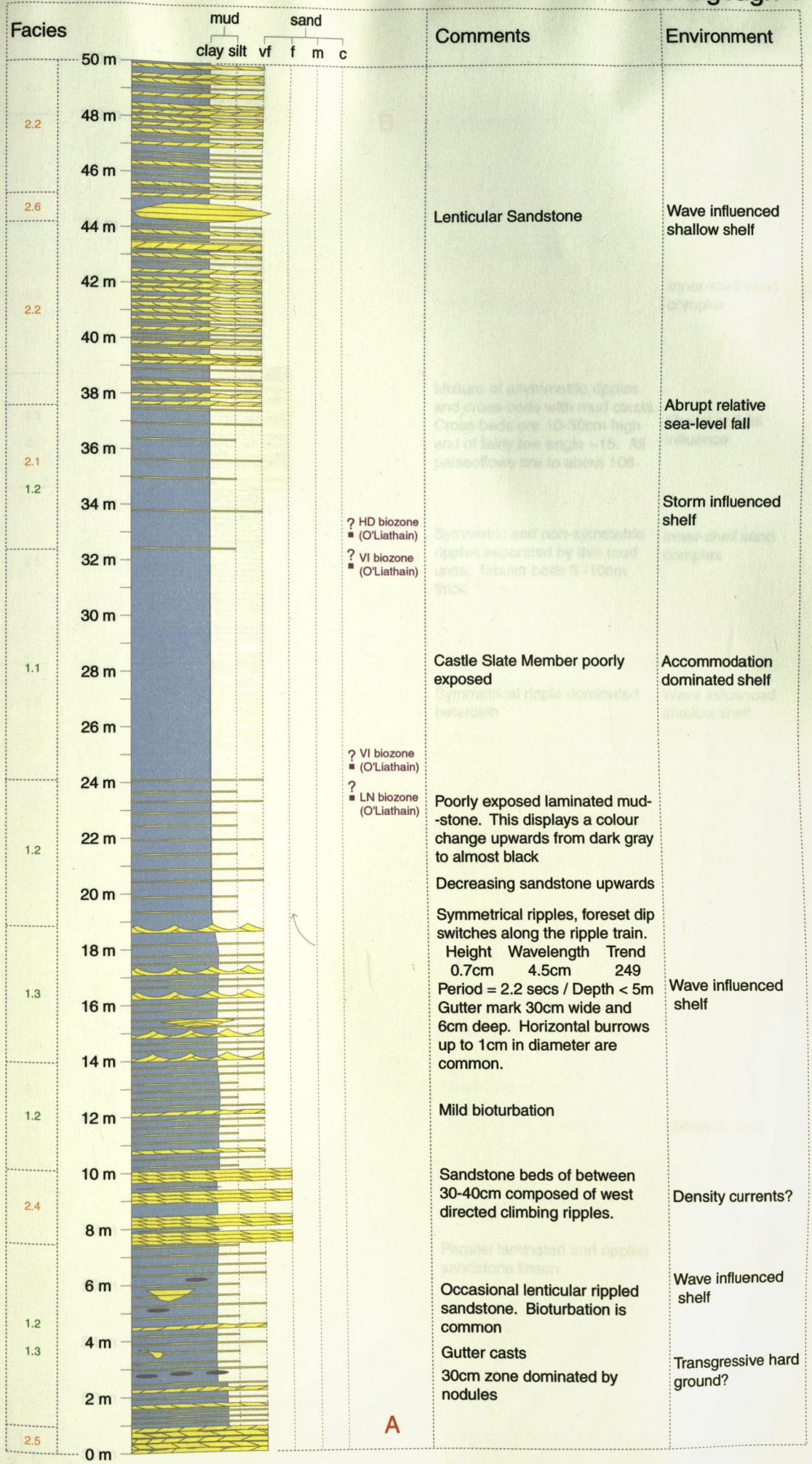


Facies	Comments	Environment
2.2	Tabular cross-bed 24cm high, dips at 29 and trends to 180	
2.8	Bidirectional ripples	
2.3		Tide influenced coastal sand complex
2.7/3.1	De-watering folds up to 70cm high, the top of this unit is truncated. All bedforms are oriented to the SE	
2.5/2.8		
2.7	Dunes migrating over a sand wave	
2.5	Height 12cm, Dip 29, Trend 184 Height 50cm, Dip 20, Trend 170 Height 15cm, Dip 35, Trend 170	Tide influenced coastal sand complex
2.2	Straight crested symmetrical ripples	Shallow shelf or inter-distributary area
	Ripples up to 1cm in height	
2.6	Foreset orientation; 145, 305, 331, 355	
	No. 4	
2.2 2.5	Mainly symmetrical ripples	Inner-shelf sand complex
	Mud drapes decrease in abundance from 15% to 5% upwards	
	Sandstone linsen 1-8mm thick. Symmetrical ripples?	
2.2	G Straight ripple crest trends 246	Shallow shelf or inter-distributary area
	Mainly symmetrical ripples	
	Inter-laminated sandstone and mudstone	
2.6	Bi-directed ripples	
2.5	Symmetrical ripples	Inner-shelf sand complex
2.6		

Bere Island 8

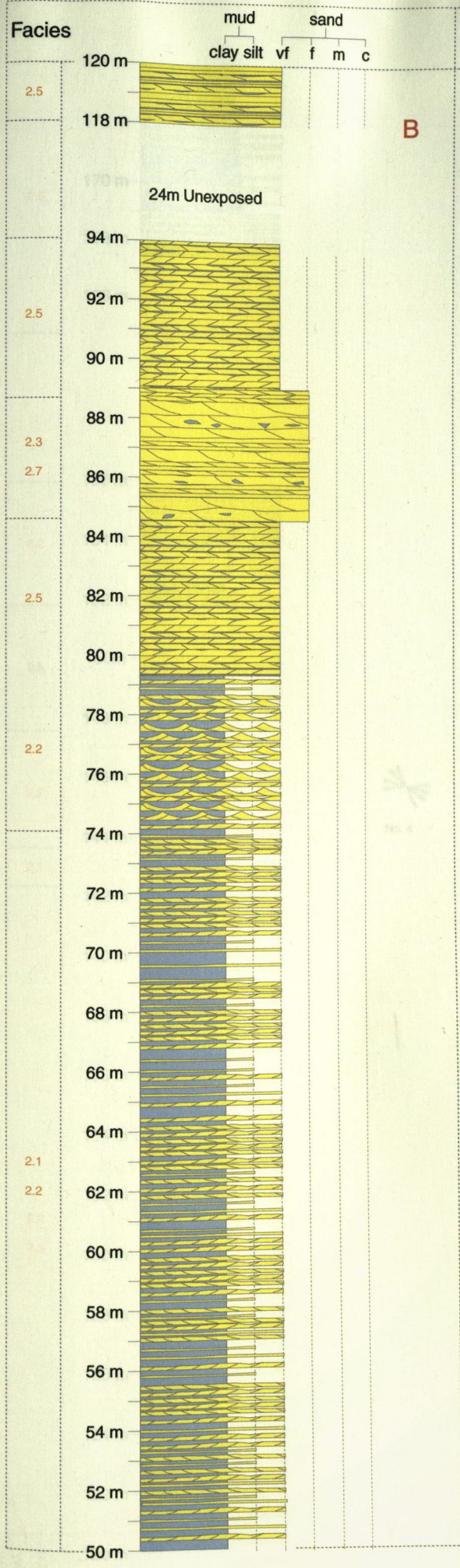


Reenagough 1



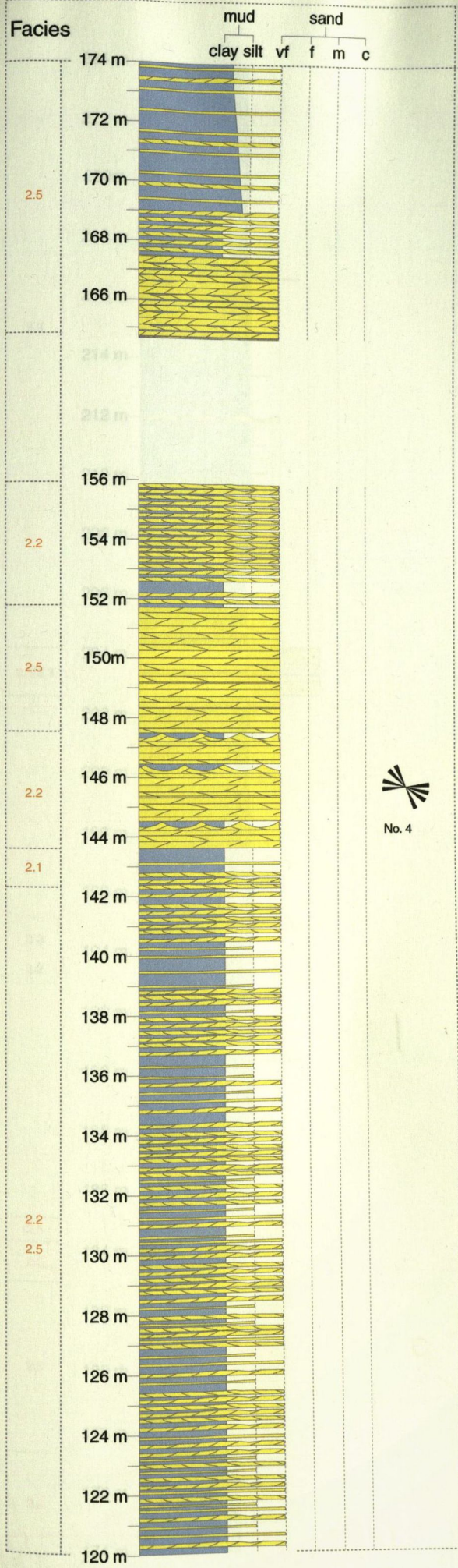
Comments	Environment
Lenticular Sandstone	Wave influenced shallow shelf
	Abrupt relative sea-level fall
	Storm influenced shelf
Castle Slate Member poorly exposed	Accommodation dominated shelf
Poorly exposed laminated mud--stone. This displays a colour change upwards from dark gray to almost black	
Decreasing sandstone upwards	
Symmetrical ripples, foreset dip switches along the ripple train. Height 0.7cm Wavelength 4.5cm Trend 249 Period = 2.2 secs / Depth < 5m Gutter mark 30cm wide and 6cm deep. Horizontal burrows up to 1cm in diameter are common.	Wave influenced shelf
Mild bioturbation	
Sandstone beds of between 30-40cm composed of west directed climbing ripples.	Density currents?
Occasional lenticular rippled sandstone. Bioturbation is common	Wave influenced shelf
Gutter casts	
30cm zone dominated by nodules	Transgressive hard ground?

Reenagough 2



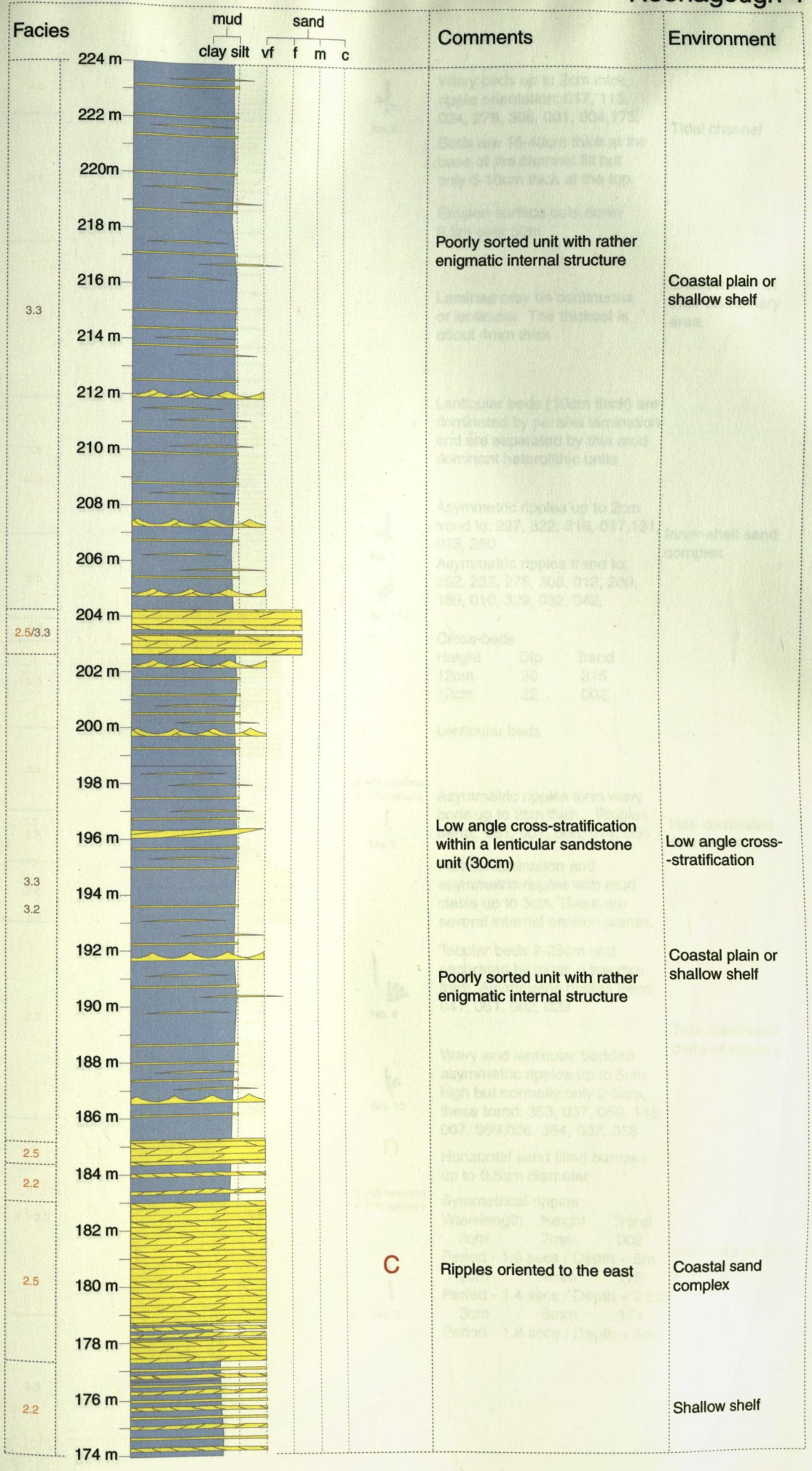
Comments	Environment
	Inner-shelf sand complex
Mixture of asymmetric ripples and cross-beds with mud clasts. Cross-beds are 10-30cm high and of fairly low angle ~15. All palaeoflows are to about 106	Fluvial or tidal influence
Symmetric and non-symmetric ripples separated by thin mud units. Tabular beds 3 -10cm thick	Inner-shelf sand complex
Symmetrical ripple dominated heterolith	Wave influenced shallow shelf
	Shallow shelf
Parallel laminated and rippled sandstone linsen	

Reenagough 3

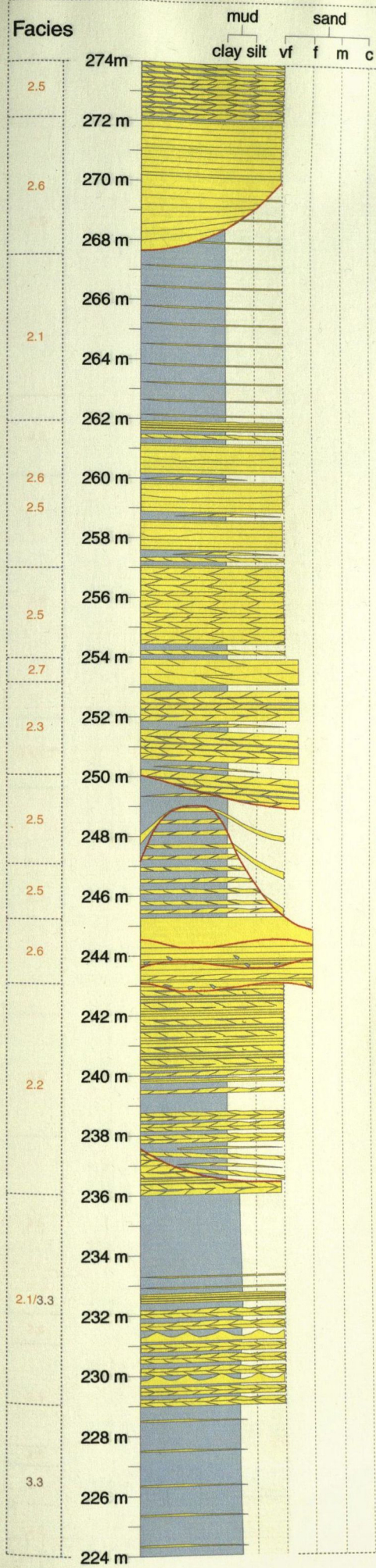


Comments	Environment
Mild bioturbation	
	Shallow shelf
Strong Bioturbation	
Mild bioturbation	
9m unexposed	
Symmetrical ripples and parallel Lamination Wavelength Height Trend 3.7cm - 106 3.8cm 4mm 123 Period - 1.9 secs / Depth < 5m 3.2cm 3mm 086 5.5cm 5mm 150	Shallow shelf or tidal flats
Flaser and wavy bedded sandstones. Many of the ripples are symmetrical.	Shallow shelf or tidal flats
Flaser and wavy bedded sandstones	
Ripples and parallel lamination	

Reenagough 4

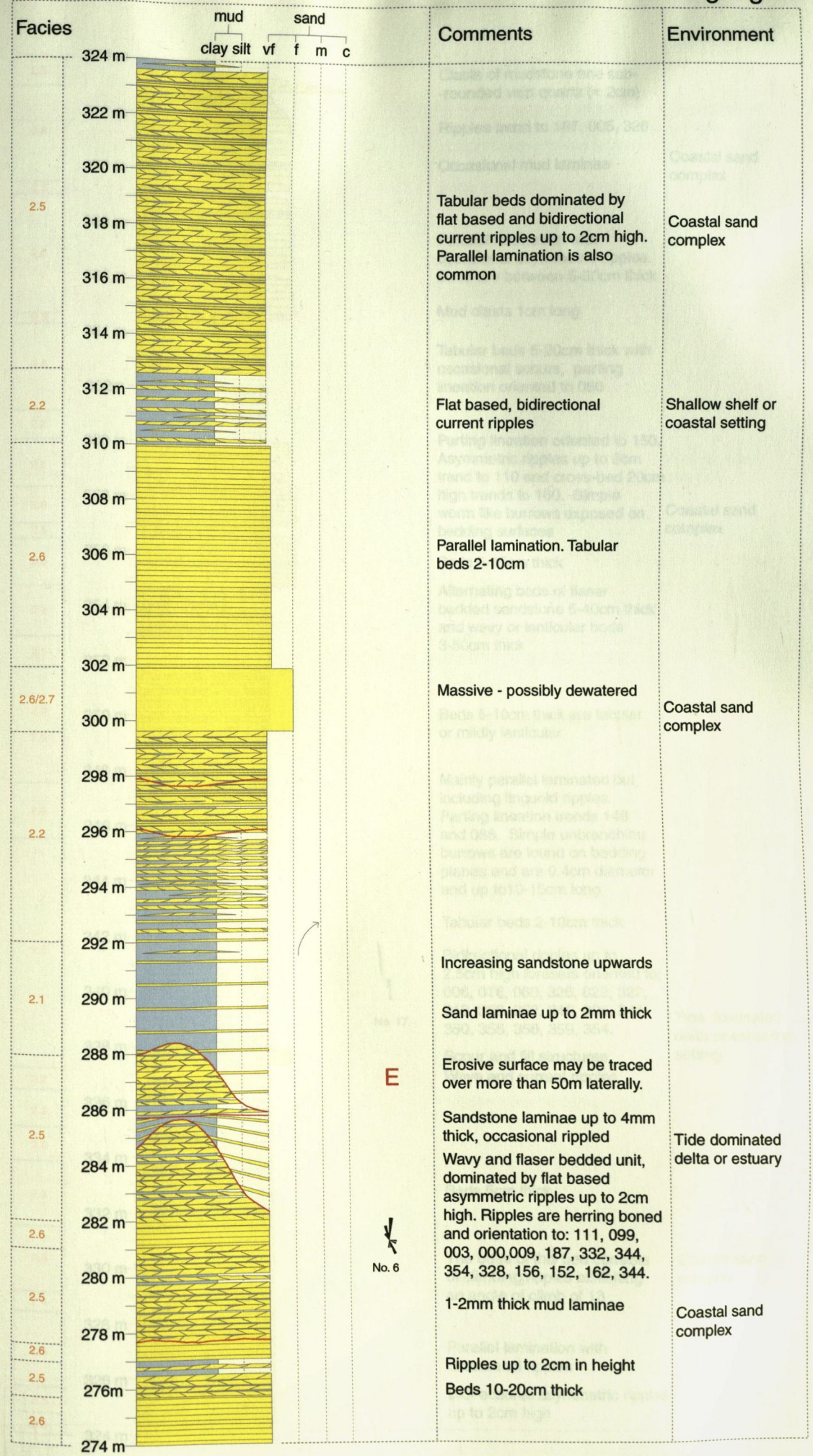


Reenagough 5

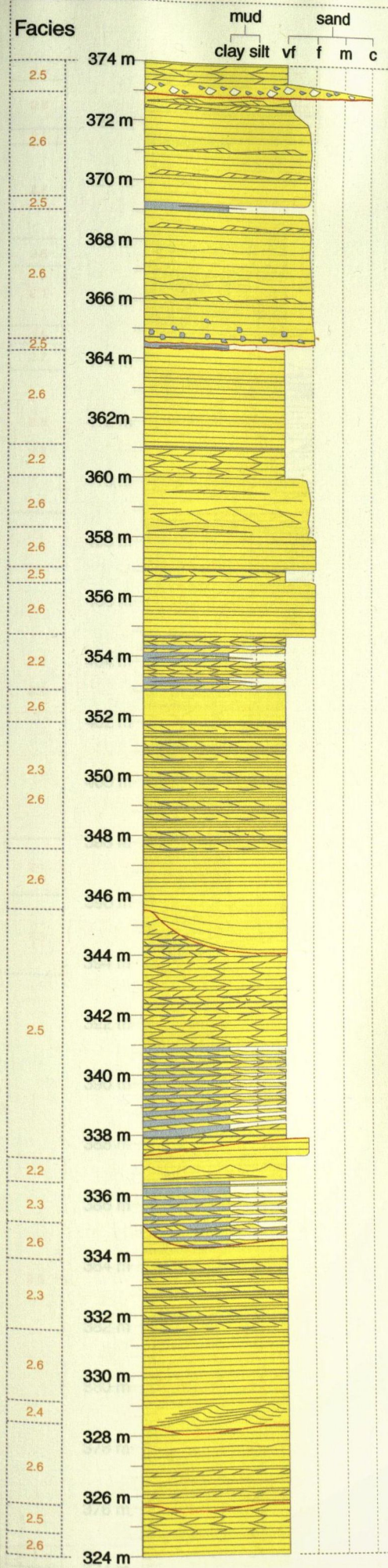


Comments	Environment
Wavy beds up to 2cm thick, ripple orientation: 017, 113, 024, 278, 308, 001, 004,175.	Tidal channel
Beds are 15-40cm thick at the base of the channel fill but only 5-10cm thick at the top.	
Erosion surface cuts down 2.5m over 50m	
Laminae may be continuous or lenticular. The thickest is about 4mm thick	Shallow shelf or inter distributary area
Lenticular beds (10cm thick) are dominated by parallel lamination and are separated by thin mud dominant heterolithic units	
Asymmetric ripples up to 2cm trend to; 297, 322, 318, 017,131, 013, 260	Inner-shelf sand complex
Asymmetric ripples trend to; 352, 232, 275, 308, 012, 289, 189, 010, 329, 032, 042,	
Cross-beds Height Dip Trend 12cm 20 315 12cm 22 002	
Lenticular beds	
Asymmetric ripples form wavy beds up to 2cm thick. Ripples trend; 061, 001, 005, 014, 006	Tide dominated delta or estuary
Parallel lamination and asymmetric ripples with mud clasts up to 3cm. There are several internal erosion planes.	
Tabular beds 2-25cm and separated by muds a few mm thick. Asymmetric ripples trend; 047, 061, 002, 029	
Wavy and lenticular bedded asymmetric ripples up to 5cm high but normally only 2-3cm, these trend: 353, 037, 059, 146, 007, 059,006, 354, 037, 358	Tide dominated delta or estuary
Horizontal sand filled burrows up to 0.5cm diameter	
Symmetrical ripples Wavelength Height Trend 3cm 7mm 002 Period - 1.9 secs / Depth < 5m 2cm 4mm 175 Period - 1.4 secs / Depth < 2.5m 3cm 6mm 174 Period - 1.8 secs / Depth < 5m	Inter-tidal or flood-plain

Reenagough 6

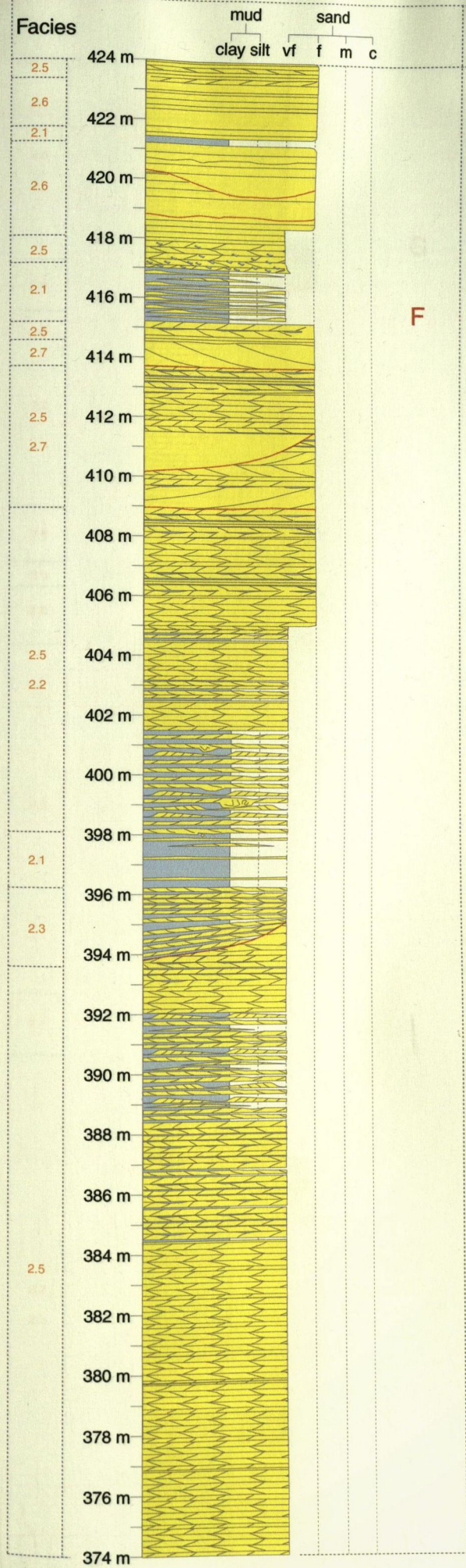


Renagough 7



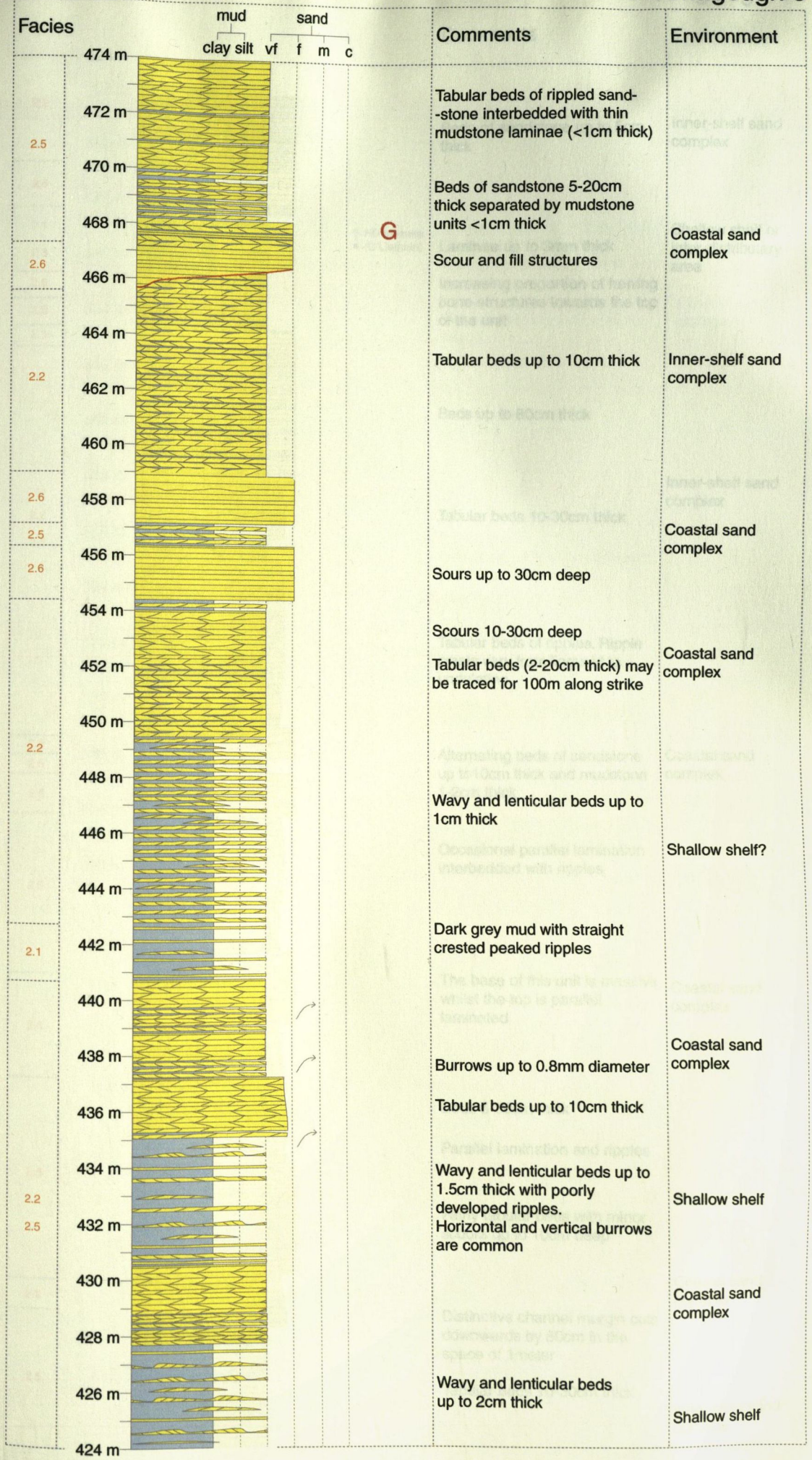
Facies	Comments	Environment
2.5	Clasts of mudstone and sub--rounded vein quartz (< 2cm)	
2.6	Ripples trend to 187, 005, 326	
2.5	Occasional mud laminae	Coastal sand complex
2.6	Parallel lamination with occasional asymmetric ripples. Beds are between 5-50cm thick	
2.5	Mud clasts 1cm long	
2.6	Tabular beds 5-20cm thick with occasional scours, parting lineation oriented to 060	
2.2		
2.6	Parting lineation oriented to 150. Asymmetric ripples up to 3cm trend to 110 and cross-bed 20cm high trends to 160. Simple worm like burrows exposed on bedding surfaces	Coastal sand complex
2.6		
2.5		
2.6	Beds 5-15cm thick	
2.2	Alternating beds of flaser bedded sandstone 5-40cm thick and wavy or lenticular beds 3-50cm thick	
2.6		
2.3	Beds 5-10cm thick are tabular or mildly lenticular	
2.6		
2.6	Mainly parallel laminated but including linguoid ripples. Parting lineation trends 148 and 088. Simple unbranching burrows are found on bedding planes and are 0.4cm diameter and up to10-15cm long	
2.5	Tabular beds 2-10cm thick	
	Bidirectional ripples up to 2.5cm high foresets oriented to; 006, 016, 060, 326, 022, 322, 319, 356, 352, 345, 006, 341, 350, 355, 356, 359, 354.	Tide dominated delta or estuarine setting
2.2	Scour and fill structures Wave and current ripples	
2.3		
2.6		
2.3	Beds 5cm thick	
2.6	The base of this bed consists of climbing ripples exhibiting an angle of climb of 13	Coastal sand complex
2.4		
2.6	Parallel lamination with occasional ripples	
2.5	Bidirectional asymmetric ripples up to 2cm high	
2.6		

Reenagough 8

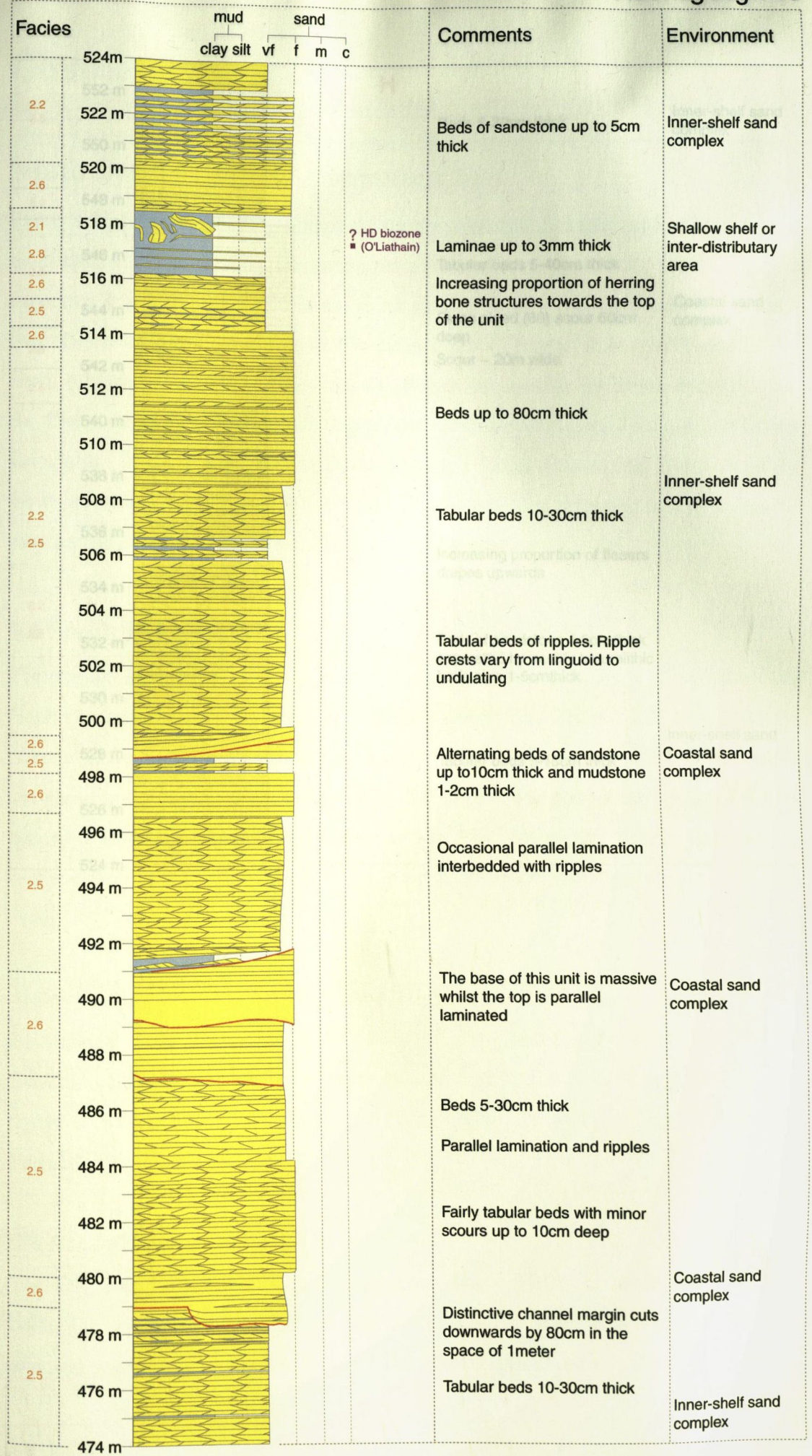


	Comments	Environment
	The base of this unit consists thick parallel laminated beds (< 50cm thick), the upper portion consists thinner beds of parallel lamination and ripples	Coastal sand complex
	Beds up to 60cm thick	
F	Sandstone laminae typically less than 8mm thick	Tidal flats?
	Beds 5-20cm thick.	
	Height Dip Trend 10cm 20 017 17cm 25 166	Coastal sand complex
	Alternating beds of sandstone and mudstone 2-10cm thick	
	Deformed wavy beds 3cm thick	
		Tide influenced delta or estuarine complex
	Tabular beds 5-30cm thick including bidirectional current ripples	
	Bidirectional, flat and scoop based ripples up to 1.5cm high	
	Tabular beds 10 30cm thick	
		Coastal sand complex
	Tabular beds	

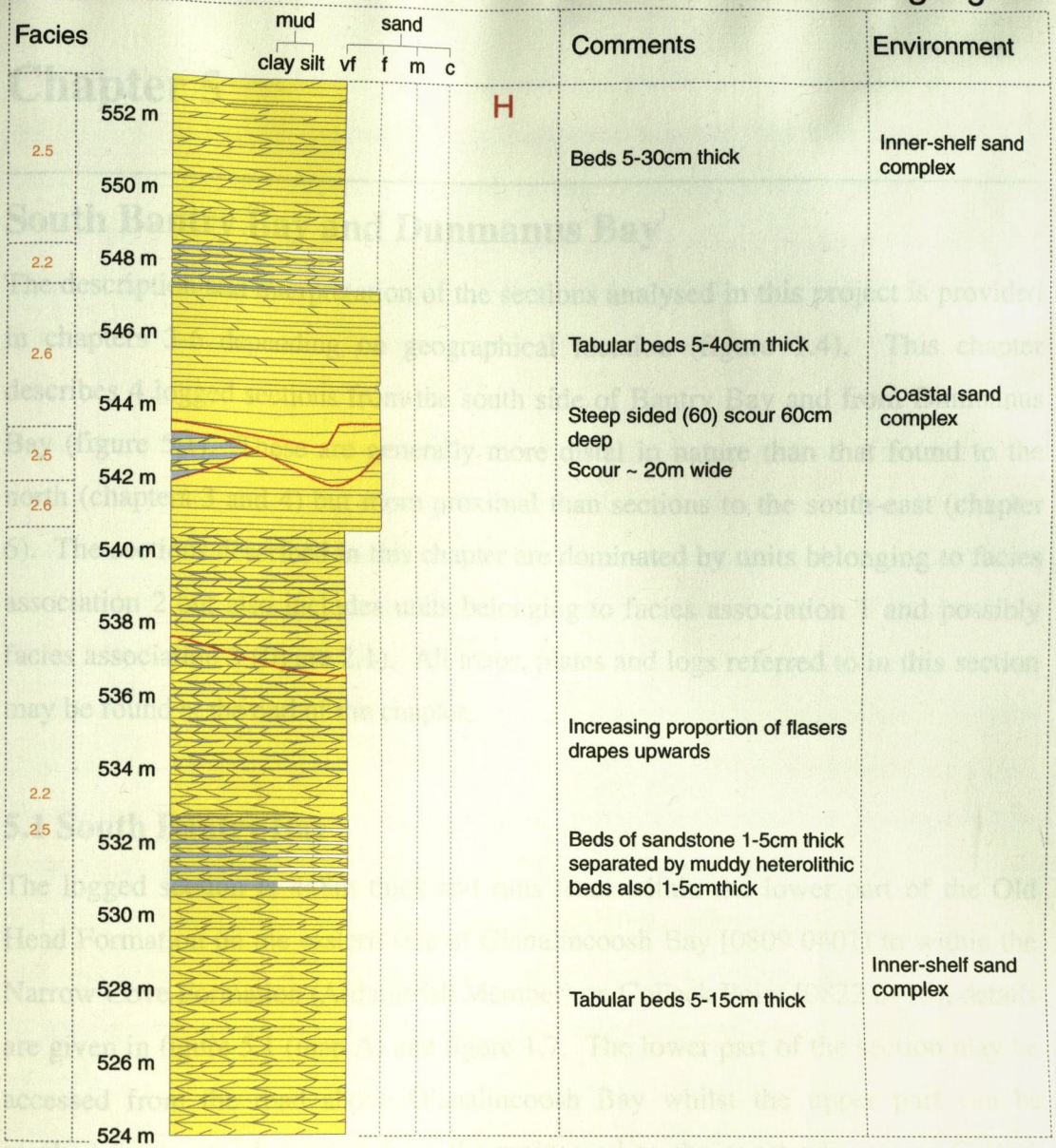
Reenagough 9



Reenagough 10



Reenagough 11



Chapter 5

South Bantry Bay and Dunmanus Bay

The description and interpretation of the sections analysed in this project is provided in chapters 3-6 depending on geographical location (figure 1.4). This chapter describes 4 logged sections from the south side of Bantry Bay and from Dunmanus Bay (figure 5.1). These are generally more distal in nature than that found to the north (chapters 3 and 4) but more proximal than sections to the south-east (chapter 6). The sections described in this chapter are dominated by units belonging to facies association 2 but also includes units belonging to facies association 1 and possibly facies association 3 (figure 2.1). All maps, plates and logs referred to in this section may be found at the end of the chapter.

5.1 South Bantry Bay

The logged section is 448m thick and runs from within the lower part of the Old Head Formation on the eastern side of Glanalincoosh Bay [0809 0401] to within the Narrow Cove Formation (Ardaturrish Member) on Collack Point [0822 0413], details are given in figure 5.1 (map A) and figure 1.7. The lower part of the section may be accessed from the road above Glanalincoosh Bay whilst the upper part can be reached from a track passing from the main road to the coast adjacent to Collack Point.

Although this section has not been dated, Higgs *et al.* (1988) report an LN miospore assemblage from 2.95m below the base of the Castle Slate Formation in the Gouladoo Slate Quarry section situated around 1km to the east. These authors also report a VI miospore assemblage 20-25cm above the base of the Castle Slate Formation in this section.

Old Head Formation

The Old Head Formation exposed between 0m - 321m is dominated by units belonging to facies association 2 (figure 2.1). The lowest portion of this unit exposed within this section is found within Glanalincoosh Cove. Although the base

of the formation is not actually exposed here, provisional survey sheets provided by the Geological Survey suggest that the transition between the Toe Head and Old Head Formations lies immediately south of the cove. This is corroborated by the logged thickness of the Old Head Formation (321m) which is comparable to that reported from the Glengarriff section (290m - Jones 1974) and from the Reenmore Section on the north side of Dunmanus Bay (297m - Naylor 1977).

Between 0.0m - 93m the sequence consists of both sandstone rich and mudstone rich units. Mudstone rich units are normally heterolithic and may include desiccation structures and down-cutting surfaces. Calculation of wave period and water depth from two of these units (51m and 73m) suggests that the symmetrical ripples were formed by locally generated surface waves in less than 3m water depth. Intervening sandstone rich units include cross-bedding (with variable palaeoflow), parallel lamination and asymmetric ripples and commonly overly down-cutting surfaces. The evidence for a shallow perhaps periodically emergent setting that is suggested by desiccation structures, down-cutting surfaces and from water depth calculation suggests that mudstone rich units developed upon tidal flats. Intervening sandstone rich packages show strong evidence of tidal influence and may reflect either migrating tidal channel systems or sand rich sub-tidal facies.

Between 93m - 202.2m the sequence consists of alternating sandstone rich and mudstone rich units. Sandstone rich packages resemble those in the underlying sequence and include cross-bedding, ripples and parallel lamination whilst mudstone rich packages are dominated by symmetrical ripples but do not include down-cutting surfaces, desiccation structures or thick laminated mudstone units. This may mean that these units reflect deposition within a shallow shelf setting rather than upon tidal flats as suggested for the sequence below. The variable palaeoflow patterns and presence of mud drapes displayed by sandstone rich packages probably indicates tidal influence although it is possible that some units with southerly directed palaeoflow patterns (e.g. 157.4m - 168.7m) reflect fluvial deposition. The alternation between mudstone and sandstone rich packages probably reflects varying proximity to the coastline with sandstone rich units deposited in a coastal setting and mudstone rich units deposited within a shallow shelf setting, perhaps during phases of slightly higher relative sea-level.

Between 202.2m - 313.1m the sequence is more mudstone rich and probably correlates with the Tower Member whereas the underlying sequence is thought to correlate with the Daunt Member. This 'upper' sequence is dominated by relatively mudstone rich heterolithic units (with variable sandstone content) that include small-scale symmetrical ripples and a number of rippled or parallel laminated sandstone beds. Mudstone rich heterolithic units were probably deposited within a shelf setting whilst the variation in sandstone content within these units may reflect changing proximity to the coastline. Parallel laminated and rippled sandstone units may have been emplaced by storms, tides or by transgressive reworking of earlier deposits.

The uppermost part of the Old Head Formation (313.1m - 321.5m) is dominated by sandstone. The lower portion of this package consists of a flaser bedded rippled sandstone unit that is bound by erosion surfaces. This is overlain by alternating mudstone and sandstone rich heterolithic units and culminates with a thin parallel laminated sandstone that includes several orange coloured weathered horizons. The thick rippled sandstone package at the base of the sequence may reflect a tide influenced lowstand or falling stage shoreface sequence whilst the enclosing mudstone rich units reflect deposition within a shelf setting during phases of higher relative sea-level. The sharp upper and lower surfaces of this sand rich package are typical of lowstand shoreface sequences. The thinner sandstone units in the upper part of the package may also reflect lowstand shoreface sequences. However, considering the thickness of these it is also possible that they were generated during transgressive reworking of an earlier formed coastal sequence. The orange weathering seen in the uppermost unit probably results from decalcification and perhaps suggests that shell debris was present within this unit (plate 5.7). Such material may have become concentrated during a phase of pronounced transgression because of the associated reduction in clastic depositional rates.

Castle Slate Formation

The base of the Castle Slate Formation is juxtaposed with the upper part of the Old Head Formation across a bedding parallel thrust. Although this is associated with some local deformation the sequencing of facies and thickness of the Castle Slate Formation suggest minimal out of section displacement. The Castle Slate Formation

exposed between 321.5m - 331.9m consists of a dark grey homogenous mudstone and was probably deposited within a distal shelf setting during a phase of relative sea-level rise.

Narrow Cove Formation

Only the Ardaturrish Member at the base of the Narrow Cove Formation is exposed in this section (331.9m - 448m). Although this unit includes facies belonging to association 1 at its base it is dominated by association 2 (figure 2.1).

At the base of the Ardaturrish Member (331.9m - 341.0m) a laminated mudstone package exhibits a cyclic alternation in sandstone content and also a marked increase in sandstone content at around 335m which coincides with the first appearance of gutter casts. This sequence (belonging to facies association 1) probably reflects deposition within a storm influenced offshore transitional setting. The abrupt increase in sandstone content and appearance of gutter casts at 335m suggests an increase in coastal proximity that was probably generated by a reduction of relative sea-level. The cyclic variation in sandstone content seen throughout the package probably reflects high frequency fluctuations of relative sea-level.

At 341.0m the sequence exhibits a dramatic increase in sandstone content and change in facies type which persist until the top of the section at 448.3m. This part of the sequence consists of a series of mudstone rich heterolithic packages (7-19m in thickness) that are inter-bedded with sandstone rich packages (6-16m in thickness) and in this sense resembles the sequence developed within parts of the underlying Old Head Formation. Mudstone rich packages sometimes display a cyclic variation in sandstone content and often include small scale symmetrical ripples (crests typically oriented NE-SW) whilst bioturbation which is prolific in the lower part of the package becomes less common up section (plate 5.1). Sandstone rich units vary in style, the lowermost (350.1-362.0m) and uppermost (434.7-448.3m) of these are predominantly rippled (with bi-modal current patterns) whilst the other two sandstone rich zones (376.5-399.4m and 418.5-424.7m) are associated with down-cutting surfaces (plate 5.2), cross-bedding and southerly directed bed-forms. The variation between mudstone and sandstone rich portions of this sequence probably reflects changing proximity to the coastline. Mudstone rich packages were probably

deposited upon a shallow wave influenced shelf setting whilst sandstone rich units reflect deposition within a tide influenced coastal setting during lowstands of relative sea-level. Variation in the style of the sandstone rich packages possibly reflects the position of the lowstand coastline with channelised and cross-bedded sequences reflecting deposition within more proximal settings than those dominated by ripples. The sharp based channelised sandstone packages are in many ways similar to recently described tide influenced falling stage and low-stand deposits (Willis and Gabel 2001; Seidler and Streel 2001).

5.2 Dooneen - North Dunmanus Bay

The logged section is 500m thick and runs from within the lower part of the Old Head Formation south-east of Caher [0794 0359] to within the the Narrow Cove Formation (Reenagough Member) on the Carrignacappul Peninsula [0801 0355], details are given in figure 5.1 (map B). All parts of the section may be accessed from a track leading from the main Kilcrohane road through Dooneen towards the coast.

Although this section has not been dated, Naylor *et al.* (1977) report LN miospore assemblages from within the Toe Head and overlying Old Head Formations in sections at Reenmore and Carrigreagh situated 3-5km to the east. The highest LN assemblage is reported from close to the top of the Old Head Formation. The authors also report VI miospore assemblages from immediately above the base of the Castle Slate Formation whilst the highest VI assemblage is reported from within the lower part of the Narrow Cove Formation (60m above the base of the Castle Slate Formation). HD miospore assemblages are recorded from the upper part of the Narrow Cove Formation.

Old Head Formation

The base of the Old Head Formation is not exposed at the coast in this section but is shown on provisional survey sheets to lie some several 10's of metres inland from the base of the logged section. Consequently the logged thickness of this section (251m) is slightly less than that reported for the Old Head Formation from the adjacent Reenmore section where Naylor *et al.* (1977) records 297m. This unit is dominated by facies belonging to facies association 2 (figure 2.1).

The basal portion of the Old Head Formation (0m - 131.5m) is slightly more sandstone rich than the upper portion and is dominated by alternating sandstone rich and mudstone rich sequences although these are often poorly defined. Mudstone rich sequences are dominated by heterolithic facies and may include both asymmetric and symmetric ripples (crests oriented WNW-ESE) as well as thin parallel laminated lenses but do not include down-cutting surfaces. Sandstone rich sequences (3.7-27.6m, 50.7-58.0m, 84.1-96.0m and 114.2-131.5m) are normally dominated by ripples (symmetric and asymmetric) but may also include down-cutting surfaces and variably oriented cross-beds. One sequence also includes sandstone filled polygonal cracks that are associated with small-scale symmetrical ripples and down-cutting surfaces (55m). Sandstone rich sequences were probably deposited within a coastal setting whilst mudstone rich packages were deposited within a shallow shelf setting during phases of higher relative sea-level.

The upper portion of the Old Head Formation (131.5m - 242.2m) is more mudstone rich than the underlying sequence and probably correlates with the Tower Member whereas the sequence below is thought to correlate with the Daunt Member. However this 'upper' sequence also consists of alternating mudstone rich and relatively sandstone rich packages both of which are dominated by symmetrical ripples (crests oriented ENE-WSW) although these do not contain down-cutting surfaces and sandstone rich packages are much more disparate than those below. The lack of down-cutting surfaces and disparate nature of sandstone rich packages may indicate that the coastline was more distal at this stage although periodic emergence is still suggested from small wavelength symmetrical ripples (215m).

The upper portion of the Old Head Formation consists of a thick sandstone unit (242.2 - 251.1m). This is dominated by north oriented cross-beds and ripples but also includes some parallel lamination. The basal portion of the package includes thick beds (60cm) whilst the upper portion is dominated by thinner beds (15cm) and includes discontinuous orange weathered horizons (plate 5.8) which may reflect decalcification. The package is overlain by a thin siltstone and sandstone laminated mudstone unit. This sequence probably reflects deposition within either a coastal setting or as a transgressive sand sheet reworked from earlier sequences. The later

interpretation fits well for the upper part of this package which includes decalcified layers probably generated when depositional rates were low thus allowing shell material to concentrate. The sharp upper surface of this package probably reflects a pronounced landward shift of facies belts.

Castle Slate Formation

Between 251.1m - 258.7m the Castle Slate Formation consists of dark grey homogenous mudstone and probably reflects a pronounced rise of relative sea level compared to the underlying sequence. The thickness of this (~7m) is comparable to that in the South Bantry Bay section (~ 10m) but is slightly thicker than in the South Dunmanus Bay section (~4m).

Narrow Cove Formation

At the base of the Narrow Cove Formation the Ardaturrish Member (258.7m - 405m) is thinner (146m) than that measured from the Reenagough section (204m), the Cahermore section (182m) and the Bere Island section (184m) to the north. However, like sections to the north this unit is dominated by facies belonging to associations 2 although facies belonging to association 1 are encountered at the base of this unit (figure 2.1).

At the base of the Ardaturrish Member the sequence exhibits a gradational upwards increase in sandstone content and change in sedimentary structures (258.7m - 274.8m). The basal portion of this sequence is dominated by graded beds (plate 5.3), the middle portion includes gutter casts, symmetrical ripples, parallel lamination and possibly HCS (figure 2.5) whilst the top is dominated by symmetrical ripples. Bioturbation is common throughout this sequence (plate 5.4). The upwards change in sandstone content and sedimentary structures probably reflects a phase of shoaling and increased coastal proximity. This appears to have been accompanied by replacement of storm (facies association 1) by lower energy wave influence (facies association 2) perhaps as a result of wave attenuation as water depth was reduced.

Between 274.8m - 286.3m the sequence is dominated by two sharp based symmetrical rippled sandstone packages separated by a thin mudstone rich heterolithic unit. Sandstone rich packages probably reflect deposition within an

inner-shelf setting perhaps during lowstands of relative sea-level whilst the intervening mudstone rich unit suggests that this was interrupted by a phase of relative sea-level rise.

Between 286.3m - 305m the sequence consists of alternating sandstone rich and mudstone rich heterolithic units (2-3m in thickness) that probably reflect changes between accommodation and supply dominance upon a shallow shelf. This package is capped by a mudstone dominated heterolithic sequence that includes symmetrical ripples and down-cutting surfaces (305m - 314m) and which was probably deposited within an inter-tidal or shallow sub-tidal setting.

In the overlying package (314m - 405m) cyclic alternation between sandstone and mudstone rich packages occurs on a larger scale (6-12m). Mudstone rich zones are dominated by pinching and swelling sandstone laminae and symmetrical ripples (crests oriented ENE-WSW). Intervening sandstone rich packages may include cross-beds, ripples and parallel lamination and are often associated with down-cutting surfaces. One unit (376m - 385m) also includes two surfaces upon which sandstone filled polygonal cracks are developed (plates 5.5 and 5.6). Sandstone rich portions of this sequence probably reflect phases of reduced relative sea-level with deposition upon tidal flats cross-cut by channels and within sand rich sub-tidal settings, similar deposits are described by Willis and Gabel (2001) and by Seidler and Streel (2001). Mudstone rich zones probably reflect deposition within a shallow shelf setting during phases of higher relative sea-level.

From 405.0m until the top of the section at 500.0m the sequence is more sandstone rich than the underlying sequence but is also dominated by units belonging to facies association 2 (figure 2.1). It is believed that this relatively sandstone rich sequence forms the lower part of the Reenagough Member. This unit commences with an erosive based and sharp-topped sandstone package (16m thick). The lower portion of this unit includes rhythmic alternation of parallel lamination and ripples (plate 5.11) and north oriented bedforms suggesting tidal influence. The upper portion of this unit includes south oriented asymmetric ripples and large tabular cross-beds (plate 5.12) which may reflect either tidal or fluvial influence.

Overlying this between 421.2m - 451.4m the sequence is dominated by relatively sandstone rich heterolithic units that usually include symmetrical ripples (plate 5.13) although these are interspersed with nodular mudstone rich horizons. Variation in sandstone content throughout this package probably reflect changes between supply and accommodation dominance within a shallow shelf setting. Heterolithic lateral accretion surfaces exposed at 438m probably reflect deposition within an inter-tidal or shallow sub-tidal setting.

Between 451.4m - 464.4m an erosive based sandstone package similar to that found at the base of the Reenagough Member is dominated by south-west directed asymmetric ripples and occasional cross-beds. This package may reflect lowstand fluvial or tidal deposition. The upper portion of the package includes several down-cutting surfaces that enclose channels (plate 5.14) and in one case includes a wavy bedded heterolithic package. This may reflect gradual inundation of the coastal plain and dissection by tidal channels. The parallel laminated sandstone developed between 462.6m - 464.2m may reflect beach or lower shoreface settings developed as this sequence was drowned.

Between 464.6m - 500m the sequence is dominated by sandstone rich heterolithic units reflecting deposition within a relatively proximal, supply dominated shelf setting. However the sequence also includes mudstone rich symmetrical units which probably indicate phases when relative sea-level was higher. The sequence also includes a sandstone dominated package including parallel lamination, ripples and cross-beds (469m -474.1m) and a tidal channel including heterolithic lateral accretion surfaces (486m - plate 5.9) that was probably generated within a coastal setting.

5.3 Reenmore - North Dunmanus Bay

The logged section is 36m thick and runs from within the upper part of the Old Head Formation through the Castle Slate Formation and into the base of the Narrow Cove Formation, details are provided in figure 5.1 (map C) and figure 1.7. All parts of the section may be accessed from the small harbour south west of Rosskerrig [0850 0381].

Naylor *et al.* (1977) report LN miospore assemblages from near the top of the Old Head Formation and VI assemblages from near the base of the Castle Slate Formation in this section. The highest VI assemblage is reported from approximately 60m above the base of the Castle Slate Formation in this section.

Old Head Formation

Only the uppermost part of the Old Head Formation is included in this study, this dominated by units belonging to facies association 2. At the base of the section (0m - 5m) the sequence consists of mudstone dominated heterolithic material and was probably deposited within a shallow shelf setting. This is overlain between 5m - 10m by a package that includes laminated mudstone and a series of lenticular cross-bedded and rippled sandstone units. This probably reflects deposition upon coastal mudflats that were intersected by sand filled tidal channels and suggests a reduction in relative sea level compared to the underlying package and to the laminated mudstone unit that succeeds it (10m - 13.4m).

At the top of the Old Head Formation two thick sandstone units are separated by a thin symmetrical rippled heterolithic unit (13.4m - 19m). Sandstone units include symmetrical ripples, cross-beds and parallel lamination and probably reflect deposition within a coastal setting although it is also possible that they were generated from transgressive reworking of older deposits. The sharp transition into laminated mudstone overlying the uppermost sandstone probably results from a landward shift in facies belts and possibly upper shoreface erosion as rising relative sea-level drowned this shallow water sequence.

Castle Slate Formation

Between 19m - 27.5m the Castle Slate Formation consists of homogenous mudstone and indicates a phase of pronounced relative sea-level rise.

Narrow Cove Formation

Only the basal part of the Ardaturrish Member has been studied in this section and this exhibits an upward replacement of units belonging to facies association 1 with those belonging to association 2. At the base of this unit between 27.5m - 31.4m the

sequence is mudstone rich and includes graded beds and gutter casts (oriented to the SE) but is overlain by a more sandstone rich heterolithic sequence that includes symmetrical ripples (31.4 - 36.3m). These changes reflect increasing proximity to the coastline whilst the stepped nature of both increasing sandstone content and change in sedimentary structures suggests that this was generated during phases of forced rather than normal regression (Posamentier *et al.* 1992). During episodes of relative sea-level fall the shelf profile became out of equilibrium with the reduced water depth thus encouraging phases of lower shoreface erosion or non-deposition. However, these phases were interrupted by periods of deposition that were generated during higher frequency increases in relative sea-level which briefly countered the longer term trend. The forced regressive sequence therefore consists of a series of non-depositional surfaces that each record a major basinward shift of the coastline but which are separated by phases of deposition that were generated during higher frequency increases in relative sea-level. The depositional packages found between the non-depositional horizons display progressively more proximal facies up-section because of the prevalence of the longer term trend towards reduced relative sea-level. This falling stage systems tract (FST) is markedly different to that developed where sediment supply exceeds accommodation during static or rising base level (HST or LST).

Although the remainder of the Narrow Cove Formation has not been analysed in detail from this section, a brief reconnaissance revealed several closely spaced bedding surfaces (about 100m above the base of the Narrow Cove Formation) containing sandstone filled, downwards tapering cracks (plates 5.15 and 5.16). These are polygonal and taper down-wards but are rather unusually shaped with long straight edges. Recessive weathering of the mudstone between these cracks has removed the surface layer of the mudstone rich unit thereby destroying the horizon that may have included mud curls. In summary, it is unclear whether these cracks result from sub-aerial exposure, synaeresis or interstatal processes (Tanner 1998).

5.4 South Dunmanus Bay

The logged section is 87.8m thick and runs from within the upper part of the Old Head Formation [0857 0356] through the Castle Slate Formation and into the base of

Narrow Cove Formation [0858 0357], details are given in figure 5.1 (map D) and figure 1.7. The section may be accessed from the road that passes through Knockeens from Dunmanus East.

O'Liatháin (1992) reports an LE miospore assemblage from approximately 34m above the base of the Old Head Formation whilst LN assemblages are recorded from 74m above the base of the Old Head Formation and 5m below the top of this unit. O'Liatháin (1992) also reports VI assemblages from 0.1m and 0.5m above the base of the Castle Slate Formation and HD assemblages from 3m above the base of the Ardaturrish Member (Narrow Cove Formation), 0.3m below the top of this unit and from 19m above the base of the Pigs Cove Formation. Higgs *et al.* (1988) report similar findings although these authors these authors report a VI assemblage from low in the Narrow Cove Formation.

Old Head Formation

Only the upper part of the Old Head Formation has been studied in this section and this mainly includes units belonging to facies association 2. Between 0.0m - 13.7m the sequence consists of a series of relatively sandstone rich heteroliths. These contain rippled and parallel laminated sandstone linsen and are associated with abundant horizontal and vertical burrows (1-6mm in diameter). This package probably reflects deposition within a fairly proximal wave and possibly tide influenced shelf.

From 13.7m - 27.8m the sequence consists of a series of poorly sorted mudstone rich heterolithic units. Considering the high degree of bioturbation in the underlying sequence it is possible that the poor sorting exhibited in this sequence results from partial homogenisation and reworking of thinner sandstone linsen by burrowing organisms although this is not clear. The dominance of mudstone within this sequence may indicate a phase of accommodation dominance within a shallow shelf setting.

At the top of the Old Head Sandstone (26.2m - 36.0m) the sequence consists of a series of rippled or cross-bedded sandstone packages separated by mudstone rich heterolithic units. The two thinner sandstone packages (27.8m - 28.2m and 29.8m -

30.4m) in the lower part of the sequence are perhaps most likely to reflect transgressive deposits generated by reworking whilst the thicker sandstone unit (31.3m - 34.6m) may reflect a lowstand coastal sequence. The orange decalcified horizons at the top of the thicker unit may have originated as shelly material that became concentrated during the low rates of deposition common during periods of relative sea-level rise (plate 5.10). Intervening mudstone rich units probably reflect deposition within an accommodation dominated shelf setting.

The uppermost part of the Old Head Formation (34.6m - 36m) consists of a laminated mudstone with occasional decalcified layers and was probably deposited within a offshore transitional shelf setting.

Castle Slate Formation

The Castle Slate Formation exposed between 36.0m - 40.0m consists of dark grey homogenous mudstone and is thinner (~4m) than in adjacent northern sections (North Dunmanus Bay ~ 7m, South Bantry Bay ~ 10m). The Castle Slate Formation is likely to have been deposited during a phase of relative sea-level rise.

Narrow Cove Formation

Only the basal part of the Ardaturrish Member has been studied in this section. At the base of this unit between 40.0m - 48.0m the sequence is dominated by a mudstone rich package containing gutter casts, graded bed and symmetrical ripples (facies association 1). This displays an overall increase in sandstone content upwards. The sequence probably reflects deposition within an offshore transitional storm dominated setting whilst the upwards increase in sandstone content probably indicates increasing proximity of the coastline.

At 48.0m the sequence exhibits a marked increase in sandstone content and change in sedimentary structures reflecting replacement of units belonging to facies association 1 with those belonging to association 2, this sequence persists until the top of logged section at 86.7m. This sequence consists of both sandstone rich and mudstone rich heterolithic packages but does not include either graded beds or gutter casts. Small scale symmetrical ripples and parallel lamination are found throughout this sequence and are associated with prolific bioturbation although this decreases

upwards. Variation in sandstone content throughout this sequence probably reflects changes in relative sea-level. The dramatic change in both sandstone content and facies type found at the base of this sequence probably reflects relative sea-level fall thus allowing replacement of storm influence by wave influence as a result of wave attenuation.

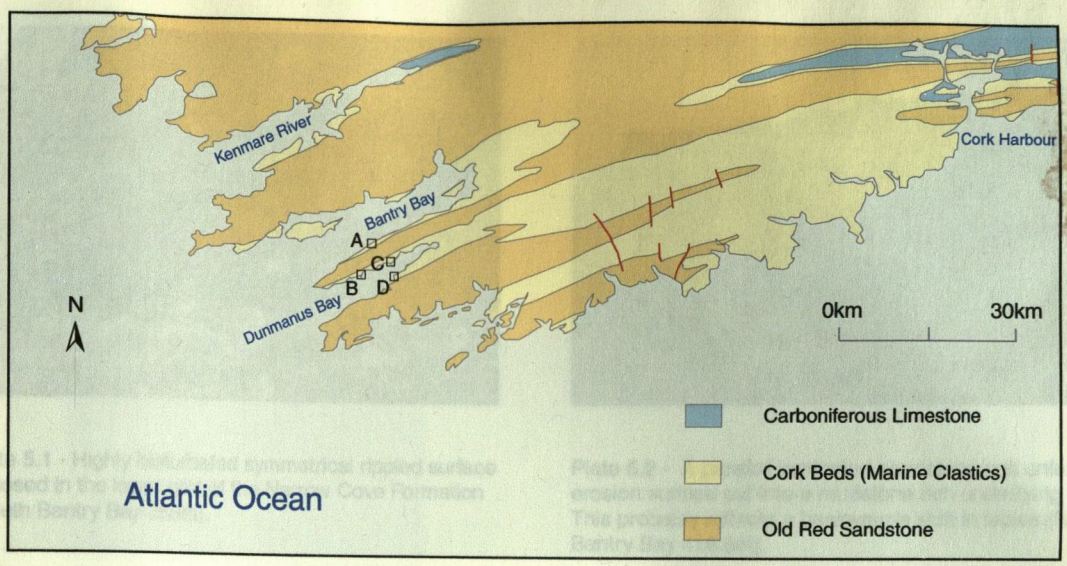
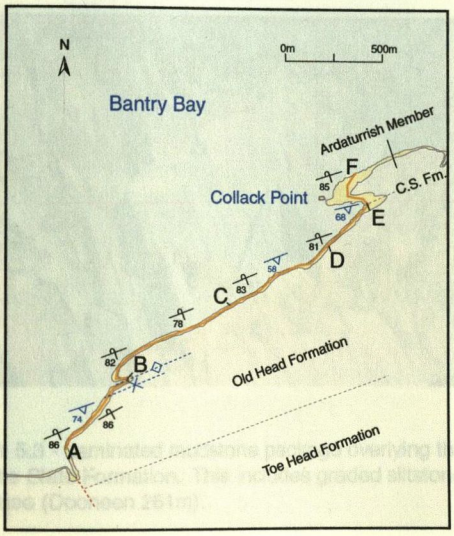
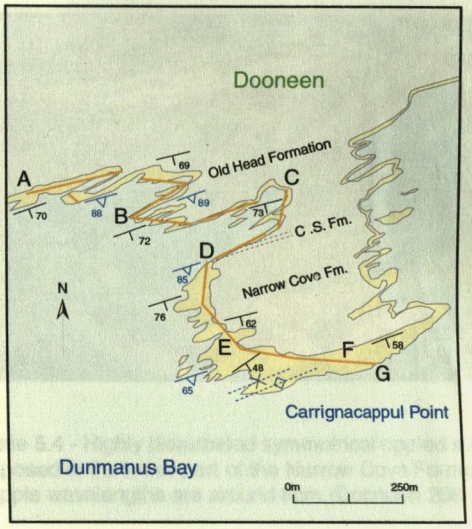


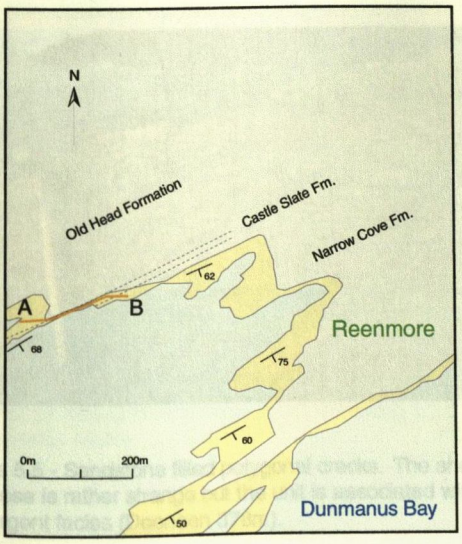
Figure 5.1 - Location of logged sections from the south of Bantry Bay and Dunmanus Bay.



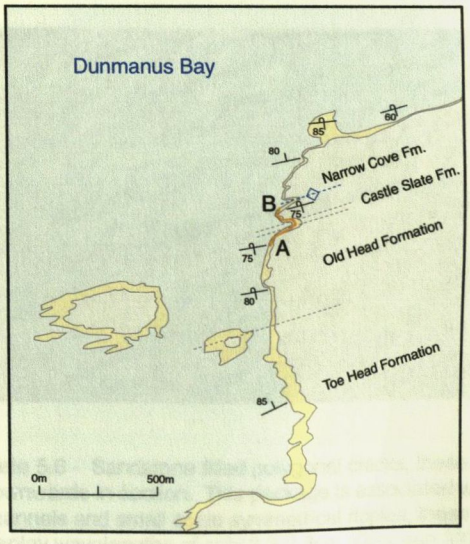
Map A - South Bantry Bay. C.S. Fm. is the Castle Slate Formation



Map B - Dooneen, North Dunmanus Bay.



Map C - Reenmore, North Dunmanus Bay.



Map D - South Dunmanus Bay. Modified from Naylor (1975)



Plate 5.1 - Highly bioturbated symmetrical rippled surface exposed in the lower part of the Narrow Cove Formation (South Bantry Bay 358m).



Plate 5.2 - A parallel laminated sandstone unit onlaps an erosion surface cut into a mudstone rich underlying unit. This probably reflects a basinwards shift in facies (South Bantry Bay 418.5m).



Plate 5.3 - Laminated mudstone package overlying the Castle Slate Formation. This includes graded siltstone laminae (Dooneen 261m).



Plate 5.4 - Highly bioturbated symmetrical rippled surface exposed in the lower part of the Narrow Cove Formation. Ripple wavelengths are around 8cm (Dooneen 268m).



Plate 5.5 - Sandstone filled polygonal cracks. The shape of these is rather strange but the unit is associated with emergent facies (Dooneen 378m).



Plate 5.6 - Sandstone filled polygonal cracks, these taper downwards in section. This package is associated with channels and small scale symmetrical ripples, these display wavelengths of only 2.3-3.8cm (Dooneen 387m)

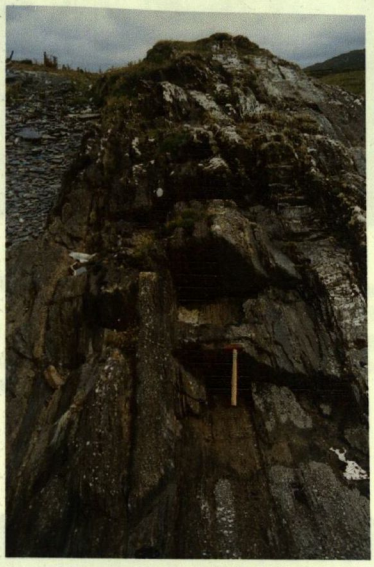


Plate 5.7 - Junction between the Castle Slate Formation (left) and the top of the Old Head Formation (right) which includes several orange weathering patches that may reflect decalcification (South Bantry Bay 322m).

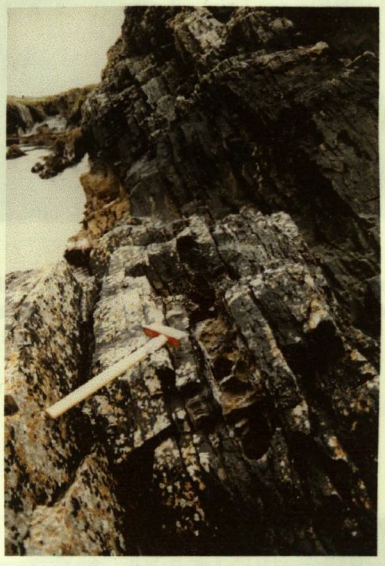


Plate 5.8 - The upper-most sandstone unit of the Old Head Formation lying directly below the Castle Slate Formation. The weathered orange lenses probably reflects decalcification (Dooneen 247m).

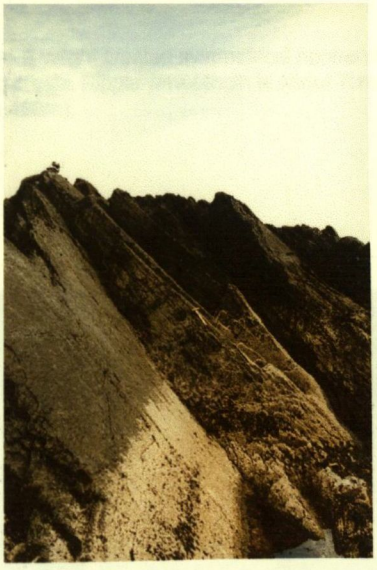


Plate 5.9 - Lateral accretion surfaces within the Narrow Cove Formation. These probably reflect deposition within an inter-tidal or shallow sub-tidal setting (Dooneen 485m).

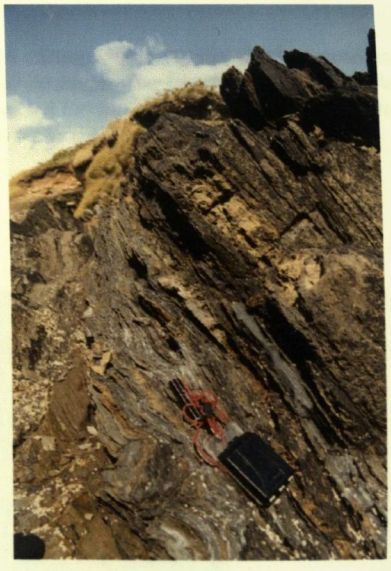


Plate 5.10 - Junction between the Castle Slate Formation (left) and the top of the Old Head Formation (right). The top of the Old Head Formation includes several orange weathering patches that may reflect decalcification (South Dunmanus 35m).



Plate 5.11 - Alternating units consisting of asymmetric ripples or parallel lamination. This is found in the basal portion of a thick erosive based sandstone package and may reflect changes in the tidal cycle within a nearshore setting (Dooneen 407m).

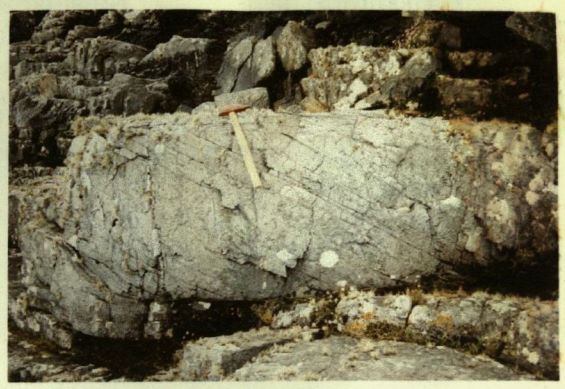


Plate 5.12 - Very large scale (80cm) tabular cross-beds developed within a thick sandstone package. These are oriented to the south (Dooneen 420m).



Plate 5.13 - Straight crested symmetrical ripples with bifurcating crests. Ripple wavelength is about 7cm (Dooneen 428m).



Plate 5.14 - Steep sided channel within a sandstone dominated package. The basal part of the channel fill is massive but the top includes east dipping lateral accretion surfaces (Dooneen 459m).

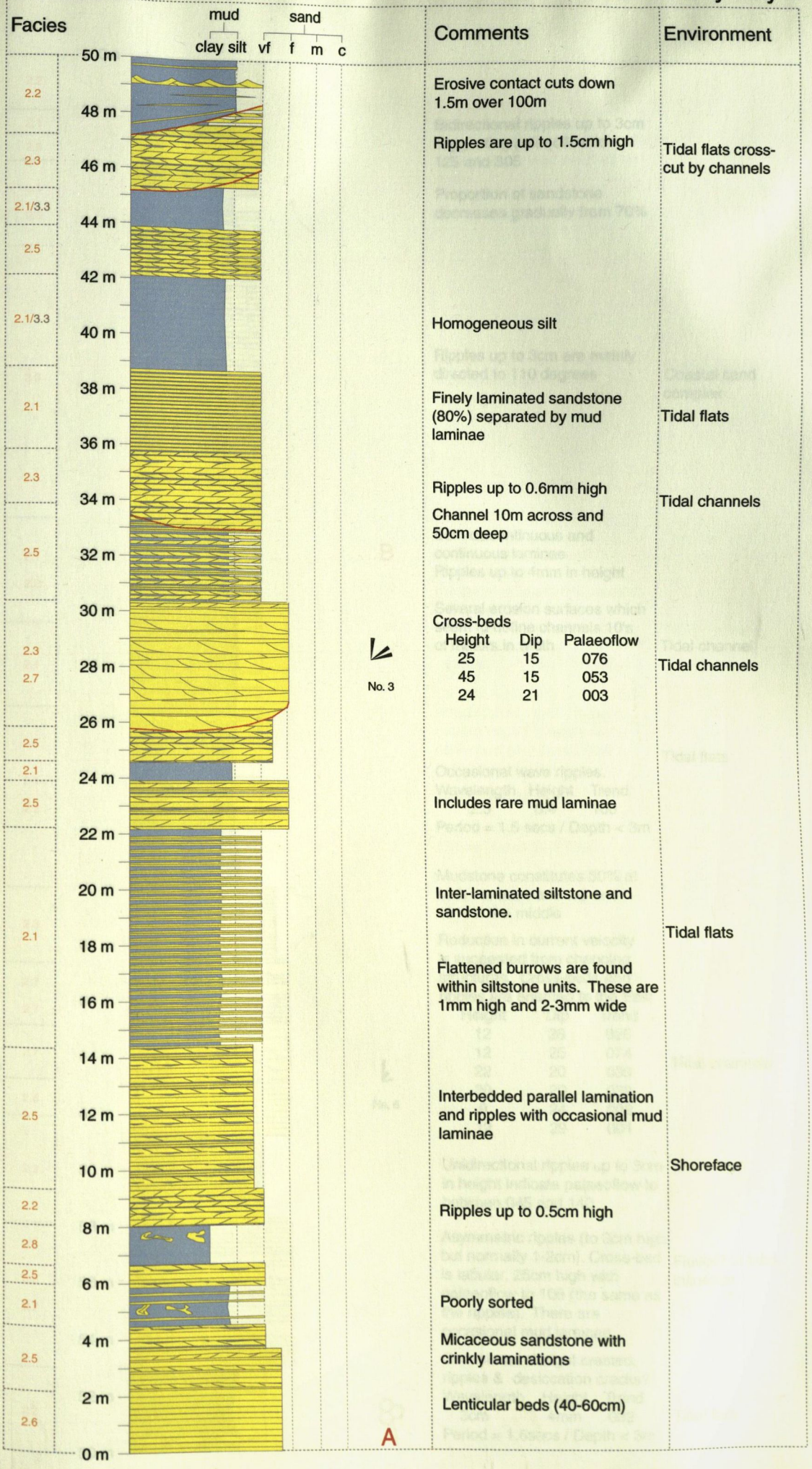


Plate 5.15 - Downwards tapering sandstone filled cracks. It is unclear whether these were generated by desiccation (Reenmore).

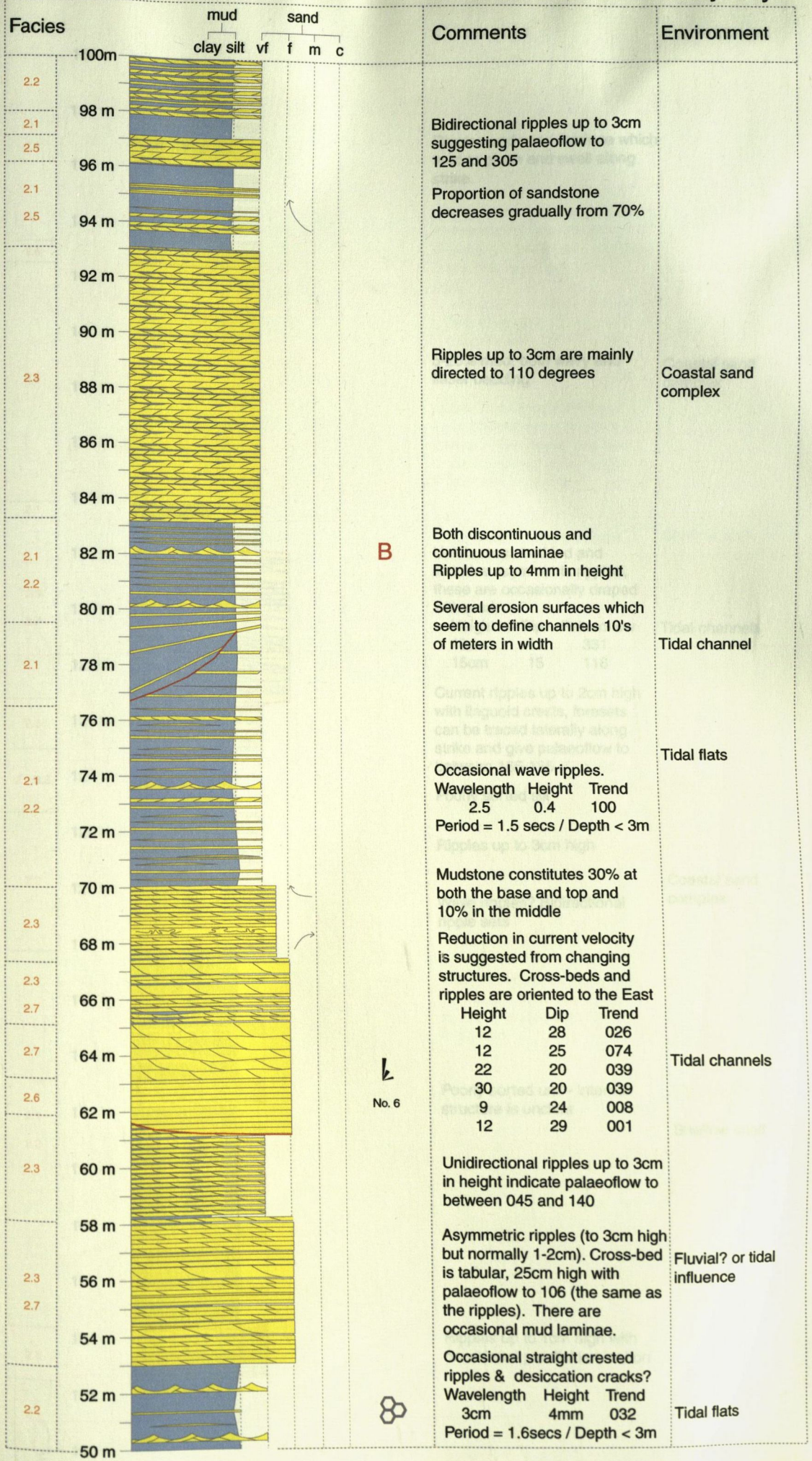


Plate 5.16 - Downwards tapering sandstone filled cracks. It is unclear whether these were generated by desiccation (Reenmore).

South Bantry Bay 1

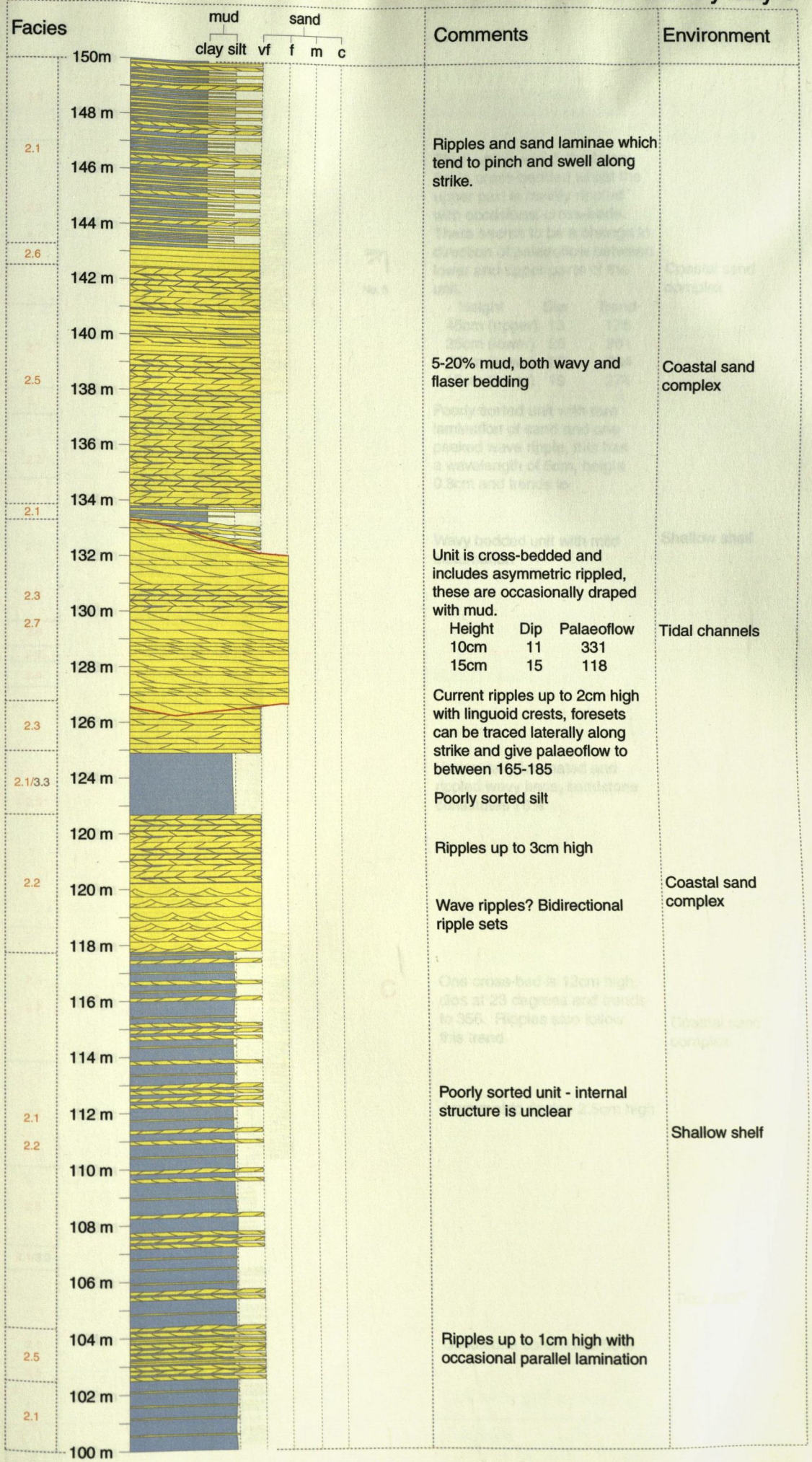


South Bantry Bay 2



Comments	Environment
Bidirectional ripples up to 3cm suggesting palaeoflow to 125 and 305 Proportion of sandstone decreases gradually from 70%	
Ripples up to 3cm are mainly directed to 110 degrees	Coastal sand complex
Both discontinuous and continuous laminae Ripples up to 4mm in height Several erosion surfaces which seem to define channels 10's of meters in width	Tidal channel
Occasional wave ripples. Wavelength Height Trend 2.5 0.4 100 Period = 1.5 secs / Depth < 3m	Tidal flats
Mudstone constitutes 30% at both the base and top and 10% in the middle Reduction in current velocity is suggested from changing structures. Cross-beds and ripples are oriented to the East Height Dip Trend 12 28 026 12 25 074 22 20 039 30 20 039 9 24 008 12 29 001	Tidal channels
Unidirectional ripples up to 3cm in height indicate palaeoflow to between 045 and 140 Asymmetric ripples (to 3cm high but normally 1-2cm). Cross-bed is tabular, 25cm high with palaeoflow to 106 (the same as the ripples). There are occasional mud laminae.	Fluvial? or tidal influence
Occasional straight crested ripples & desiccation cracks? Wavelength Height Trend 3cm 4mm 032 Period = 1.6secs / Depth < 3m	Tidal flats

South Bantry Bay 3

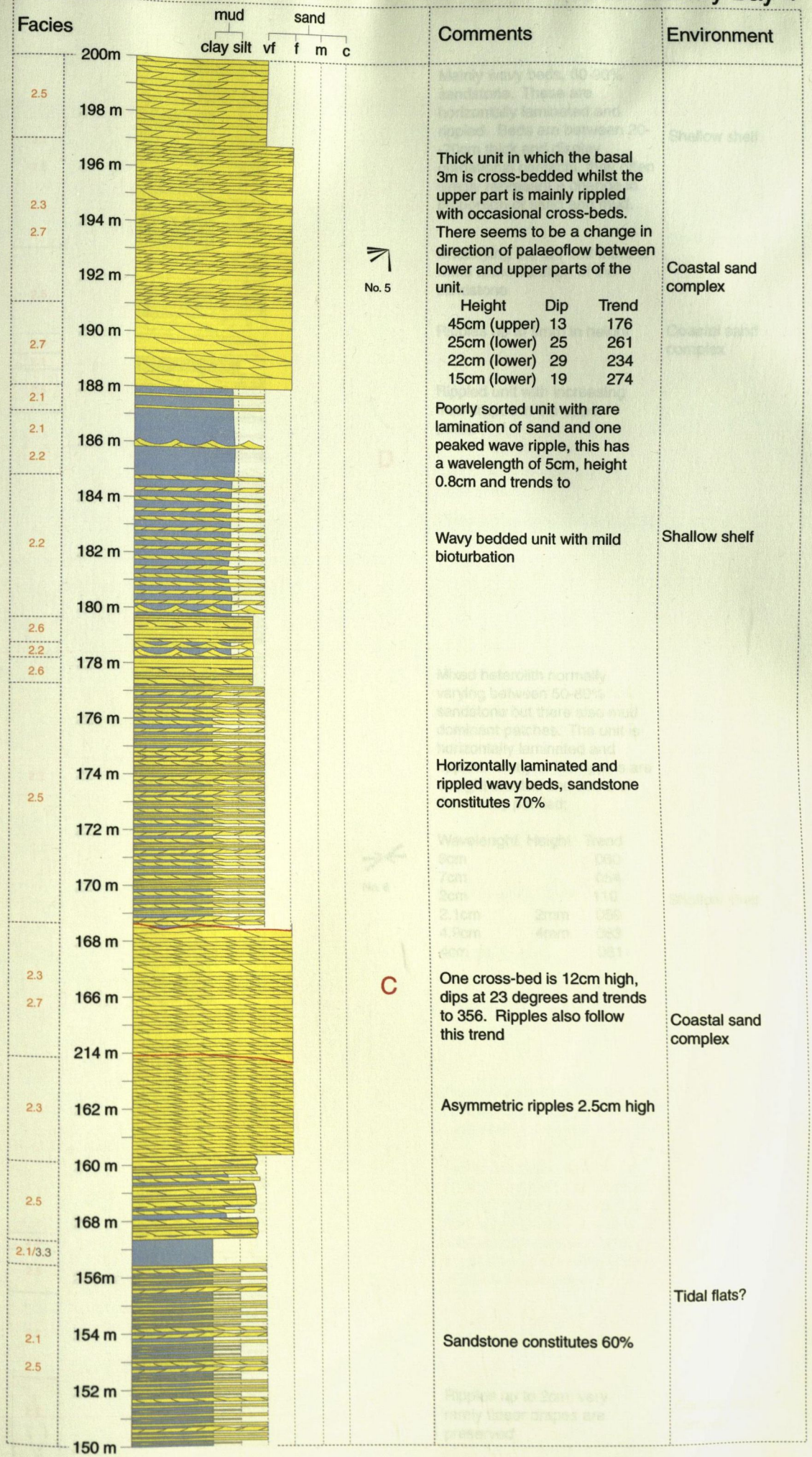


Comments	Environment
Ripples and sand laminae which tend to pinch and swell along strike.	
5-20% mud, both wavy and flaser bedding	Coastal sand complex
Unit is cross-bedded and includes asymmetric rippled, these are occasionally draped with mud.	

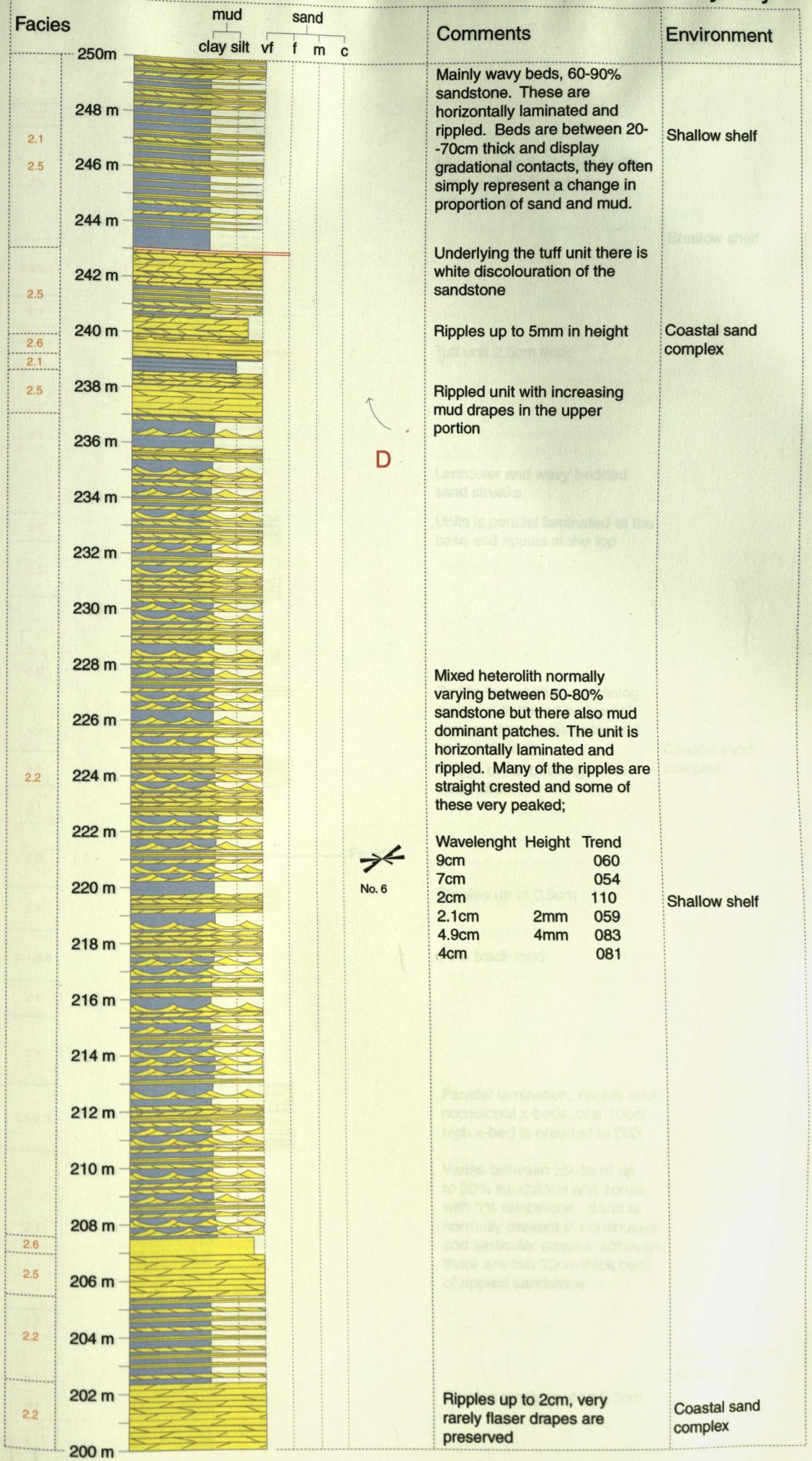
Height	Dip	Palaeoflow
10cm	11	331
15cm	15	118

Comments	Environment
	Tidal channels
Current ripples up to 2cm high with linguoid crests, foresets can be traced laterally along strike and give palaeoflow to between 165-185	
Poorly sorted silt	
Ripples up to 3cm high	
Wave ripples? Bidirectional ripple sets	Coastal sand complex
Poorly sorted unit - internal structure is unclear	Shallow shelf
Ripples up to 1cm high with occasional parallel lamination	

South Bantry Bay 4

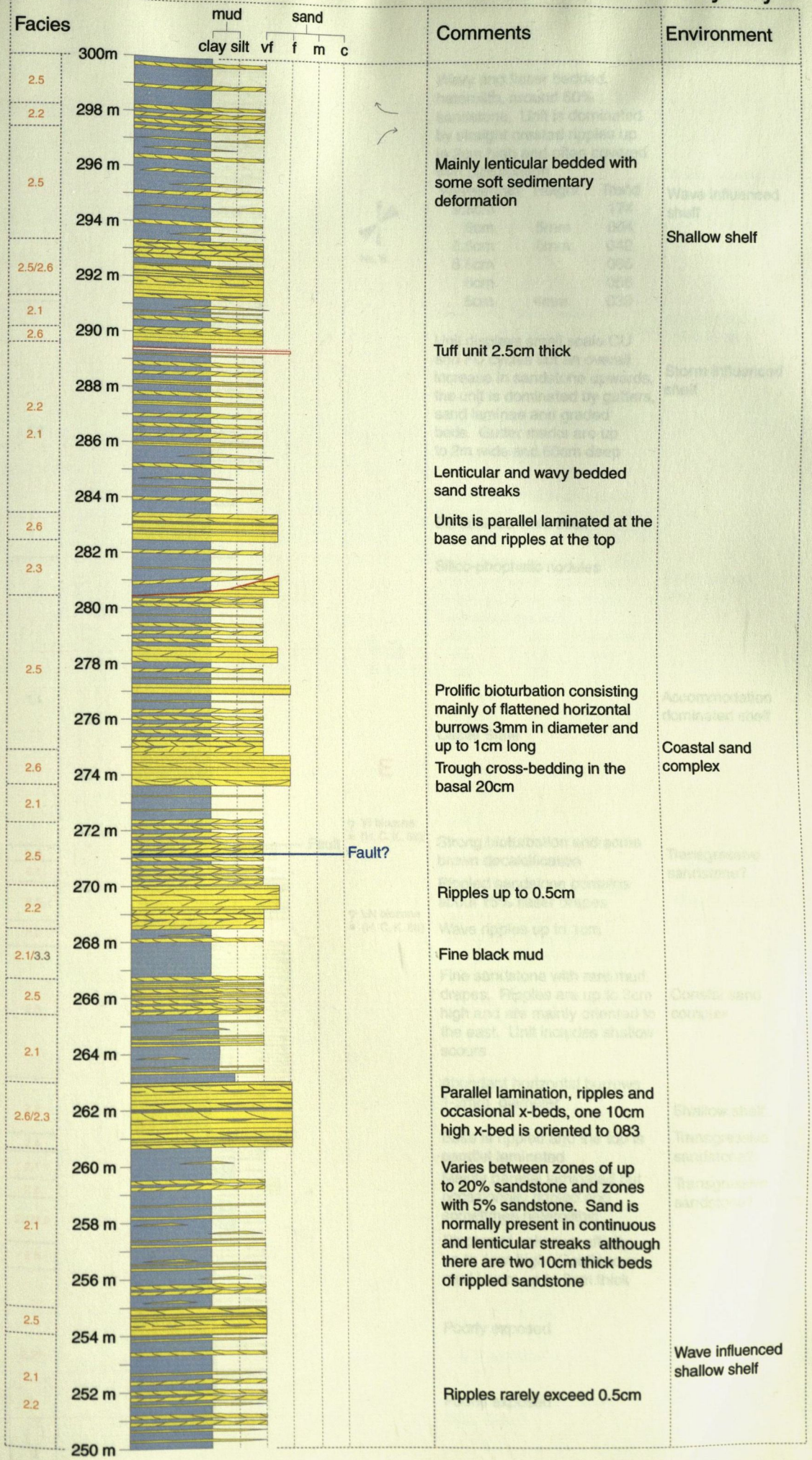


South Bantry Bay 5

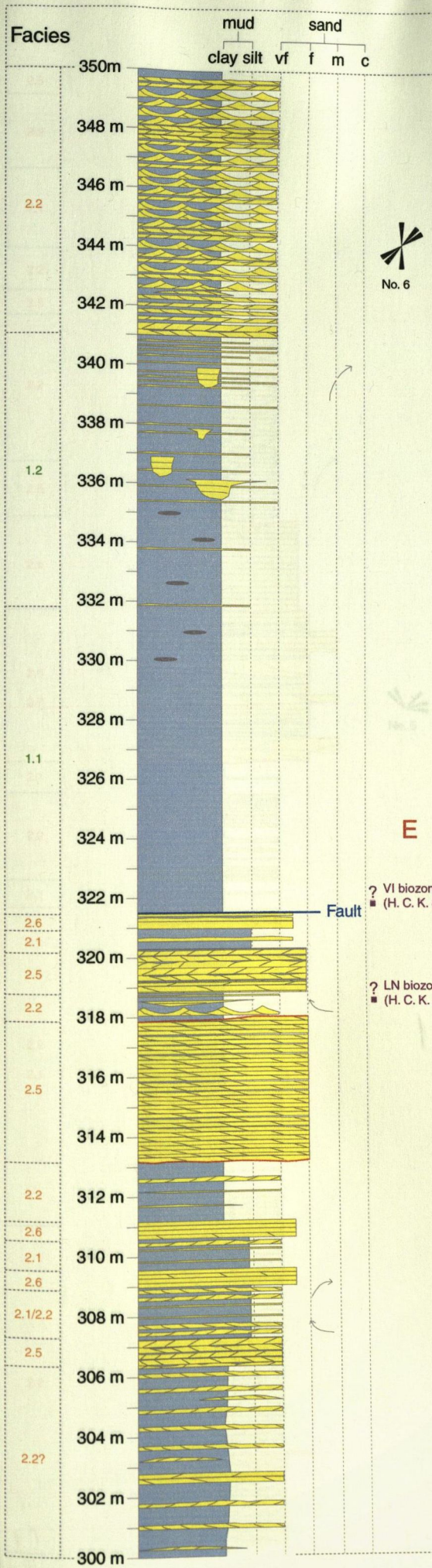


Comments	Environment
Mainly wavy beds, 60-90% sandstone. These are horizontally laminated and rippled. Beds are between 20--70cm thick and display gradational contacts, they often simply represent a change in proportion of sand and mud.	Shallow shelf
Underlying the tuff unit there is white discolouration of the sandstone	
Ripples up to 5mm in height	Coastal sand complex
Rippled unit with increasing mud drapes in the upper portion	
Mixed heterolith normally varying between 50-80% sandstone but there also mud dominant patches. The unit is horizontally laminated and rippled. Many of the ripples are straight crested and some of these very peaked;	
Wavelenght Height Trend 9cm 060 7cm 054 2cm 110 2.1cm 2mm 059 4.9cm 4mm 083 4cm 081	Shallow shelf
Ripples up to 2cm, very rarely flaser drapes are preserved	Coastal sand complex

South Bantry Bay 6

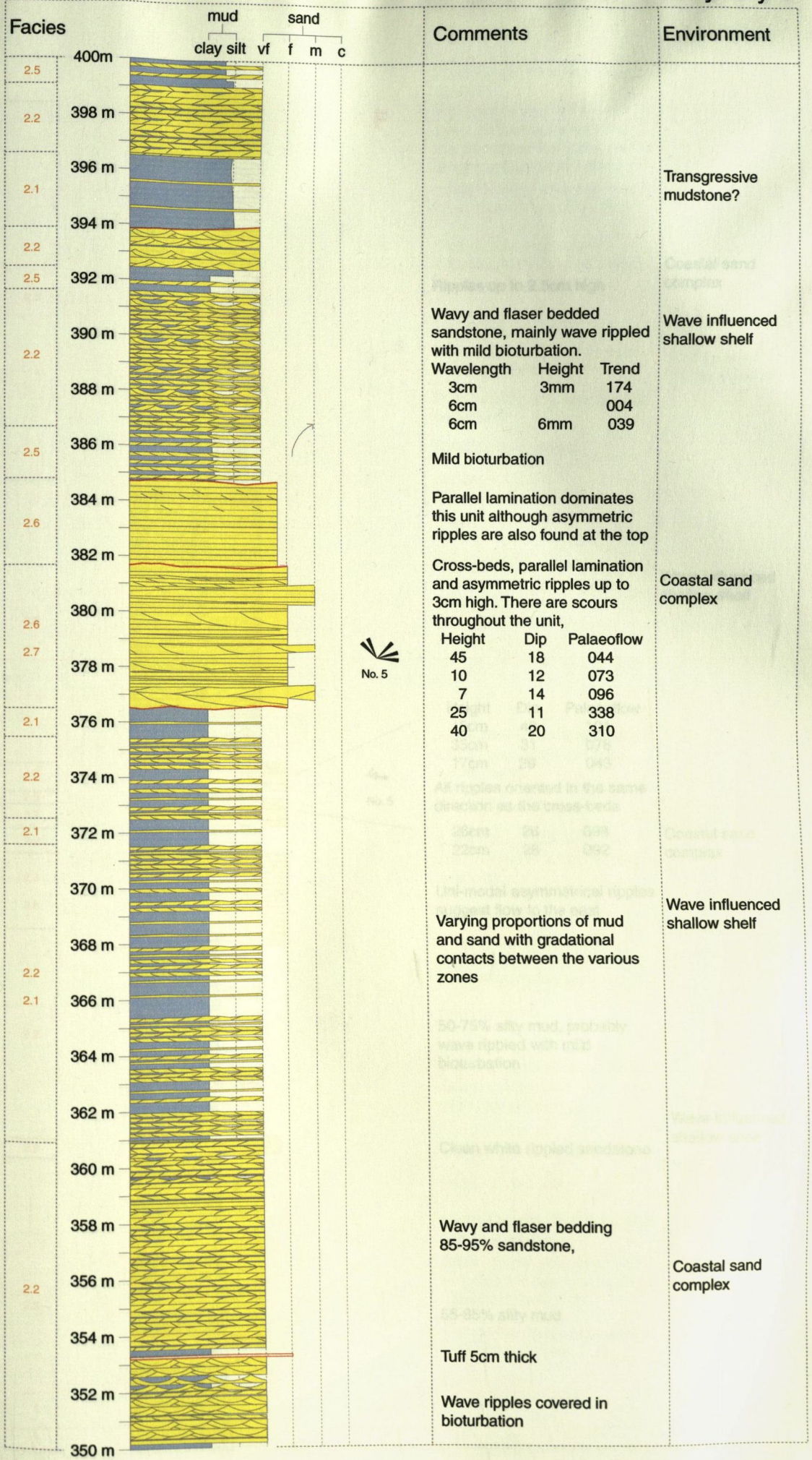


South Bantry Bay 7



Facies	Comments	Environment
2.2	Wavy and flaser bedded heterolith, around 60% sandstone. Unit is dominated by straight crested ripples up to 2cm high and often covered with bioturbation Wavelength / Height / Trend 9.5cm / 174 6cm / 5mm / 004 6.5cm / 5mm / 042 6.5cm / 065 6cm / 056 5cm / 4mm / 039	Wave influenced shelf
1.2	Unit displays small scale CU and FU cycles but an overall increase in sandstone upwards, the unit is dominated by gutters, sand laminae and graded beds. Gutter marks are up to 2m wide and 60cm deep	Storm influenced shelf
	Silt laminae 1mm thick	
	Silico-phophatic nodules	
1.1	Castle Slate	Accommodation dominated shelf
2.6	Strong bioturbation and some brown decalcification	Transgressive sandstone?
2.1	Rippled sandstone contains about 15% flaser drapes	
2.5	Wave ripples up to 1cm	
2.2	Fine sandstone with rare mud drapes. Ripples are up to 3cm high and are mainly oriented to the east. Unit includes shallow scours	Coastal sand complex
2.5	Abundant horizontal burrows 1-2mm diameter	Shallow shelf
2.2	Base is rippled and the top is parallel laminated	Transgressive sandstone?
2.6	Mainly parallel laminated but occasionally rippled and sometimes heterolithic	Transgressive sandstone?
2.1	Ripples of unknown affinity up to 1cm high. Continuous mud layers up to 3cm thick	
2.6	Poorly exposed	Wave influenced shallow shelf
2.1/2.2	Poorly exposed	
2.5		
2.2?		

South Bantry Bay 8



Comments

Wavy and flaser bedded sandstone, mainly wave rippled with mild bioturbation.

Wavelength	Height	Trend
3cm	3mm	174
6cm		004
6cm	6mm	039

Mild bioturbation

Parallel lamination dominates this unit although asymmetric ripples are also found at the top

Cross-beds, parallel lamination and asymmetric ripples up to 3cm high. There are scours throughout the unit,

Height	Dip	Palaeoflow
45	18	044
10	12	073
7	14	096
25	11	338
40	20	310

Varying proportions of mud and sand with gradational contacts between the various zones

Wavy and flaser bedding 85-95% sandstone,

Tuff 5cm thick

Wave ripples covered in bioturbation

Environment

Transgressive mudstone?

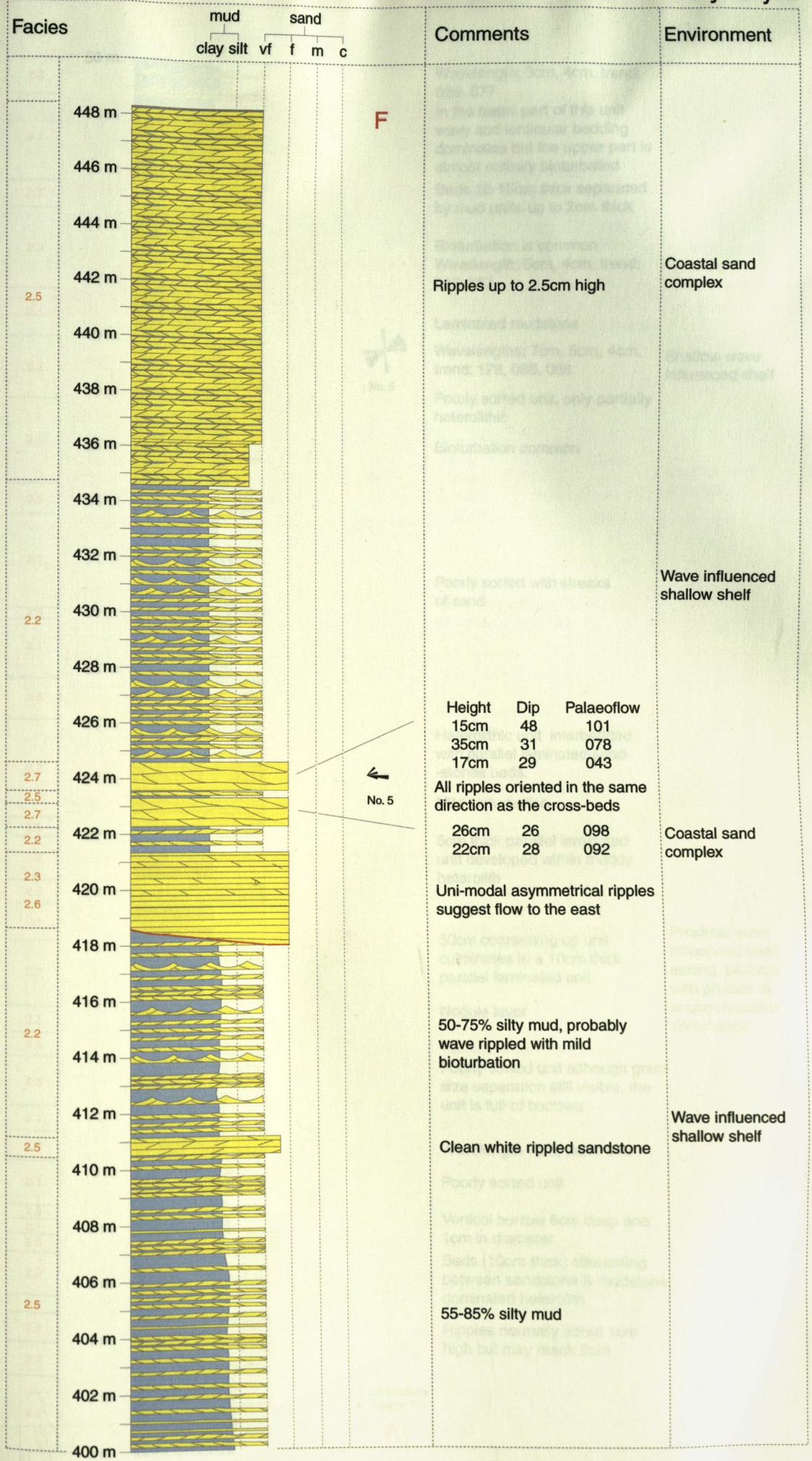
Wave influenced shallow shelf

Coastal sand complex

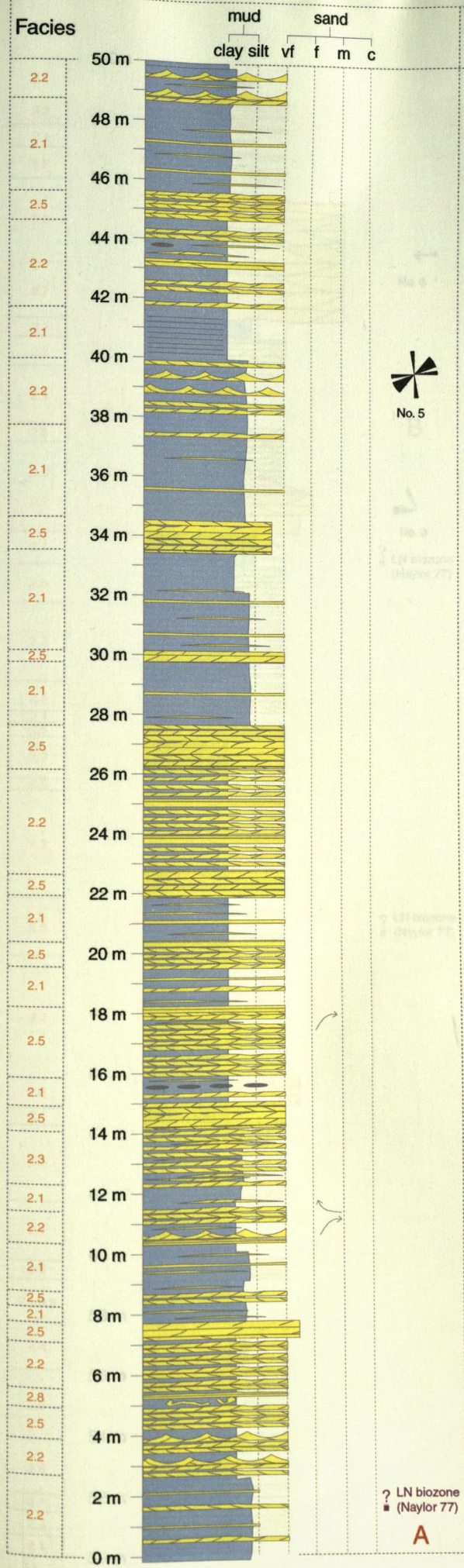
Wave influenced shallow shelf

Coastal sand complex

South Bantry Bay 9

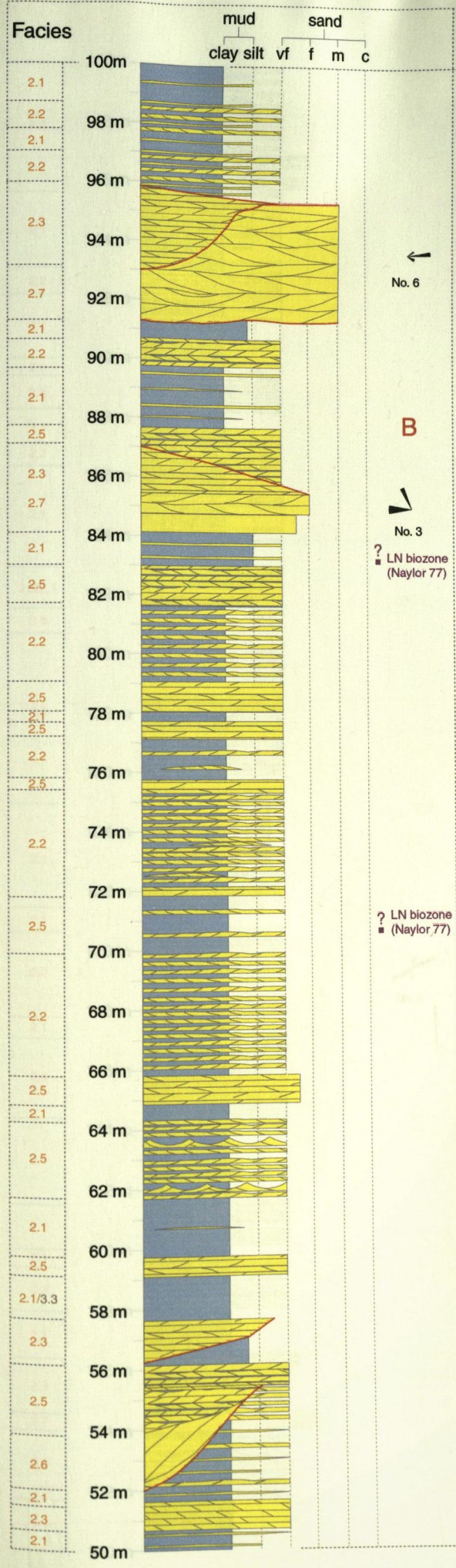


Dooneen 1



Comments	Environment
Wavelength; 3cm, 4cm, trend; 066, 077 In the basal part of this unit wavy and lenticular bedding dominates but the upper part is almost entirely bioturbated	Shallow wave influenced shelf
Beds 10-15cm thick separated by mud units up to 2cm thick	
Bioturbation is common Wavelength; 5cm, 4cm, trend; 042, 057	
Laminated mudstone	
Wavelengths; 7cm, 5cm, 4cm, trend; 178, 085, 066	
Poorly sorted unit, only partially heterolithic	
Bioturbation common	
Poorly sorted with streaks of sand	
Heterolithic unit interbedded with parallel laminated sand--stones beds.	Proximal wave influenced shelf setting, perhaps with phases of accommodation dominance
Mild bioturbation	
5cm thick parallel laminated unit developed within muddy heterolith	
50cm coarsening up unit culminates in a 10cm thick parallel laminated unit	
Nodule layer	
Poorly sorted unit although grain size separation still visible, the unit is full of burrows	
Wavelength 7cm, trend 048	
Poorly sorted unit	
Vertical burrow 6cm deep and 1cm in diameter	
Beds (10cm thick) alternating between sandstone & mudstone dominated heterolith	
Ripples normally about 1cm high but may reach 2cm	

Dooneen 2



No. 6

B

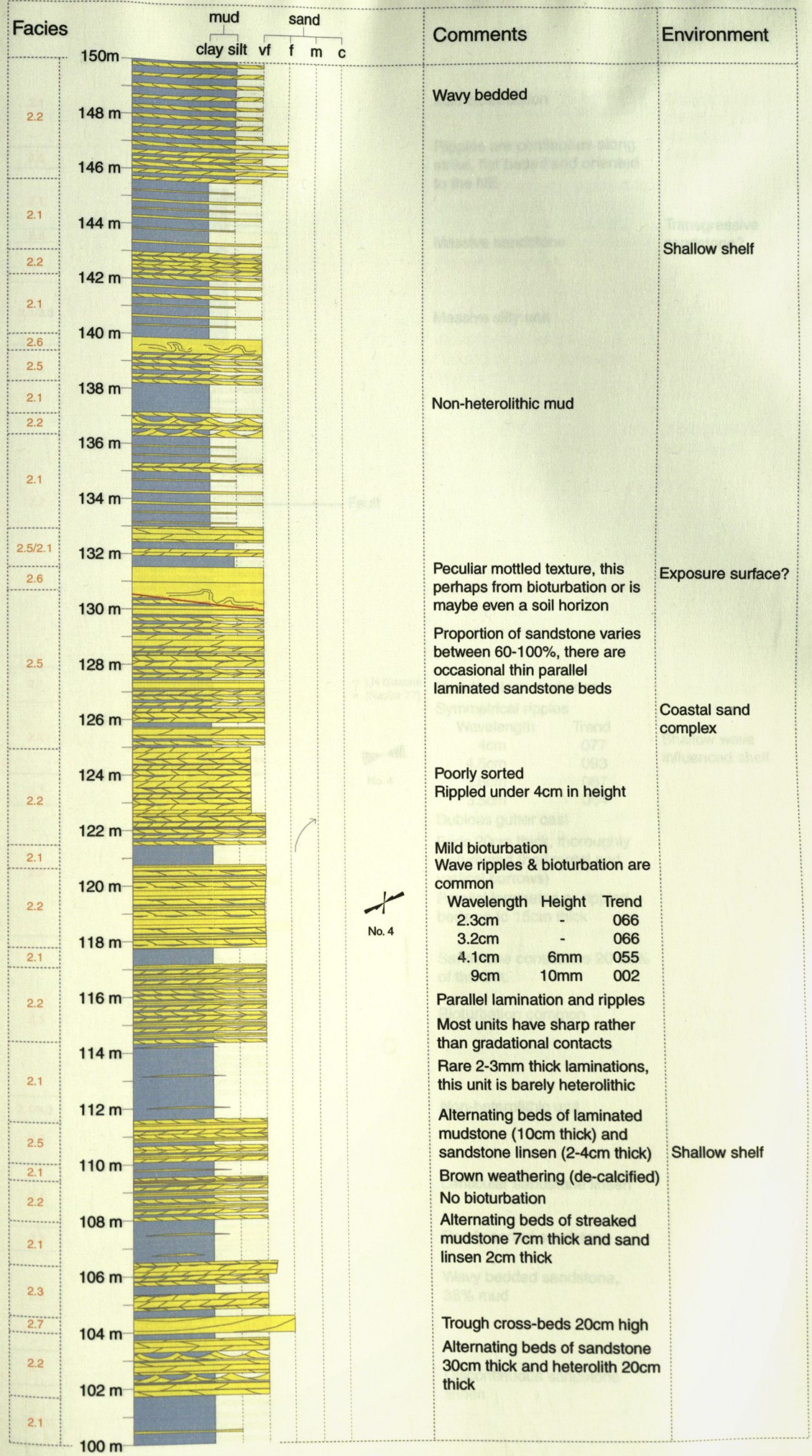
No. 3

? LN biozone (Naylor 77)

? LN biozone (Naylor 77)

Comments	Environment
Streaks of silt and sand (1mm thick)	
Trough cross-bedded unit, Height Dip Trend 11cm 25 122 30cm 15 111 20cm 9 084 20cm 16 081 22cm 16 081 40cm 21 054	Coastal sand complex
Wave ripples, wavelength 3cm, crest trend; 070	Tidal flats?
Cross beds: Height Dip Trend 25cm 34 276 28cm 31 267 7cm 35 339	Coastal sand complex
Wavy and flaser bedded unit, partially bioturbated	
Mild bioturbation	
Wavy and lenticular beds	Shallow wave influenced shelf
Partially tectonised unit, internal structure unclear	
Varying proportions of sandstone from 20% to 80%. Very straight ripple crests with wavelength of 4cm, and trend to 067. Also interference ripples	
Strongly bioturbated	
At the top of this unit there microripples wavelength 1.5cm, possibly also desiccation cracks	Tidal flats crosscut by tidal channels
Cross-bed is 20cm high, dips at 15 and trends to 336	
Linguoid ripples all oriented to 050. Ripples are 0.5cm-2cm high	

Dooneen 3

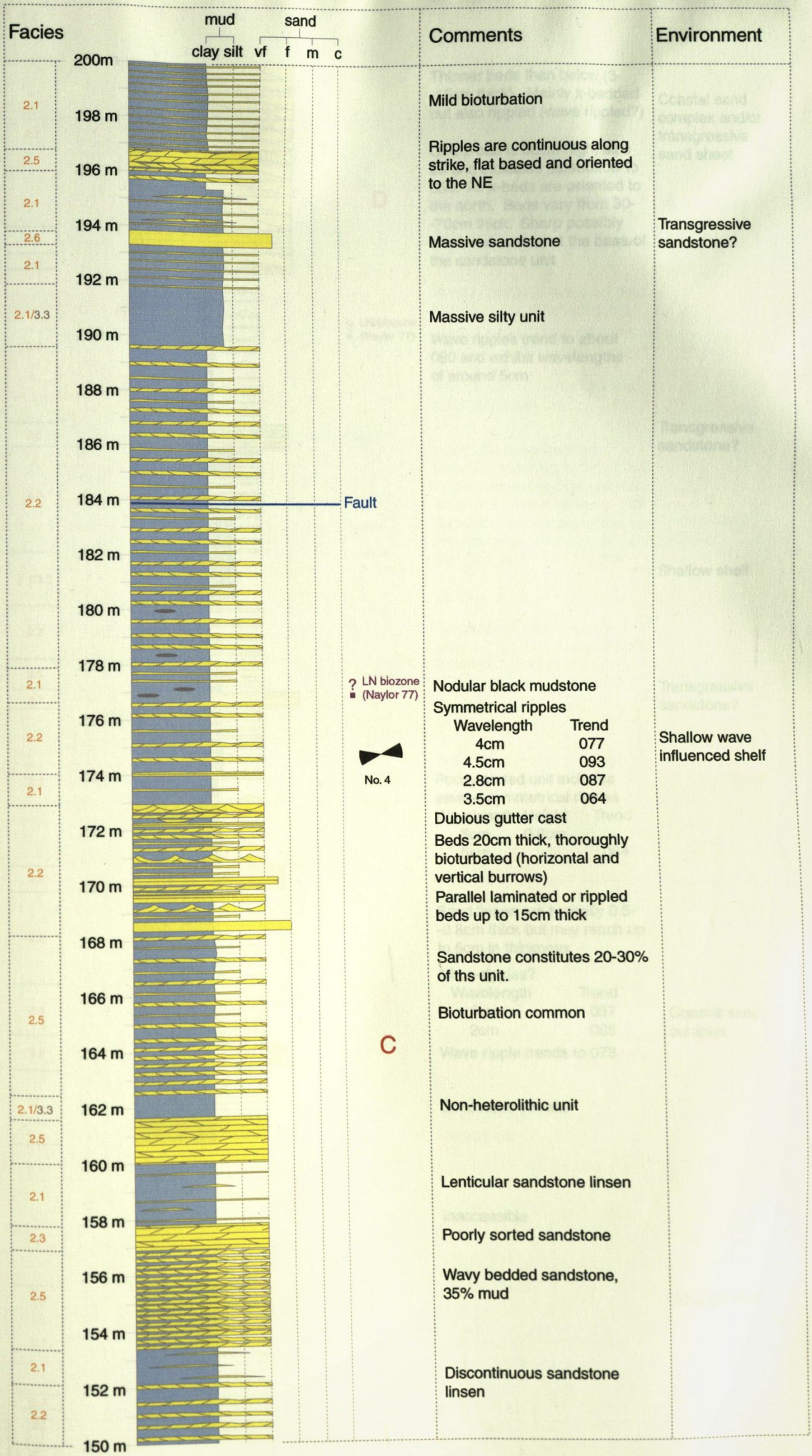


Comments	Environment
Wavy bedded	
	Shallow shelf
Non-heterolithic mud	
Peculiar mottled texture, this perhaps from bioturbation or is maybe even a soil horizon	Exposure surface?
Proportion of sandstone varies between 60-100%, there are occasional thin parallel laminated sandstone beds	
	Coastal sand complex
Poorly sorted Rippled under 4cm in height	
Mild bioturbation Wave ripples & bioturbation are common	

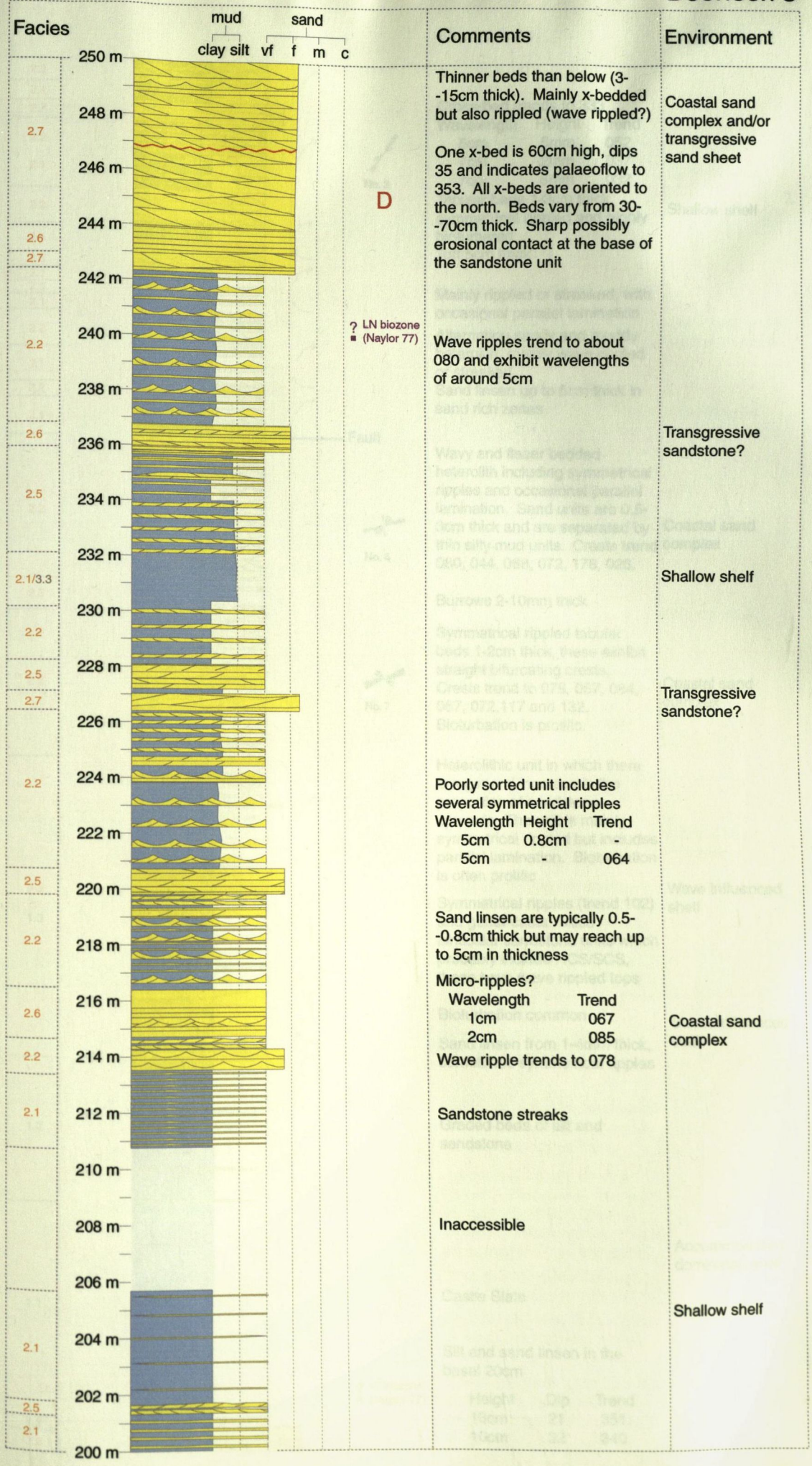
Wavelength	Height	Trend
2.3cm	-	066
3.2cm	-	066
4.1cm	6mm	055
9cm	10mm	002

Comments	Environment
Parallel lamination and ripples Most units have sharp rather than gradational contacts Rare 2-3mm thick laminations, this unit is barely heterolithic	
Alternating beds of laminated mudstone (10cm thick) and sandstone linsen (2-4cm thick) Brown weathering (de-calcified) No bioturbation	Shallow shelf
Alternating beds of streaked mudstone 7cm thick and sand linsen 2cm thick	
Trough cross-beds 20cm high	
Alternating beds of sandstone 30cm thick and heterolith 20cm thick	

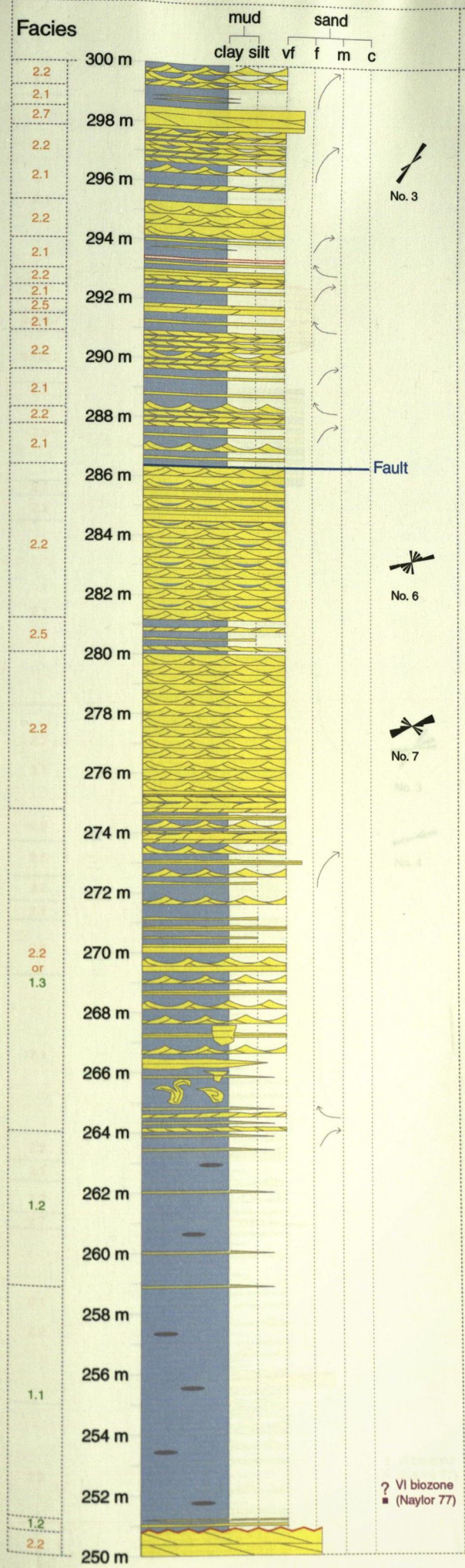
Dooneen 4


Facies
mud
clay silt
sand
vf f m c
Comments
Environment
200m
198 m
196 m
194 m
192 m
190 m
188 m
186 m
184 m
182 m
180 m
178 m
176 m
174 m
172 m
170 m
168 m
166 m
164 m
162 m
160 m
158 m
156 m
154 m
152 m
150 m
2.1
2.5
2.1
2.6
2.1
2.1/3.3
2.2
2.1
2.2
2.1
2.2
2.5
2.1/3.3
2.5
2.1
2.3
2.5
2.1
2.2
Fault
? LN biozone
(Naylor 77)
No. 4
C
Mild bioturbation
Ripples are continuous along strike, flat based and oriented to the NE
Massive sandstone
Massive silty unit
Nodular black mudstone
Symmetrical ripples
Wavelength Trend
4cm 077
4.5cm 093
2.8cm 087
3.5cm 064
Dubious gutter cast
Beds 20cm thick, thoroughly bioturbated (horizontal and vertical burrows)
Parallel laminated or rippled beds up to 15cm thick
Sandstone constitutes 20-30% of ths unit.
Bioturbation common
Non-heterolithic unit
Lenticular sandstone linsen
Poorly sorted sandstone
Wavy bedded sandstone, 35% mud
Discontinuous sandstone linsen
Transgressive sandstone?
Shallow wave influenced shelf

Dooneen 5

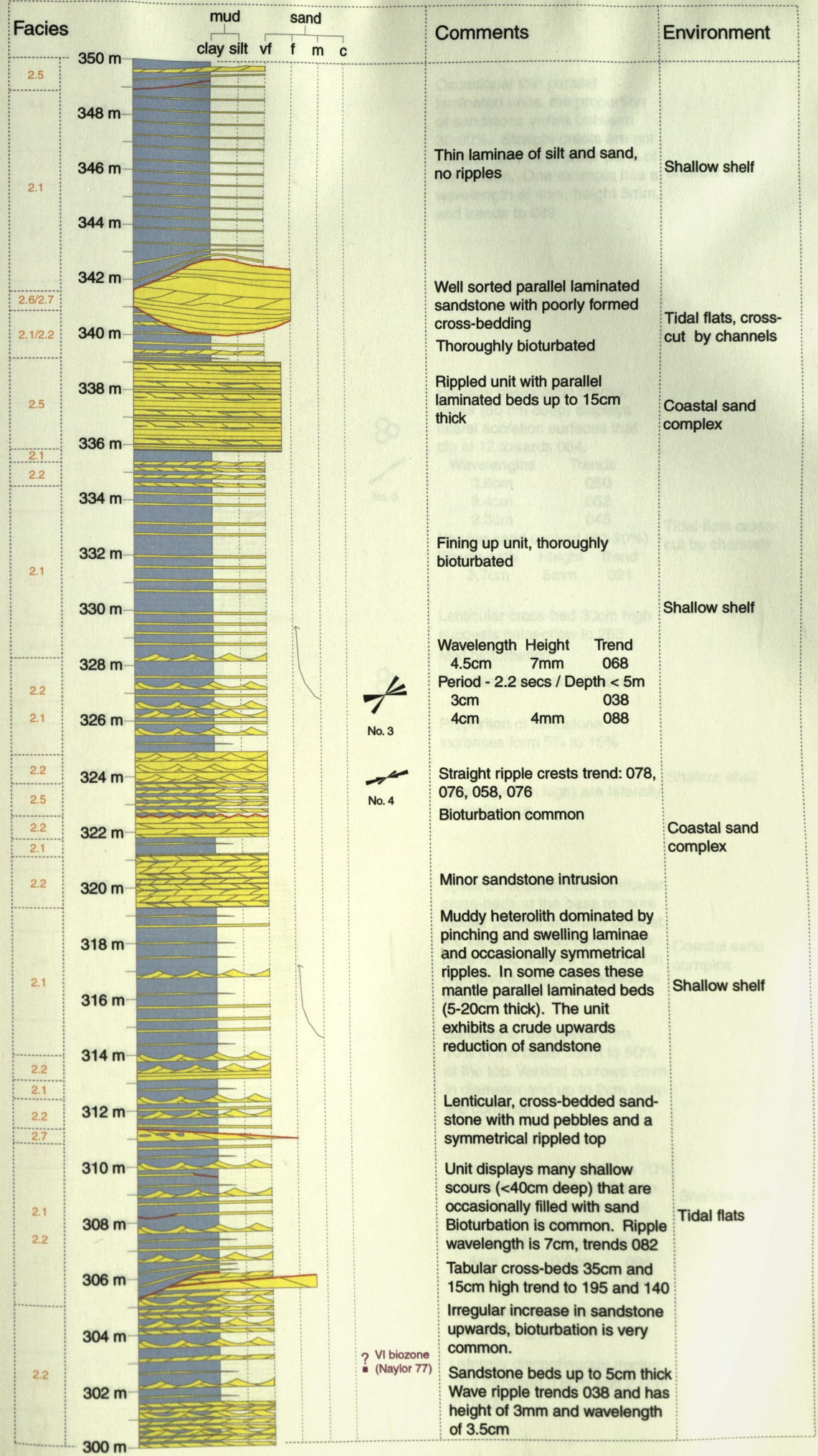

Facies
mud
clay silt
sand
vf f m c
250 m
248 m
246 m
244 m
242 m
240 m
238 m
236 m
234 m
232 m
230 m
228 m
226 m
224 m
222 m
220 m
218 m
216 m
214 m
212 m
210 m
208 m
206 m
204 m
202 m
200 m
2.7
2.6
2.7
2.2
2.6
2.5
2.1/3.3
2.2
2.5
2.7
2.2
2.5
2.2
2.6
2.2
2.1
2.1
2.5
2.1
D
? LN biozone
(Naylor 77)
Comments
Thinner beds than below (3--15cm thick). Mainly x-bedded but also rippled (wave rippled?)
One x-bed is 60cm high, dips 35 and indicates palaeoflow to 353. All x-beds are oriented to the north. Beds vary from 30--70cm thick. Sharp possibly erosional contact at the base of the sandstone unit
Wave ripples trend to about 080 and exhibit wavelengths of around 5cm
Poorly sorted unit includes several symmetrical ripples
Wavelength Height Trend
5cm 0.8cm -
5cm - 064
Sand linsen are typically 0.5--0.8cm thick but may reach up to 5cm in thickness
Micro-ripples?
Wavelength Trend
1cm 067
2cm 085
Wave ripple trends to 078
Sandstone streaks
Inaccessible
Environment
Coastal sand complex and/or transgressive sand sheet
Transgressive sandstone?
Shallow shelf
Transgressive sandstone?
Coastal sand complex
Shallow shelf

Dooneen 6

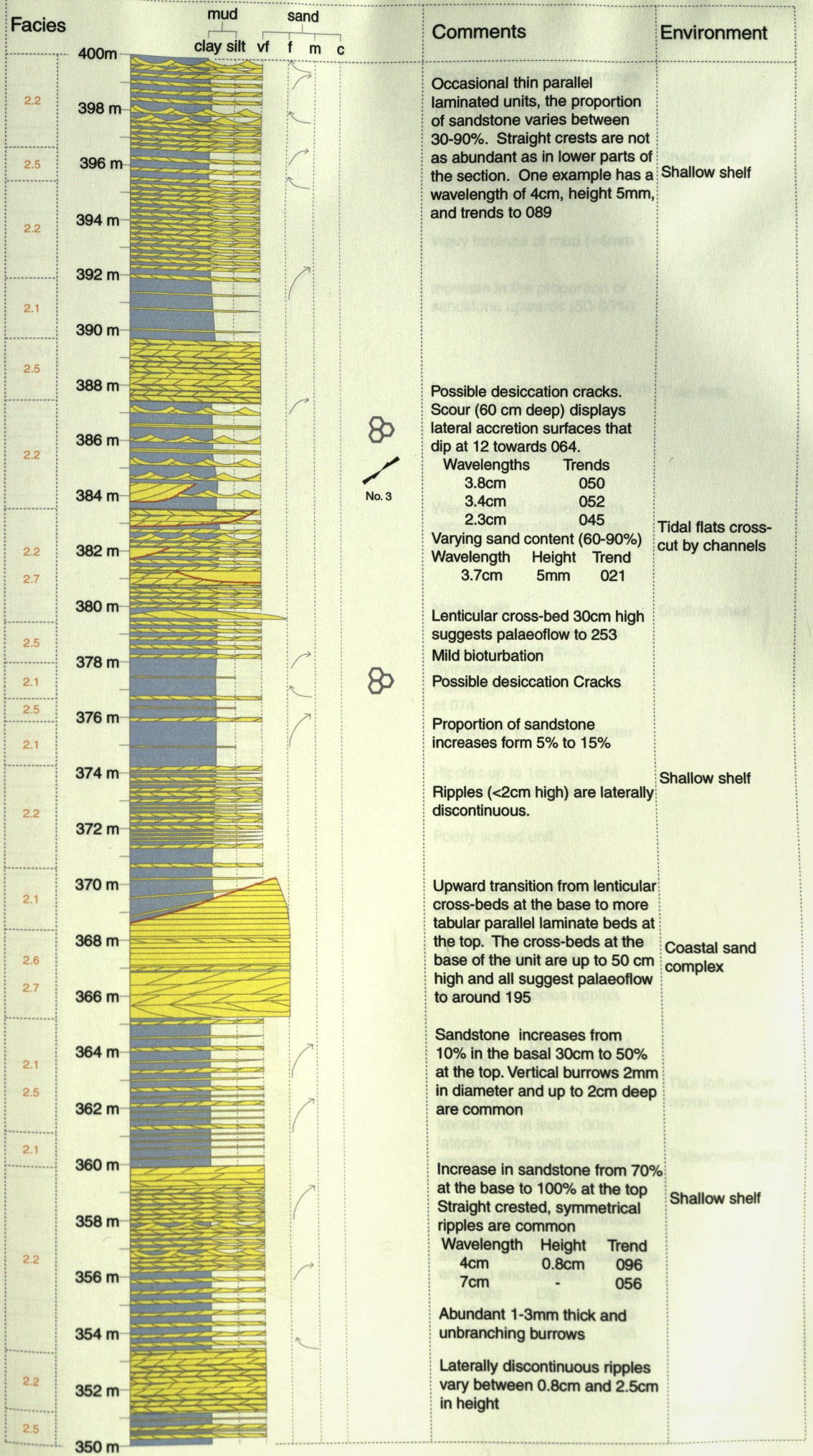


Comments	Environment
Cross-bed trends to 333 Wavelength Height Trend 5cm 5mm 052 7cm 2mm 037 7cm 6mm 032 Tabular beds 1-3cm thick, symmetrical rippled and highly bioturbated Tuff 5cm thick	Shallow shelf
Mainly rippled or streaked, with occasional parallel lamination	
Alternating sandy and muddy heterolith, mainly wave rippled or streaked. Sand linsen up to 5cm thick in sand rich zones	
Wavy and flaser bedded heterolith including symmetrical ripples and occasional parallel lamination. Sand units are 0.5-3cm thick and are separated by thin silty mud units. Crests trend 080, 044, 068, 072, 178, 026.	Coastal sand complex
Burrows 2-10mm thick	
Symmetrical rippled tabular beds 1-2cm thick, these exhibit straight bifurcating crests, Crests trend to 079, 067, 084, 067, 072,117 and 132. Bioturbation is prolific.	Coastal sand complex
Heterolithic unit in which there is a general increase in the proportion of sandstone upwards. The unit is mainly symmetrical rippled but includes parallel lamination. Bioturbation is often prolific	
Symmetrical ripples (trend 102) and gutter casts. Also lenticular sandstone units which probably include HCS/SCS, these have wave rippled tops	Wave influenced shelf
Bioturbation common	
Sand linsen from 1-4mm thick, sometimes symmetrical ripples	Storm influenced shelf
Graded beds of silt and sandstone	
	Accommodation dominated shelf
Castle Slate	
Silt and sand linsen in the basal 20cm Height Dip Trend 13cm 21 351 10cm 32 340	

Dooneen 7

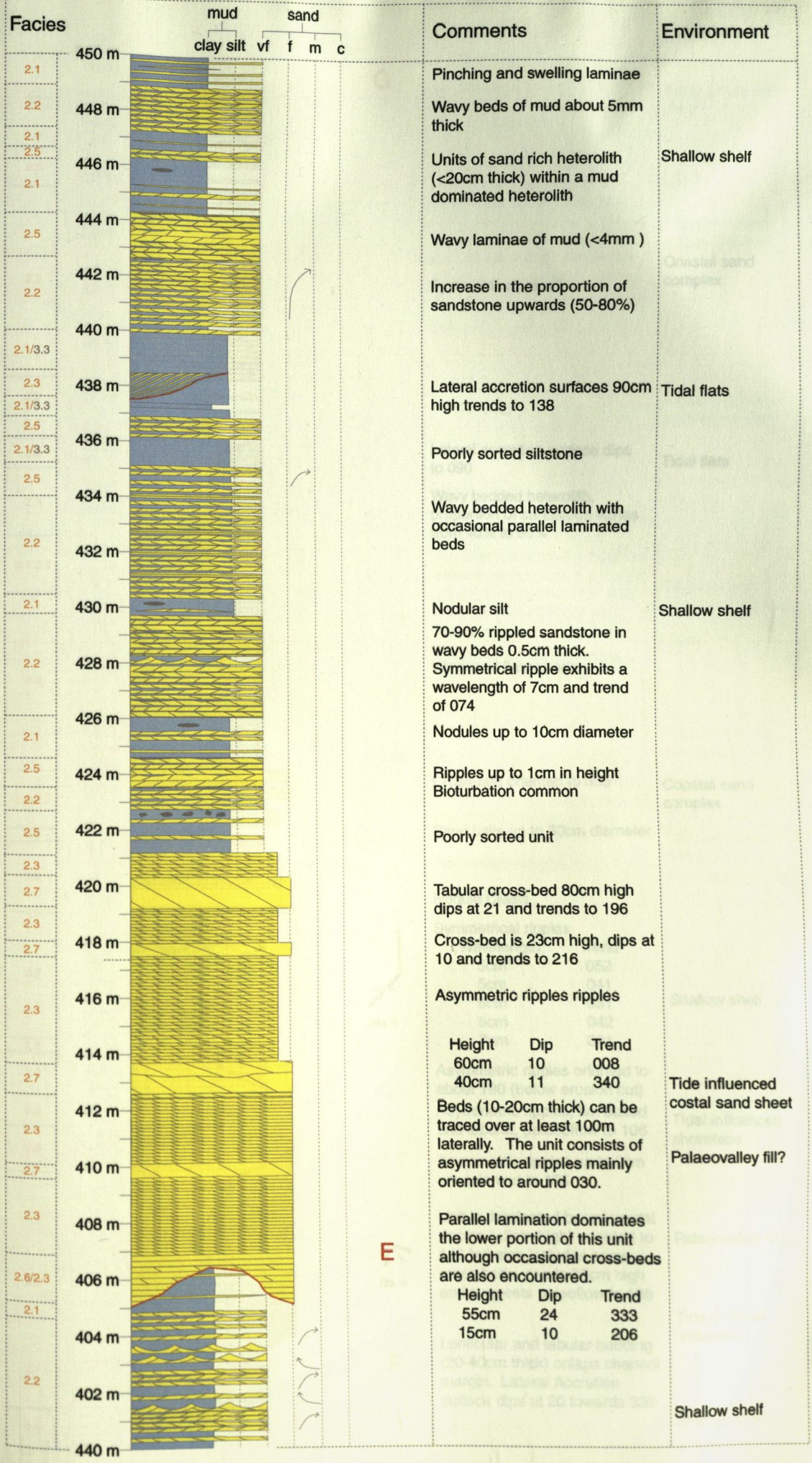

Facies
mud
clay silt
sand
vf f m c
Comments
Environment
350 m
348 m
346 m
344 m
342 m
340 m
338 m
336 m
334 m
332 m
330 m
328 m
326 m
324 m
322 m
320 m
318 m
316 m
314 m
312 m
310 m
308 m
306 m
304 m
302 m
300 m
2.5
2.1
2.6/2.7
2.1/2.2
2.5
2.1
2.2
2.1
2.2
2.1
2.2
2.5
2.2
2.1
2.2
2.1
2.2
2.7
2.1
2.2
2.2
Thin laminae of silt and sand, no ripples
Shallow shelf
Well sorted parallel laminated sandstone with poorly formed cross-bedding
Thoroughly bioturbated
Tidal flats, cross-cut by channels
Rippled unit with parallel laminated beds up to 15cm thick
Coastal sand complex
Fining up unit, thoroughly bioturbated
Shallow shelf
Wavelength Height Trend
4.5cm 7mm 068
Period - 2.2 secs / Depth < 5m
3cm 038
4cm 4mm 088
No. 3
No. 4
Straight ripple crests trend: 078, 076, 058, 076
Bioturbation common
Coastal sand complex
Minor sandstone intrusion
Muddy heterolith dominated by pinching and swelling laminae and occasionally symmetrical ripples. In some cases these mantle parallel laminated beds (5-20cm thick). The unit exhibits a crude upwards reduction of sandstone
Shallow shelf
Lenticular, cross-bedded sandstone with mud pebbles and a symmetrical rippled top
Unit displays many shallow scours (<40cm deep) that are occasionally filled with sand Bioturbation is common. Ripple wavelength is 7cm, trends 082
Tabular cross-beds 35cm and 15cm high trend to 195 and 140
Irregular increase in sandstone upwards, bioturbation is very common.
Sandstone beds up to 5cm thick Wave ripple trends 038 and has height of 3mm and wavelength of 3.5cm
Tidal flats
? VI biozone (Naylor 77)

Dooneen 8



Comments	Environment
Occasional thin parallel laminated units, the proportion of sandstone varies between 30-90%. Straight crests are not as abundant as in lower parts of the section. One example has a wavelength of 4cm, height 5mm, and trends to 089	Shallow shelf
Possible desiccation cracks. Scour (60 cm deep) displays lateral accretion surfaces that dip at 12 towards 064. Wavelengths: 3.8cm, 3.4cm, 2.3cm Trends: 050, 052, 045 Varying sand content (60-90%) Wavelength: 3.7cm; Height: 5mm; Trend: 021	Tidal flats cross-cut by channels
Lenticular cross-bed 30cm high suggests palaeoflow to 253 Mild bioturbation	
Possible desiccation Cracks	
Proportion of sandstone increases form 5% to 15%	
Ripples (<2cm high) are laterally discontinuous.	Shallow shelf
Upward transition from lenticular cross-beds at the base to more tabular parallel laminate beds at the top. The cross-beds at the base of the unit are up to 50 cm high and all suggest palaeoflow to around 195	Coastal sand complex
Sandstone increases from 10% in the basal 30cm to 50% at the top. Vertical burrows 2mm in diameter and up to 2cm deep are common	
Increase in sandstone from 70% at the base to 100% at the top Straight crested, symmetrical ripples are common Wavelength: 4cm, 7cm; Height: 0.8cm, -; Trend: 096, 056	Shallow shelf
Abundant 1-3mm thick and unbranching burrows	
Laterally discontinuous ripples vary between 0.8cm and 2.5cm in height	

Dooneen 9



Comments	Environment
Pinching and swelling laminae	
Wavy beds of mud about 5mm thick	
Units of sand rich heterolith (<20cm thick) within a mud dominated heterolith	Shallow shelf
Wavy laminae of mud (<4mm)	
Increase in the proportion of sandstone upwards (50-80%)	
Lateral accretion surfaces 90cm high trends to 138	Tidal flats
Poorly sorted siltstone	
Wavy bedded heterolith with occasional parallel laminated beds	
Nodular silt	Shallow shelf
70-90% rippled sandstone in wavy beds 0.5cm thick. Symmetrical ripple exhibits a wavelength of 7cm and trend of 074	
Nodules up to 10cm diameter	
Ripples up to 1cm in height Bioturbation common	
Poorly sorted unit	
Tabular cross-bed 80cm high dips at 21 and trends to 196	
Cross-bed is 23cm high, dips at 10 and trends to 216	
Asymmetric ripples ripples	

Height	Dip	Trend
60cm	10	008
40cm	11	340

Tide influenced costal sand sheet

Beds (10-20cm thick) can be traced over at least 100m laterally. The unit consists of asymmetrical ripples mainly oriented to around 030.

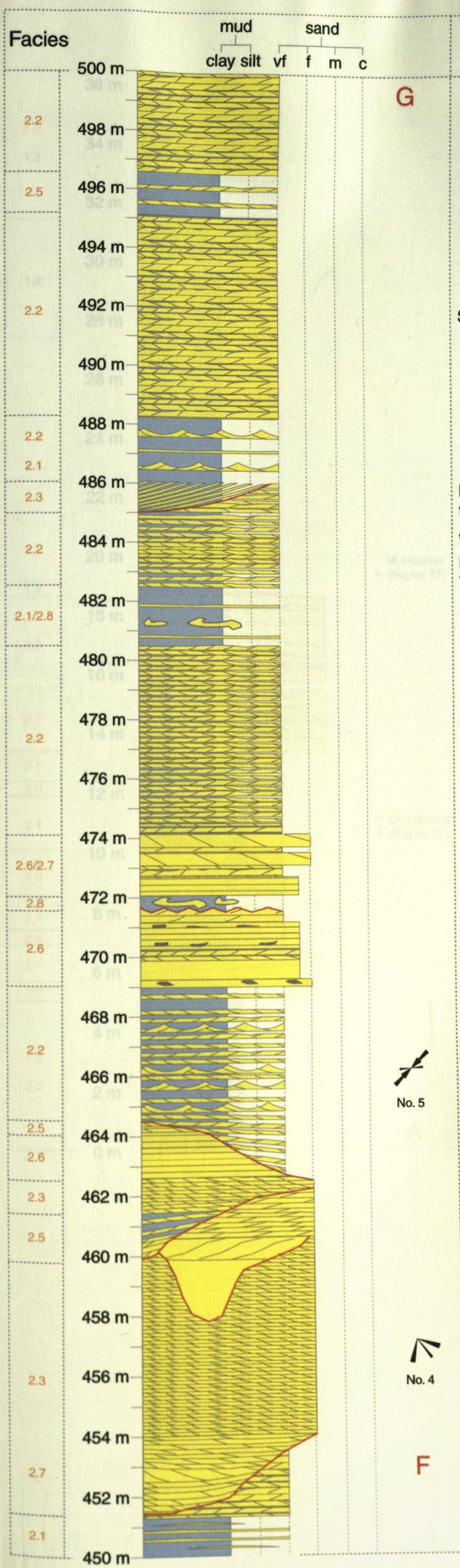
Palaeovalley fill?

Parallel lamination dominates the lower portion of this unit although occasional cross-beds are also encountered.

Height	Dip	Trend
55cm	24	333
15cm	10	206

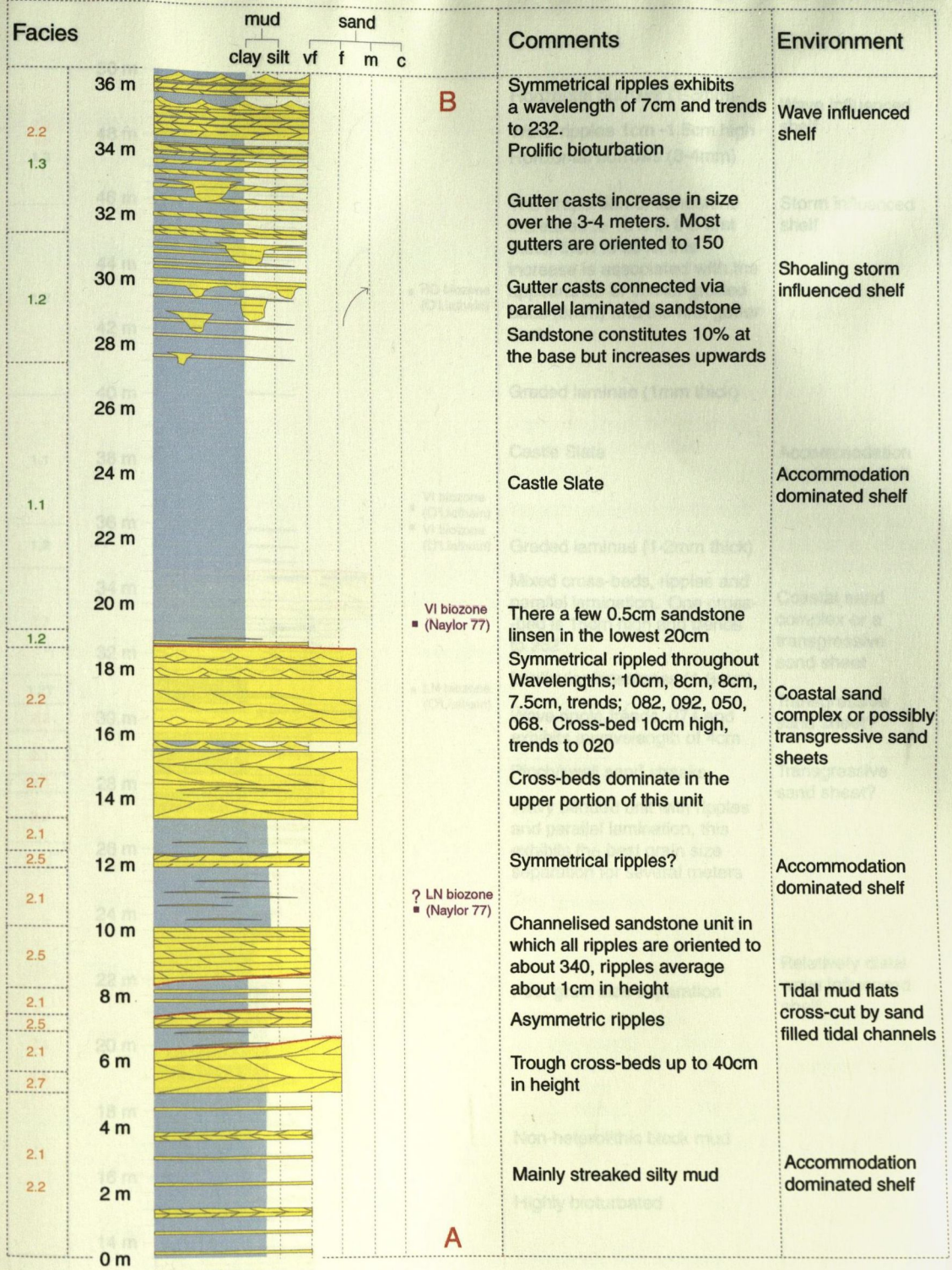
Shallow shelf

Dooneen 10



Comments	Environment
Symmetric ripples?	Coastal sand complex
Lateral accretion surface dips to 090	Tidal flats
Wavy bedded heterolith, proportion of sandstone varies from 40% to 95%	
Wavy and flaser beds	
Cross-bed oriented to 355	Coastal sand complex
Sand balls up to 30cm diameter	
Nodule Clasts	
Symmetrical ripples Wavelength / Trend 5cm 052 5cm 041 6cm 031 6cm 042 7cm 081	Shallow shelf
Asymmetric ripples oriented to about 190 (below erosion cut)	
Asymmetric ripples, flat based and tabular, palaeoflow to 106	Tidal influenced shoreface
Asymmetric ripples up to 3cm are oriented to 196	
Unit is dominated by uni-modal ripples (<3cm high) oriented to 110 but also includes some cross-beds, one is 35cm high and suggests paleoflow to 138	Palaeovalley fill?
Lenticular and tabular bedding (20-40cm thick) onlaps channel margin. Lateral Accretion surface dips at 20 towards 339	Tide or fluvial influence Shallow shelf

Reenmore 1


Facies
mud
clay silt
sand
vf f m c
36 m
34 m
32 m
30 m
28 m
26 m
24 m
22 m
20 m
18 m
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14 m
12 m
10 m
8 m
6 m
4 m
2 m
0 m
2.2
1.3
1.2
1.1
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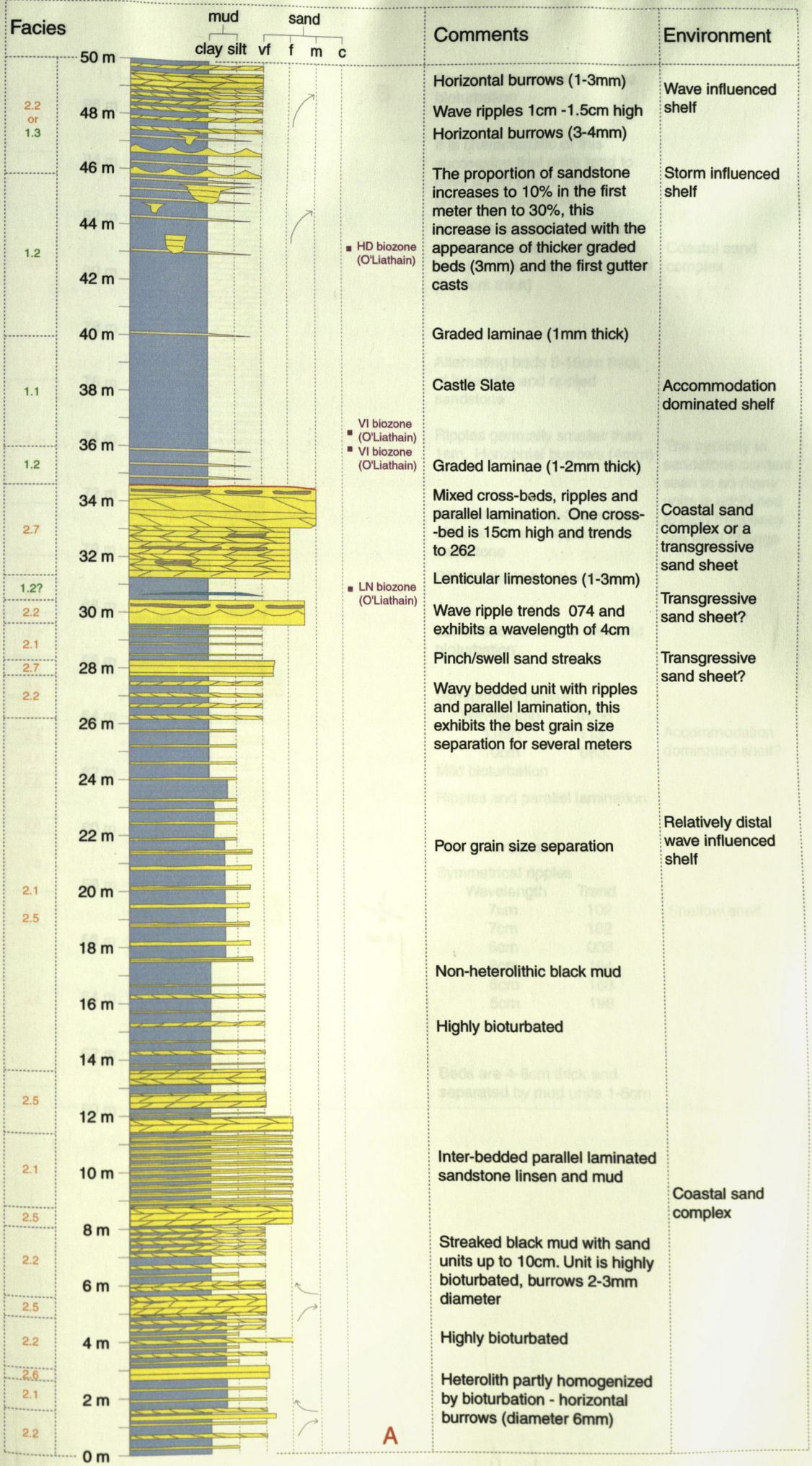
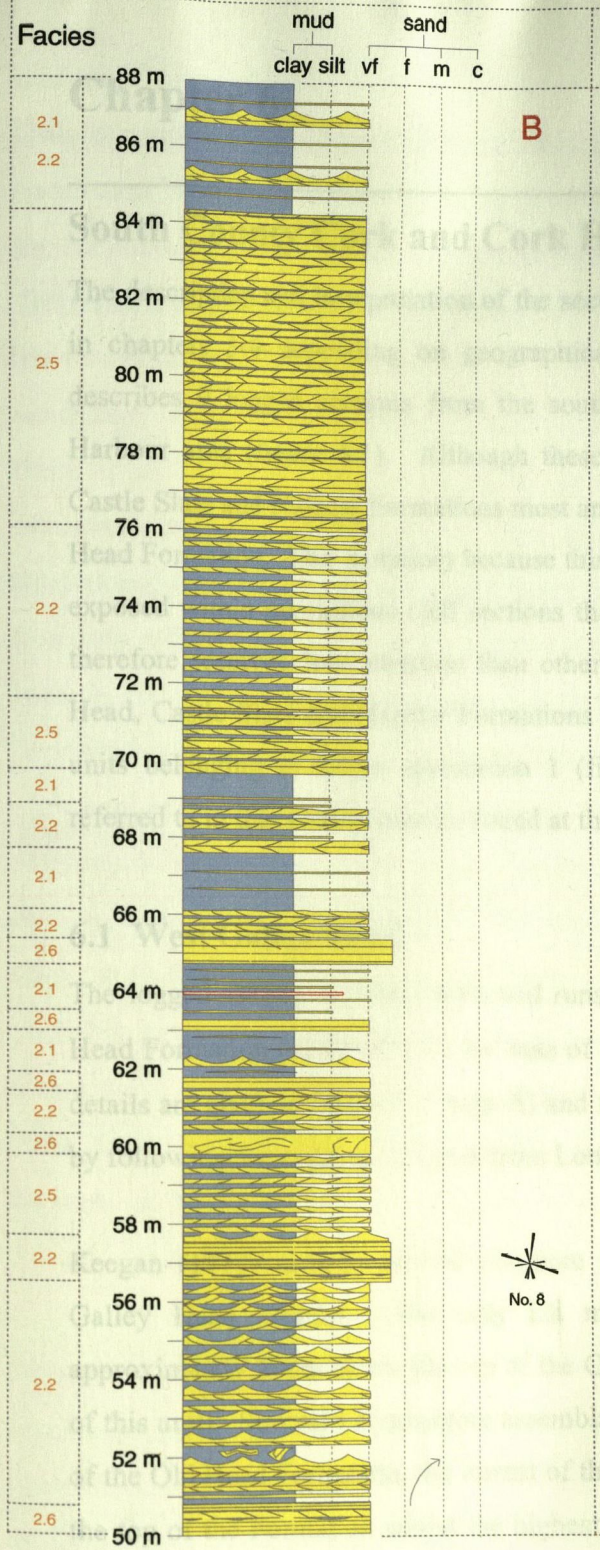
2.2
2.7
2.1
2.5
2.1
2.5
2.1
2.5
2.1
2.7
2.1
2.2
B
A
VI biozone (Naylor 77)
? LN biozone (Naylor 77)
Comments
Environment
Symmetrical ripples exhibits a wavelength of 7cm and trends to 232.
Prolific bioturbation
Gutter casts increase in size over the 3-4 meters. Most gutters are oriented to 150
Gutter casts connected via parallel laminated sandstone
Sandstone constitutes 10% at the base but increases upwards
Wave influenced shelf
Shoaling storm influenced shelf
Castle Slate
Accommodation dominated shelf
There a few 0.5cm sandstone linsen in the lowest 20cm
Symmetrical rippled throughout
Wavelengths; 10cm, 8cm, 8cm, 7.5cm, trends; 082, 092, 050, 068. Cross-bed 10cm high, trends to 020
Cross-beds dominate in the upper portion of this unit
Coastal sand complex or possibly transgressive sand sheets
Symmetrical ripples?
Accommodation dominated shelf
Channelised sandstone unit in which all ripples are oriented to about 340, ripples average about 1cm in height
Asymmetric ripples
Trough cross-beds up to 40cm in height
Tidal mud flats cross-cut by sand filled tidal channels
Mainly streaked silty mud
Accommodation dominated shelf

South Dunmanus 1



Comments	Environment
Horizontal burrows (1-3mm) Wave ripples 1cm -1.5cm high Horizontal burrows (3-4mm)	Wave influenced shelf
The proportion of sandstone increases to 10% in the first meter then to 30%, this increase is associated with the appearance of thicker graded beds (3mm) and the first gutter casts	Storm influenced shelf
Graded laminae (1mm thick)	
Castle Slate	Accommodation dominated shelf
Graded laminae (1-2mm thick)	
Mixed cross-beds, ripples and parallel lamination. One cross--bed is 15cm high and trends to 262	Coastal sand complex or a transgressive sand sheet
Lenticular limestones (1-3mm)	
Wave ripple trends 074 and exhibits a wavelength of 4cm	Transgressive sand sheet?
Pinch/swell sand streaks	Transgressive sand sheet?
Wavy bedded unit with ripples and parallel lamination, this exhibits the best grain size separation for several meters	
Poor grain size separation	Relatively distal wave influenced shelf
Non-heterolithic black mud	
Highly bioturbated	
Inter-bedded parallel laminated sandstone linsen and mud	Coastal sand complex
Streaked black mud with sand units up to 10cm. Unit is highly bioturbated, burrows 2-3mm diameter	
Highly bioturbated	
Heterolith partly homogenized by bioturbation - horizontal burrows (diameter 6mm)	

South Dunmanus 2



Comments	Environment
Streaked mudstone with mild bioturbation	
It is characteristic of this succession that units tend to have sharp rather than gradational contacts	
Alternating beds of sandstone dominated heterolith (5-40cm thick) and pure sandstone units (5-15cm thick)	Coastal sand complex
Alternating beds 5-15cm thick of heterolith and rippled sandstone	
Ripples generally smaller than 1cm. Horizontal burrows (4mm)	The cyclicity in sandstone content seen in so many units is attributed to high frequency sea level change
Alternating beds 5-30cm thick of heterolith and rippled sandstone	
Silt streaks in basal portion	
Laminated mudstone with mild bioturbation	
Symmetrical ripples; Wavelength Trend 11cm 113 10cm 083. Mild bioturbation	Accommodation dominated shelf?
Ripples and parallel lamination	
Mild bioturbation	
Symmetrical ripples Wavelength Trend 7cm 102 7cm 102 6cm 008 8cm 164 6cm 168 5cm 198	Shallow shelf
Beds are 4-8cm thick and separated by mud units 1-5cm	

Chapter 6

South County Cork and Cork Harbour

The description and interpretation of the sections analysed in this project is provided in chapters 3-6 depending on geographical location (figure 1.4). This chapter describes 9 logged sections from the south coast of County Cork and the Cork Harbour area (figure 6.1). Although these sections intersect both the Old Head, Castle Slate and Narrow Formations most are focused upon the upper part of the Old Head Formation. This is mainly because this part of the Old Head Formation is often exposed within precipitous cliff sections that are only accessible by boat and have therefore received less attention than other portions of the stratigraphy. The Old Head, Castle Slate and Narrow Formations analysed in this study consist wholly of units belonging to facies association 1 (figure 2.1). All maps, plates and logs referred to in this section may be found at the end of the chapter.

6.1 West Galley Head

The logged section is 100m thick and runs from within the upper part of the Old Head Formation [1337 033] to the base of the Castle Slate Formation [1337 0330], details are given in figure 6.1 (map A) and figure 1.7. The section may be accessed by following the coast southwards from Long Strand beach.

Keegan (1977) records several miospore assemblages from throughout the west Galley Head section. The only LE miospore assemblage is reported from approximately 200m below the top of the Old Head Formation (67m above the base of this unit). Several LN miospore assemblages are recorded from the overlying part of the Old Head Formation, the lowest of these is recorded from around 130m below the top of the Formation whilst the highest is reported from immediately below the top of the Formation. The first VI biozonal assemblage is reported from the base of the overlying Castle Slate Formation.

Old Head Formation

Only the upper 91m of the Old Head Formation was analysed in this study and is dominated by units belonging to facies association 1 (figure 2.1). The lower 12m of the measured section is tentatively placed within the top of the Daunt Member whilst the remainder of the section is though to correlate with the more mudstone rich Tower Member. This sequence begins (0m - 53.9m) with alternating packages of sandstone, wavy bedded heterolith and laminated mudstone. Variation between these units probably reflects changing proximity to the coastline. Laminated mudstone units are likely to have been deposited within a fairly distal offshore transitional or offshore setting whilst wavy bedded units with symmetrical ripples probably reflect a more proximal offshore transitional setting. Sandstone units may include parallel lamination, ripples and cross-beds and are likely to have been deposited within wave influenced shoreface rather than tidally influenced sand-sheet (Johnson *et al.* 1981) or tidal sand-bank (Kenyon *et al.* 1981) settings because asymmetric ripples are not common. The sharp basal and upper boundaries exhibited by sandstone units suggest that relative sea-level change was the driving force for these shifts in facies location. The sharp lower surfaces of sandstone units were probably generated by phases of incision or non-deposition caused by lowering of storm wave base during relative sea level fall (e.g. Ainsworth and Pattison 1994; Plint 2000; Posamentier and Morris 2000). The sharp upper surfaces probably result because of a rapid landwards shift in facies belts and entrapment of sand within estuary mouths as relative sea-level rose.

Between 53.9m - 75.5m the sequence consists of 3 thick and highly mature, parallel laminated sandstone units (plate 6.1) that are separated by relatively sandstone rich wavy bedded heterolithic units. The parallel laminated sandstone units are believed to reflect deposition within an upper shoreface setting during a lowstand of relative sea-level. The intervening wavy bedded units were deposited within a proximal offshore transitional setting during phases of higher relative sea-level.

At 75.5m the sequence becomes more mudstone rich but includes numerous rippled sandstone linsen. This rather abrupt lithological change is believed to correlate with similar changes seen in the Lions Cove (128m) and the Old Head of Kinsale (78m)

sections. This sequence is thought to reflect deposition within a relatively distal offshore transitional setting.

At the top of the Old Head Formation (75.5m - 91.2m) two highly mature, parallel laminated sandstone units are separated by a thinner mudstone rich package. These units probably reflect deposition within shoreface and offshore transitional setting respectively. Overlying the uppermost of these sandstone packages is a thin mudstone dominated sequence containing ripples and this is in turn overlain by the Castle Slate Formation. Together these units are likely to represent a pronounced landward shift in facies associated with a major increase in relative sea-level.

6.2 Lions Cove - Seven Heads

The logged section is 172m thick and runs from within the upper part of the Old Head Formation [1460 0372] to the base of the Castle Slate Formation [1459 0374], details are given in figure 6.1 (map B) and figure 1.7. The section has not been dated. The basal portion of this section may be accessed from the road on the cliff top (Turkeyland) but the upper portion of the section is only accessible by boat.

Old Head Formation

Only the upper 168m of the Old Head Formation has been analysed in this study and is dominated by units belonging to facies association 1 (figure 2.1). The logs commence within a mudstone rich package that appears to mark a change in stratification style between the underlying and overlying stratigraphy. The sequence below consists of a sandstone rich and predominately rippled succession which is believed to correlate with the Daunt Member whilst the sequence above consists of a series of alternating sandstone rich and mudstone rich packages that probably correlates with the more mudstone rich Tower Member. Sandstone rich units in the overlying sequence include parallel lamination, cross-bedding and ripples whilst mudstone rich packages are dominated by graded beds and symmetrical rippled sandstone linsen.

The first sandstone rich package is encountered between 2.4m - 5.3m. This exhibits sharp basal and upper surfaces and includes both ripples and cross-bedding. The

package is interpreted to reflect deposition within a shoreface setting during a lowstand of relative sea-level. The sharp basal surface to this package is believed to result from wave incision as base level fell. The sharp upper surface probably reflects a rapid termination of sediment supply in response to a combination of landwards migration of facies and entrapment of sand within estuary mouths and embayments during subsequent base level rise.

At 5.3m the succession becomes dominated by mudstone rich facies reflecting a rise in relative sea-level. However, the sequence between 5.3m - 8.7m then exhibits a gradual increase in sandstone content upward which culminates in a rippled sandstone package. This sequence reflects a phase of shoreface progradation. This trend of increasing coastal proximity probably continues, albeit in staggered fashion, into the overlying package (8.7m - 16.8m) which consists principally of parallel laminated or cross-bedded sandstone. The erosive base to this sequence may reflect either lowering of relative sea-level or systematic migration of rip channels on a barred coastline. Hunter *et al.* (1979) report that rip channels may form widespread erosional discontinuities as they migrate along the coast in the direction of littoral drift at speeds of up to 150-300m a month. The sharp upper surface of this package probably indicates a subsequent phase of relative sea-level rise.

Between 16.8m - 19m the sequence exhibits a further staggered upward increase in sandstone content suggesting increasing coastal proximity. This sequence culminates in a thick parallel laminated, cross-bedded and rippled sandstone package (19m - 37.3m) that exhibits sharp basal and upper surfaces. Parallel lamination is most frequent in upper and lower portions of the package whist ripples predominate in the central part. The changes between these stratification styles may reflect changing proximity to the coastline within the shoreface sequence.

This pattern of thick sandstone packages separated by thinner mudstone rich packages (plates 6.2 and 6.3) reflects alternating deposition within shoreface and distal offshore transitional settings and persists upwards until 127.3m. The thickness of some of the sandstone packages suggests that they consist of several stacked shoreface sequences.

At 127.3m the sequence exhibits an increase in mudstone rich facies that persists upwards until 157.4m although this sequence also includes several relatively thick sandstone units. This rather abrupt lithological change is believed to correlate with similar changes seen in the Galley Head (75.5m) and Old Head of Kinsale (78m) sections. Mudstone rich units reflect deposition within a distal offshore transitional setting whilst sandstone units were deposited in a shoreface setting during lowstands of relative sea-level.

As in the Galley Head and Nohoval Cove sections the upper part of the Old Head Formation consists of two thick sandstone units separated by a relatively sandstone rich, wavy bedded heterolithic package (157.4m - 165.5m). The sandstone units include parallel lamination and probably SCS and are interpreted to reflect deposition within an upper shoreface setting. The intervening wavy bedded unit was probably deposited in a proximal offshore transitional setting. Overlying this sequence (165.5m) the Castle Slate Member consists of homogenous mudstone and was probably deposited during a pronounced rise in relative sea-level.

6.3 West Dunworly Bay - Seven Heads

The logged section is 324m thick and runs from within the upper part of the Tower Member at the top of the Old Head Formation [1472 0374] through the Castle Slate and Narrow Cove Formations and culminates within the base of the Pigs Cove Formation [1474 0378], details are given in figure 6.1 (map C) and figure 1.7. The entire section may be accessed from the small slipway on the west side of the bay.

Van Gelder and Clayton (1978) record an LN miospore assemblage from 20m below the top of the Old Head Formation and VI assemblages from the base of the Castle Slate Formation.

Old Head Formation

Only the upper portion (~12m) of the Tower Member is included in this study and this is dominated by facies belonging to facies association 1 (figure 2.1). From 0m - 8m the sequence is dominated by a thick sandstone package that includes small

wavelength symmetrical ripples, parallel lamination and cross-bedding but is often massive. Analysis of a symmetrical ripple developed at the base of the section indicates deposition within a shallow water setting (< 5m). The unit is overlain by an erosive based lag deposit (10-15cm thick) that includes mud clasts and medium grained sandstone. The thick sandstone package forming the bulk of this sequence is believed to reflect deposition within a shoreface setting probably during a lowstand of sea-level. The thin lag deposit capping the sequence probably results from upper shoreface erosion during a subsequent rise in relative sea-level (Swift 1976).

From 8.1m - 12m the sequence is dominated by mudstone rich facies that include graded and non-graded sandstone linsen and thin limestone lenses containing broken crinoid stems. The package is thought to reflect deposition within an offshore transitional or offshore setting and therefore reflects a phase of transgression relative to the underlying package. Both clastic and carbonate linsen are believed to be tempestite generated and allocthonthous.

Castle Slate Formation

Between 12m - 30m the Castle Slate Formation consists of strongly cleaved homogenous mudstones that includes flattened silico-phosphatic nodules in the upper portion. This package was probably deposited within an offshore setting and reflects a major phase of relative sea-level rise.

Narrow Cove Formation

At the base of the Narrow Cove Formation the Ardaturrish Member (30m - 100m) is considerably thinner (70m) than that measured from the Reenagough Point section (204m), the Cahermore section (182m), the Ballycrovane section (171m), the Bere Island section (184m) and the Dooneen section (116m) in the west of the basin. This probably reflects the relatively distal location of this section but may also relate to reduced subsidence of this area because of the adjacent Glandore structural high (figure 1.4). The Ardaturrish Member also differs from sections to the north-west in that it consists of facies belonging to facies association 1 rather than associations 2 and 3 (figure 2.1).

At the base of the Ardaturrish Member (30m - 66.1m) the sequence, although remaining relatively mudstone rich shows an overall increase in the proportion of sandstone. Interestingly, these increases are not gradational disparate changes but are focussed upon certain relatively thin portions of the section. These zones of rapidly increasing sandstone content are found between 42m - 45m and between 53 - 54m, the first of these coincides with the first appearance of gutter casts (plate 6.4) whilst the second is associated with the first ripples. In addition to an overall increase in sandstone content upwards the upper part of the sequence displays several marked fluctuations in sandstone content. In general terms the sequence is likely to reflect increasing proximity to the coastline. However, the focussing of much of the upwards increase in sandstone content into a few relatively thin zones suggests that this was achieved during phases of relative sea-level fall rather than simple progradation and thus indicates a series of forced regressions (Posamentier *et al.* 1992). The superimposed fluctuation of sandstone content in the upper part of the sequence probably results from higher frequency relative sea-level oscillation. Although the upper part of the sequence which includes symmetrical ripples clearly formed in an offshore transitional setting it is unclear if the underlying sequence formed above or below storm wave base.

Between 66.1m - 71.3m the sequence consists of a series of sandstone packages separated by thinner mudstone units, sandstone packages exhibit sharp basal and upper bounding surfaces (plate 6.7). Sandstone beds are up to 40cm in thickness and include ripples, parallel lamination, cross-beds (palaeoflow to 116°) and possibly SCS. Sandstone units were probably deposited by storm generated currents within either the lower shoreface or the upper part of the offshore transition. These features reflect a pronounced basin-ward shift in facies relative to enveloping mudstone rich packages suggesting that deposition progressed during a lowstand of relative sea-level.

From 71.3m - 100m the sequence becomes dominated by mudstone but include gutter casts, graded and non-graded laminae and rippled or parallel laminated sandstone linsen. This package probably reflects deposition within an offshore transitional setting. Interestingly, several parts of the sequence include gradual upward increases in sandstone content followed by a more rapid subsequent

decrease. This is likely to reflect phases of coastal progradation followed by drowning.

At 100m the section shows an abrupt increase in the proportion of sandstone which continues up section until around 211.4m. This portion of the sequence probably correlates with the Reenagough Member to the west (Cahermore section 293.7m - +622m) but is clearly considerably thinner. The Reenagough Member in this section also differs from that in the west in that it consists of facies belonging to facies association 1 rather than associations 2 and 3 (figure 2.1).

Between 100m - 211.4 the section consists of a series of sandstone rich packages separated by mudstone rich units. In general, sandstone rich packages exhibit sharp basal and upper surfaces and are normally dominated by wavy bedded symmetrical rippled and parallel laminated sandstone linsen (plate 6.8) although mudstone drapes are not always present. Occasionally sandstone rich packages also include thicker parallel laminated, swale cross-stratified or south oriented cross-bedded units and may include mudstone intra-clasts. It is believed that in most cases sandstone rich zones formed through a gradual accumulation of thin storm generated sand linsen and that this probably occurred during lowstands of relative sea-level. Because individual sandstone rich packages lack repeatable vertical changes in structure, exhibit an abundance of mud drapes and have sharp basal and upper surfaces it is unlikely that they were generated by migration of large scale tide or storm generated bedforms as is suggested by De Raaf *et al.* (1977) from neighbouring sections. Mudstone rich packages were probably deposited in an offshore transitional setting during phases of higher relative sea-level.

The Black Ball Member at the top of the Narrow Cove Formation is exposed between 211.4m - 310m and is dominated by mudstone rich facies but becomes sandstone rich at the top of the section, this pattern mimics that seen in the Cahermore and Ballycrovane sections. At the base of this unit between 211.4m - 298.8m the sequence is dominated by mudstone although the sequence also includes occasional sharp based sandstone packages albeit in a thinner and more disparate form compared to the underlying sequence. As in the sequence below, mudstone rich packages are believed to have been deposited in an offshore transitional or

offshore setting whilst sandstone rich zones represent deposition within a lower shoreface or proximal offshore transitional setting. This thick mudstone rich sequence is likely to correlate with similar packages developed at this level throughout the South Munster Basin (e.g. Cahermore 700m - 782m, Ballycrovane 488m - 548m).

At 298.8m a (minor?) fault separates the underlying mudstone rich sequence from an overlying sandstone dominated package. This dramatic lithological boundary probably correlates with a similar lithological boundary at this level within the Cahermore section (781.5m). The package between 298.8m - 310m consists of two predominantly rippled sandstone packages separated by a thin mudstone rich unit (305m - 305.8m).

The sandstone packages probably reflect deposition within a lower shoreface setting whilst mudstone packages were probably deposited in an offshore transitional setting. The sequence is likely to reflect deposition during a lowstand of relative sea-level although the intervening mudstone rich package suggests that this was interrupted by a phase of relative sea-level rise. It is interesting that the Cahermore sequence also displays a mudstone rich zone at this level (791.1m - 804.8m).

Pigs Cove Formation

At 310m the sequence exhibits an abrupt transition from rippled sandstone into a thick mudstone dominated sequence that includes graded laminae and nodules although the basal 1.5m this sequence also includes thicker sandstone linsen. The sequence probably reflects a dramatic landwards migration of facies belts as a result of relative sea-level rise. The increased frequency of sandstone linsen in the basal portion of this sequence relative to the overlying sequence may reflect sand liberated by upper shoreface retreat during the early stages of this sea level rise.

6.4 Holeopen Bay West - The Old Head of Kinsale

The logged section is 116m thick and runs from within the central part of the Tower Member in the upper part of the Old Head Formation [1625 0405] to the base of the

Castle Slate Formation [1627 0404], details are given in figure 6.1 (map D) and figure 1.7. Most of the section is only accessible by boat.

Higgs *et al.* (1988) report an LE biozonal assemblage from approximately 220m below the top of the Old Head Formation. However this is in disagreement with the findings of O'Liatháin (1992) who records a well preserved LN biozonal assemblage from around 165m below this level (385m below the top of the Old Head Formation) and an LE biozonal assemblage from approximately 425m below the top of the Old Head Formation. This redefinition of the LN/LE boundary downwards considerably thickens the LN sequence from between 165-220m to between 385-425m. This is compatible with the thickness of the LN biozone in the Roberts Head section which is between 305m - 500m thick (based on this work and that of Van Gelder 1974). Higher in the section Higgs *et al.* (1988) record several LN biozonal assemblages, the highest of these is reported from 0.3m below the top of the Old Head Formation. These authors also record a VI biozonal assemblage from 0.1m above the base of the overlying Castle Slate Formation.

Old Head Formation

Only the upper portion (~110m) of the Old Head Formation is included in this study and this consists of units belonging to facies association 1 (figure 2.1). Previous work classifies this part of the Old Head Formation as the Holeopen Member which Kuijpers (1972) measures at 290m thick. However Kuijpers (1972) notes that sandstone content in the basal 100m of this unit is similar to the underlying sequence whilst the upper 190m contains much more mudstone. This upper mudstone rich part of the sequence is likely to correlate with the Tower Member and is of comparable thickness (190m) to this unit in the neighbouring Lions Cove section (172m) and the Roberts Head section (140-210m). The measured section of this study does not begin at the base of the Tower Member but within the upper 5m of a thick mudstone rich package (~80m) found at the base of this unit. This consists of dark grey mudstone containing graded beds, ripples and gutter casts as well as occasional parallel laminated sandstone beds and probably reflects deposition within a distal offshore transitional setting.

This mudstone rich sequence is overlain (5m - 78m) by a series of thick sandstone rich packages separated by thinner mudstone rich units. Mudstone units typically contain graded and non-graded laminae, rippled sandstone linsen and gutter casts whilst sandstone dominated packages consist of thick parallel laminated or cross-bedded sandstone units up to 10m thick. Sandstone units exhibit sharp basal and upper surfaces and may occur as independent units enveloped in mudstone (e.g. 23m - 33m) or as part of larger sandstone rich sequences. These larger packages (e.g. 35m - 54.2m) may include several parallel laminated or cross-bedded units that are separated by relatively sandstone rich wavy bedded heterolith units. The lack of mudstone drapes within the parallel laminated and cross-bedded units suggests that these were deposited within a shoreface setting whilst wavy bedded units were probably deposited in a lower shoreface or offshore transitional setting. The sharp basal surfaces displayed by sandstone packages probably result from incision of the sea-bed in response to lowering of storm wave-base during phases of relative sea-level fall. The sharp upper surfaces reflect rapid land-wards migration of facies and also entrapment of sand within estuary mouths and embayments during phases of relative sea-level rise.

From 78m-109m the sequence is dominated by mudstone but includes graded and non-graded laminae, rippled sandstone linsen and gutter casts, however the package has not been analysed in detail. The sequence probably reflects deposition within a distal offshore transitional setting. This mudstone rich portion of the stratigraphy probably correlates with similar lithological packages found at this level within the Galley Head (75.5m) and Lions Cove (127.3m) sections but is considerably more mudstone rich in this case.

The top of the sequence (109m 111m) exhibits an increase in sandstone content in the form of a series of wavy and flaser bedded units some of which include coarse sandstone. This package probably reflects a phase of increased coastal proximity with deposition in a proximal offshore transitional or lower shoreface setting. The package is overlain by the Castle Slate Formation which consists of homogenous mudstone and probably reflects deposition within an offshore setting during a phase of relative sea level rise.

6.5 Nohoval Cove

The logged section consists of three correlated logs running either side of Nohoval cove. The section is 78m thick and runs from the upper part of the Tower Member at the top of the Old Head Formation to the base of the Castle Slate Formation, details are given in figures 6.1 (map E). Most of the section is only accessible by boat.

Higgs *et al.* (1988) report LN miospore assemblages from various levels within the upper 7m of the Old Head Formation, the highest of these is from 0.26m below the base of the Castle Slate Formation. The authors also report VI biozonal assemblages from 0.45m, 3m and 30m above the base of the Castle Slate Formation.

Old Head Formation

Only the upper part of the Tower Member is included in this study (72m) and this consists of units belonging to facies association 1 (figure 2.1). Between 0m - 14m the sequence is dominated by mudstone but includes thin sandstone laminae and nodules in the basal portion (0m - 10m) and symmetrical rippled sandstone linsen and a prolific burrowing fauna in the upper part (10m - 14.5m). The increase in sandstone content upward probably reflects a change in depositional setting from a distal to a more proximal offshore transitional setting.

Between 14.5m (log 1) - 27.8m (log 1) the sequence is dominated by a series of amalgamated sandstone beds that are separated from predominantly mudstone rich enclosing units by sharp basal and upper surfaces. Sandstone beds include parallel lamination, cross-beds and symmetrical ripples and are sometimes separated by thin mudstone rich heterolithic units. This sequence is likely to reflect deposition within an upper shoreface setting and as such may represent a continuum of increasing coastal proximity that is suggested from the underlying package. The intervening mudstone and heterolithic beds represent preservation of the fair-weather sequence. The sharp basal and upper surfaces of this package probably indicate the importance of relative sea level change in the generation of this sequence.

From 26.6m (log 2) - 59.4m (log 2) the sequence consists of alternating sandstone units, symmetrical rippled heterolithic units and laminated mudstone units, changes between facies probably results from varying coastal proximity. Laminated mudstone and symmetrical rippled heterolithic units were probably deposited within an offshore transitional setting whilst sandstone units which include parallel lamination, ripples, cross-beds and possibly HCS were deposited within a shoreface setting. The abrupt lower surfaces displayed by shoreface sandstone packages were probably generated by lower shoreface erosion in response to disequilibriated shelf profiles generated by relative sea-level falls. Sharp upper surfaces reflect a subsequent rise of relative sea-level and may have been generated by erosion of an upper shoreface sequence (originally overlying this package) or simply by termination of sediment supply to the shelf as accommodation was generated in more proximal settings.

Between 59.4m - 69.9m the sequence consists of two sandstone dominated packages with relatively sharp upper and lower surfaces separated by a mudstone unit that includes ripples, graded beds and gutter casts. The lower sandstone package (59.4m -60m) includes ripples, cross-beds and parallel lamination and occasional lenticular mudstone units. The upper package (66.3m - 69.9m) includes some rippled heterolith at its base but is dominated by parallel lamination. Interestingly, the uppermost sandstone bed of this package includes quartz clasts up to 5 mm in diameter. Both sandstone packages were probably deposited within a shoreface setting although the uppermost sandstone bed from the second package may result from transgressive reworking during relative sea level rise. The intervening mudstone unit developed between these packages was deposited within an offshore transitional setting during a phase of accommodation dominance on the shelf.

An interesting aspect of this part of the Old Head Formation is that these closely spaced and overlapping measured sections suggest lateral variation between adjacent section. Although previous authors (De Raaf 1977; MaCarthy 1987; Bamford 1988) have used this type of lateral variation to suggest the development of large scale bedforms, this study interprets these changes as resulting from minor topographic changes upon the shelf. These may reflect the development of rip channels, major scours similar to those described from the continental shelf of California (Cachione

et al. 1984) or uneven incision of the shelf during forced regressive phases. Indeed undulating scour surfaces may be a common feature in ancient storm deposits (Midtgaard 1996; Rossetti *et al.* 2000; Hampson 2000)

The uppermost 30cm of the Old Head Formation consists of laminated mudstone which shows a relatively sharp transition into homogenous mudstone at the base of the Castle Slate Formation. This unit probably reflects deposition within a distal offshore transitional setting whilst the Castle Slate Formation was probably deposited in an offshore setting.

6.6 Roberts Head - South Ringabella

The logged section is 184m thick and runs from within the upper part of the Old Head Formation [1785 0535] to the base of the Castle Slate Formation [1785 0539], details are given in figures 6.1 (map F). The section is only accessible by boat.

Higgs *et al.* (1988) report LN miospore assemblages from various levels of this section. The lowest of these is from the base of the Daunt Member and the highest from the base of the Castle Slate Formation. The authors also report a VI assemblage from the lower part of the Castle Slate Formation.

Old Head Formation

The logged thickness of the Tower Member in this section is not clear because it is uncertain whether the basal part of this section (0m - 33m) forms part of the relatively sandstone rich Daunt Member (Van Gelder 1974) or simply a sandstone rich part of the Tower Member. In addition, the presence of a major fault below the base of this section means that even if the base of the logged section is part of the Tower Member it is likely that the thickness of this unit is less than the 210m previously reported (Naylor 1969; Van Gelder 1974).

Between 0m - 33m the sequence consists of alternating mudstone dominated and sandstone dominated packages. Mudstone dominated units display a wide variation in sandstone content and may include graded and non-graded laminae, gutter casts and symmetrical rippled sandstone linsen. Sandstone units typically display sharp

basal and upper surfaces and may include parallel lamination, ripples and occasionally cross-beds. Several sandstone rich units include large vertical burrows up to 14cm in length (plate 6.9) whilst one parallel laminated sandstone bed (9.7m - 10.5m) displays vertical Skolithos burrows emanating from several closely spaced internal horizons thus indicating that this unit was not deposited during a single storm event. Interestingly, mudstone and sandstone rich units are commonly arranged in a repeated sequence that consists of laminated mudstone overlain by wavy bedded symmetrical ripples overlain by parallel laminated or rippled sandstone. The sandstone packages typically exhibits sharp basal and upper surfaces. These sequences probably reflect a progressive basinward shift in facies and a change in depositional setting from offshore or distal offshore transition into shoreface environments.

From 33m - 134m the sequence is dominated by mudstone and contains thin sandstone linsen and graded beds, however much of the package is exposed in shear cliffs and is largely inaccessible. Within this sequence two relatively sandstone rich zones are found (52m - 57m, 102m - 112m). The first of these is not accessible, the second consists of two sharp based sandstone units separated by a heterolithic package containing symmetrical ripples and gutter casts. These sandstone packages are believed to reflect deposition in a lower shoreface setting.

Although the top of the Old Head Formation (134m - 173m) is also inaccessible it clearly includes groups of closely spaced and in some cases amalgamated sandstone packages separated by mudstone rich units of similar size. The uppermost and perhaps thickest of these sandstone packages is trough cross-bedded (~50cm high) and includes small quartz pebbles. The alternation between mudstone and sandstone rich packages throughout this sequence probably reflects deposition within offshore transitional and shoreface settings respectively, changes between these presumably indicate variation in relative sea-level. The abundance of fairly large quartz pebbles in the upper sandstone unit of this sequence may indicate proximity to the coastline because bedload transport adjacent to the coast is dominated by the onshore directed wave stroke. However, conglomeratic bars are occasionally reported from relatively offshore settings, for instance in the Cretaceous Moosebar-Lower Gates interval of

Western Canada where they are believed to have been emplaced by storm generated currents (Leckie and Walker 1982).

The Castle Slate Formation overlying this package was not examined in detail but probably reflects a phase of relative sea level rise with associated landward migration of facies belts.

6.7 Myrtleville - North Ringabella

The logged section is 34m thick and runs from within the upper part of the Tower Member at the top of the Old Head Formation to the base of the Castle Slate Formation, details are given in figure 6.1 (map G) and figure 1.7. The section is easily accessible from the beach at Myrtleville.

Higgs *et al.* (1988) report several LN miospore assemblages from the Old Head Formation. The lowest of these was obtained from near the base of the Old Head Formation and the highest from immediately below the pebbly sandstone unit at the top of the Formation. A VI assemblage was reported from within the Castle Slate Formation.

Old Head Formation

Only the upper 29m of the Tower Member is included in this study and this consists of units that probably belong to facies association 1 (figure 2.1). Between 0m - 14.4m the sequence displays a staggered upward transition from laminated mudstone into wavy bedded rippled units. The package also includes a massive sandstone package (2.4m - 3.2m) with sharp basal and upper surfaces. Laminated mudstone units probably reflect deposition within a distal offshore transitional or offshore setting whilst wavy bedded rippled units reflect deposition within a more proximal offshore transitional setting. The massive sandstone unit exposed between 2.4m - 3.2m may have been generated either during a low stand of relative sea-level or as a result of reworking during a rise of relative sea-level.

Between 14.4m - 27.2m the sequence is dominated by cross-bedded sandstone and pebbly sandstone (plate 6.5) but also includes symmetrical ripples and parallel

lamination. The sequence is interpreted to reflect deposition within an upper shoreface setting although the parallel laminated package capping this sequence may have been generated during transgressive reworking.

From 27.2 - 29m the sequence is mudstone rich and includes graded beds, ripples and gutter casts. This unit probably reflects deposition within an offshore transitional setting and therefore suggests a phase of relative sea-level rise. The Castle Slate Formation overlying this package was probably deposited within an offshore setting and suggests a further rise in relative sea-level.

6.8 Curraghbinny - Cork Harbour

The logged section is 27m thick and runs from within the upper part of the Tower Member at the top of the Old Head Formation through the Castle Slate Formation and into the base of the Narrow Cove Formation, details are given in figure 6.1 (map H) and figure 1.7. The section runs along the coast north of Curraghbinny Wood from where it is easily accessible.

Sleeman *et al.* (1978) report LN miospore assemblages from throughout the Old Head Formation and from the base of the Castle Slate Formation. The lowest VI miospore assemblage was recorded from 9m above the base of the Castle Slate Formation.

Old Head Formation

The logged section includes only the upper portion of the Tower Member (8.5m), this consists of units belonging to facies association 1 (figure 2.1). Between 0m - 4m the sequence consists of laminated or rippled mudstone and is similar to the underlying package in terms of low sandstone content. The unit is likely to have been deposited within an offshore transitional setting.

At 4m a featureless sandstone unit (plate 6.6) marks an abrupt increase in sandstone content that continues upwards until 8.5m. Overlying this are a series wavy bedded rippled sandstone linsen that include nodules. Both the sandstone linsen and the massive sandstone unit display orange weathering patches that may reflect

decalcification. If so, then the original state of this carbonate is unclear (shell lag or calcete?). The top of the Old Head Formation is capped by a nodular horizon possibly indicating a phase of non-deposition as a result of transgression.

Castle Slate Formation

The Castle Slate Formation exposed between 8.5m - 24.7m consists of nodular mudstone and is likely to have been deposited in response to a major rise in relative sea level.

Narrow Cove Formation

The Castle Slate Formation is sharply overlain by a sandier package that includes ripples, graded beds and gutter casts. This unit which forms the base of the Ardaturrish Member reflects deposition within a more proximal offshore transitional setting than the underlying Castle Slate Formation. The dramatic increase in sandstone at the base of this unit indicates a phase of forced regression driven by relative fall.

6.9 Cuskinny - Cork Harbour

The logged section is 33m thick and runs from within the upper part of the Tower Member at the top of the Old Head Formation through the Castle Slate Formation and into the base of the Narrow Cove Formation, details are given in figure 6.1 (map I) and figure 1.7. The section lies on the west side of Cuskinny Bay and is accessible from the main road running east of Cohb.

Sleeman *et al.* (1978) report LN miospore assemblages from two levels in the upper part of the Old Head Formation and from a low level in the Castle Slate Formation. The lowest VI miospore assemblage was recorded from 17.5m above the base of the Castle Slate Formation.

Old Head Formation

The logged section includes the upper portion of the Tower Member (11m) which consists of units belonging to facies association 1 (figure 2.1). Between 0m - 7.5m the section consists of alternating laminated mudstone, rippled heterolith and

sandstone beds (plate 6.6) all of which display sharp basal and upper surfaces. Variation in sandstone content is likely to reflect changing proximity to the coastline. Both laminated mudstone and rippled heterolithic units are likely to have been deposited within an offshore transitional setting whilst sandstone units probably reflect deposition within a shoreface setting. However it is possible that some sandstone packages (e.g. 7m - 7.5m) may result from transgressive reworking of earlier sequences during phases of relative sea-level rise.

This sequence is overlain by a mudstone dominated package (7.5m - 10.6m) that includes graded beds, gutter casts, ripples and nodules that was probably deposited within an offshore transitional setting. The uppermost sandstone unit that caps the Old Head Formation (10.6m - 11m) is dominated by cross-bedding and was probably deposited within a shoreface setting. The thin sandstone bed at the top of this unit includes mud clasts and is likely to reflect reworking associated with the relative sea-level rise at this time.

Castle Slate Formation

The Castle Slate Member between 11m - 30m consists of homogenous mudstone and is likely to have been deposited in response to a major rise in relative sea level.

Narrow Cove Formation

Only the base of the Ardaturrish Member has been analysed in this study. This sequence consists of a mudstone rich sequence containing graded beds and gutter casts and probably reflects a fall in relative sea-level relative to the underlying unit. The unusually large gutter cast exposed at the base of this unit may result from a phase of non-deposition and sediment bypass following a base-level fall.

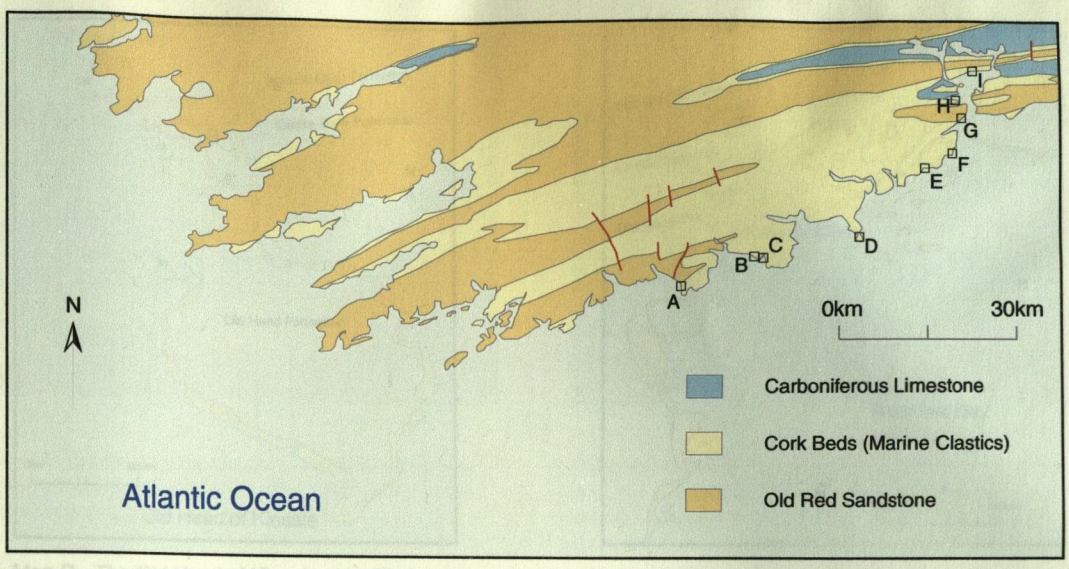
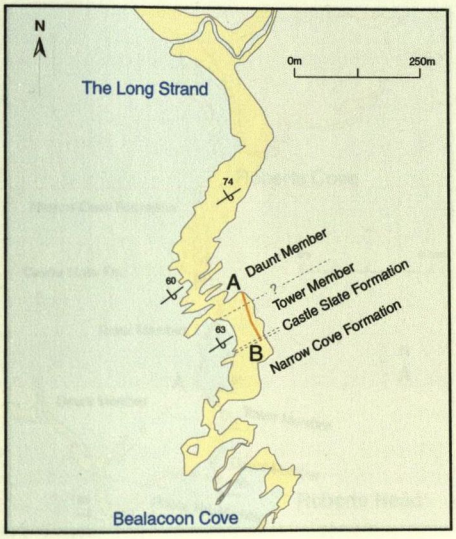


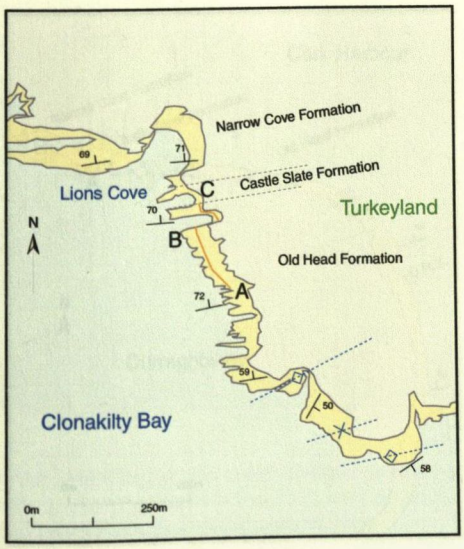
Figure 6.1 - Location of logged sections from the south coast of County Cork and Cork Harbour



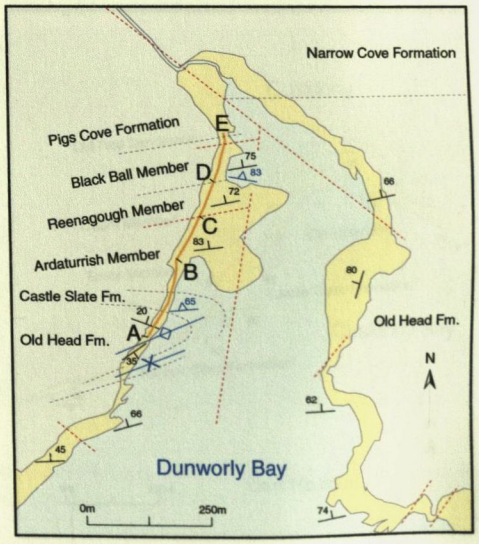
Map A - West Galley Head section

Map Location

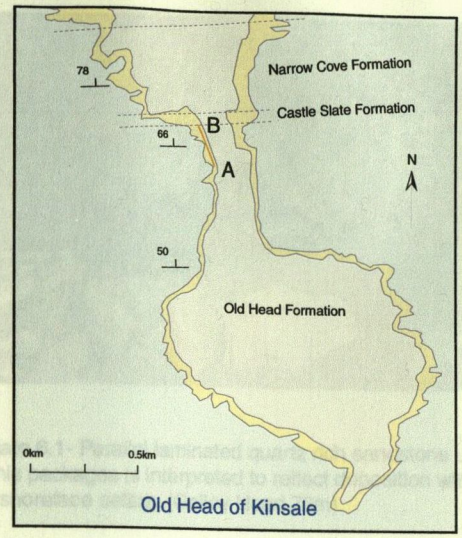
Map A - Long Strand, West Galley Head
Map B - Lions Cove, West Seven Heads
Map C - Dunworly Bay, W. Seven Heads
Map D - Holeopen Bay W., the Old Head
Map E - Nohoval Cove, Reanies Bay
Map F - Roberts Head, South Ringabella
Map G - Myrtleville, North Ringabella
Map H - Curraghbinny, Cork Harbour
Map I - Cuskinny Bay, Cork Harbour



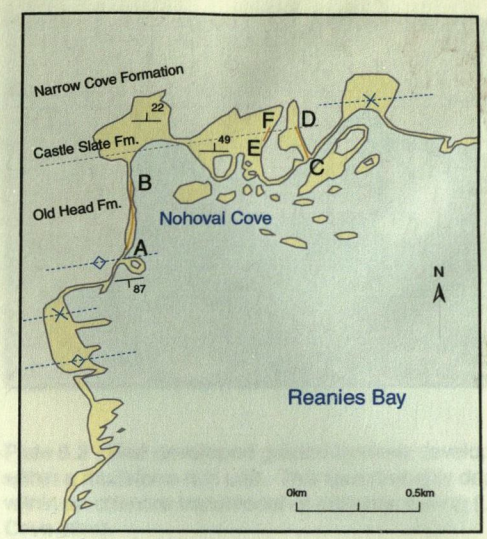
Map B - Lions Cove section. Modified from Graham and Reilly (1976)



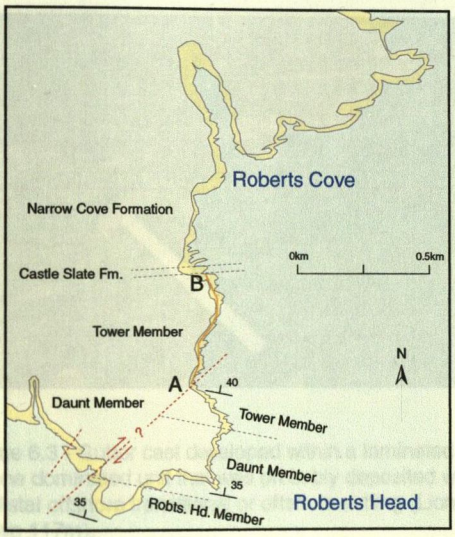
Map C - Dunworly Bay section. Modified from Graham and Reilly (1976)



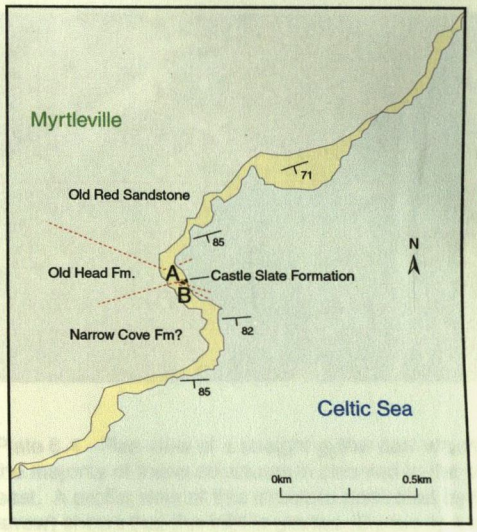
Map D - The Old Head of Kinsale. Modified from Naylor (1966)



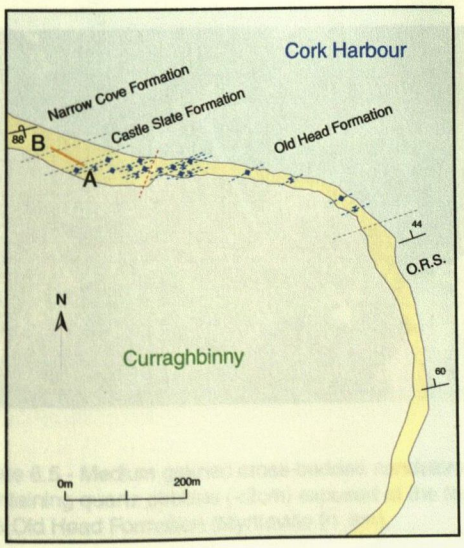
Map E - Nohoval Cove Reanies Bay. Modified from Naylor and Higgs (1980)



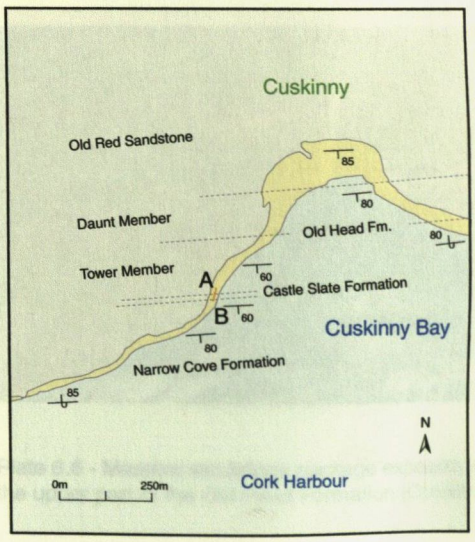
Map F - Roberts Head. Modified from Van Gelder (1974)



Map G - Myrtleville. Modified from Higgs, Clayton and Keegan (1988)



Map H - Curraghbinny. Modified from Sleeman, Reilly and Higgs (1978)



Map I - Cuskinny Bay. Modified from MacCarthy, Gardiner and Horne (1978)



Plate 6.1- Parallel laminated quartz rich sandstone unit. This packages is interpreted to reflect deposition within a shoreface setting (Galley Head 73m).



Plate 6.2 - Well developed graded laminae developed within a mudstone rich unit. This was probably deposited within an offshore transitional or offshore setting (Lions Cove 38m).



Plate 6.3 - Gutter cast developed within a laminated mudstone dominated unit that was probably deposited within a distal offshore transitional or offshore setting (Lions Cove 117m).

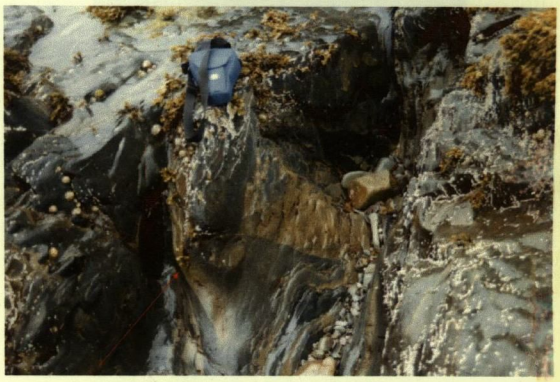


Plate 6.4 - Plan view of a straight gutter cast which like the majority of these structures is oriented to the south-east. A profile view of this structure (indicated by the red arrow) shows that the infill is graded (Dunworly 44m).



Plate 6.5 - Medium grained cross-bedded sandstone unit containing quartz pebbles (<2cm) exposed at the top of the Old Head Formation (Myrtleville 21.5m).



Plate 6.6 - Massive sandstone package exposed within the upper part of the Old Head Formation (Cuskinny 7.2m).

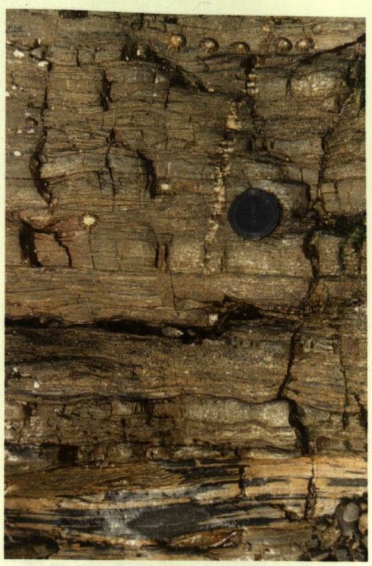


Plate 6.7 - Parallel laminated and symmetrical rippled sandstone linsen separated by thin mudstone drapes. This package is interpreted to reflect deposition within a proximal offshore transitional or lower shoreface setting. Note the sharp contact with the underlying mudstone (Dunworly 68m).

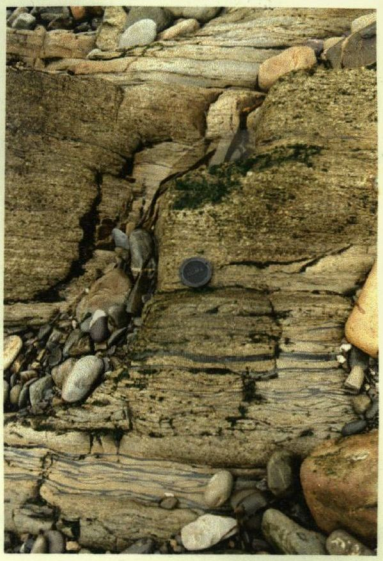


Plate 6.8 - Thickening and coarsening up package showing an upwards transition from wavy beds into low angle laminated sandstone. This probably reflects a change in environment from an offshore transitional to a lower shoreface setting (Dunworly 124m).

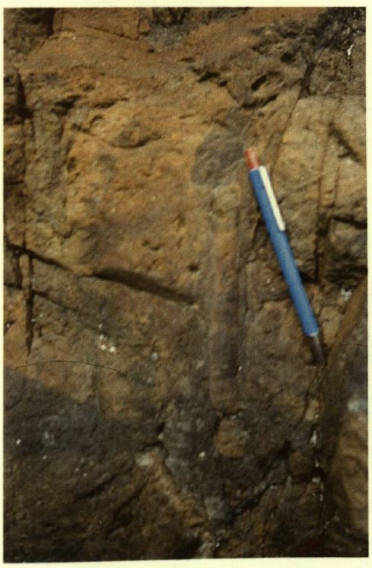
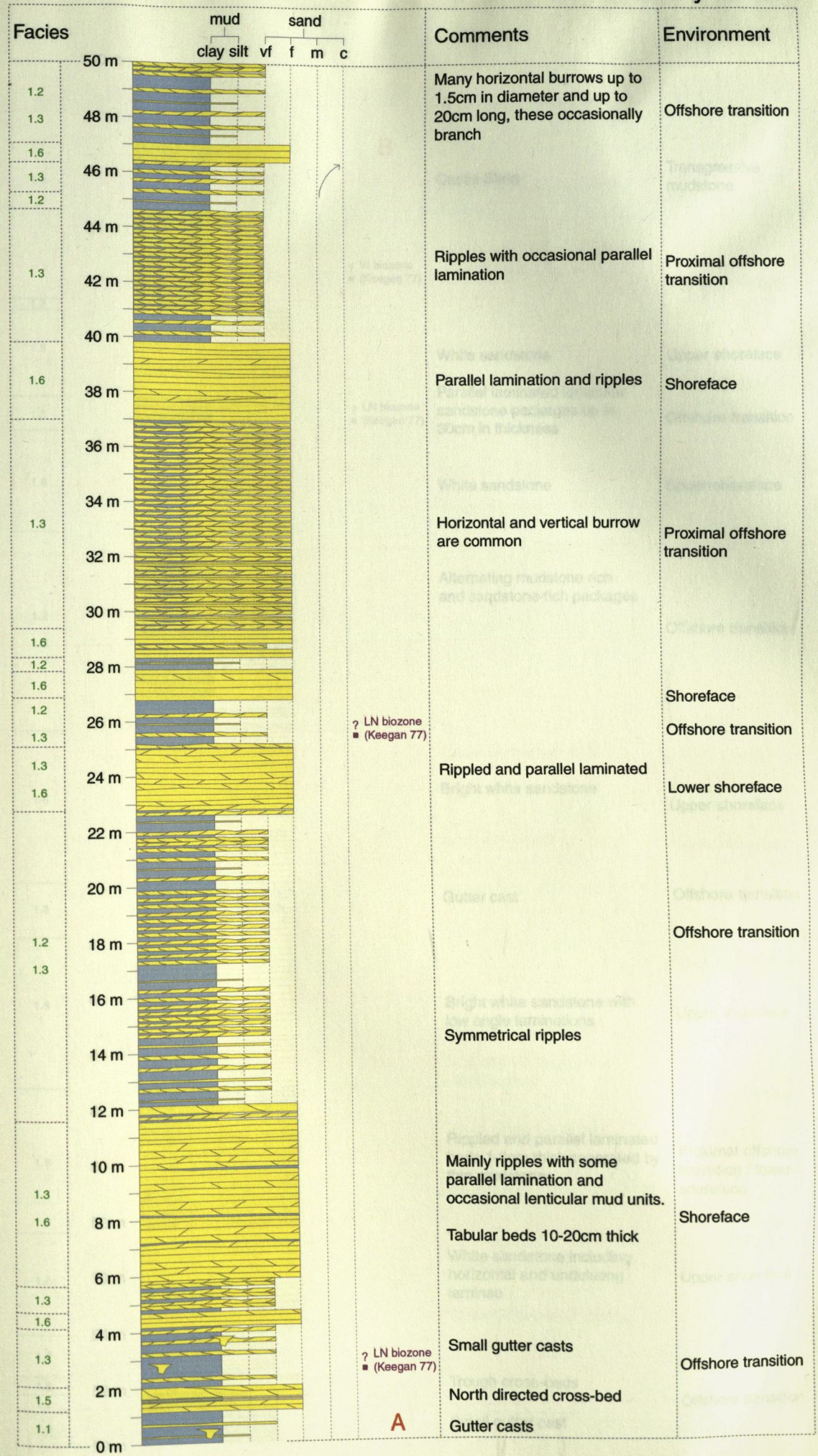


Plate 6.9 - Vertical burrow 0.8cm in diameter and 14cm in length is preserved within a weathered and heavily bioturbated heterolithic unit (Roberts Head 5m).

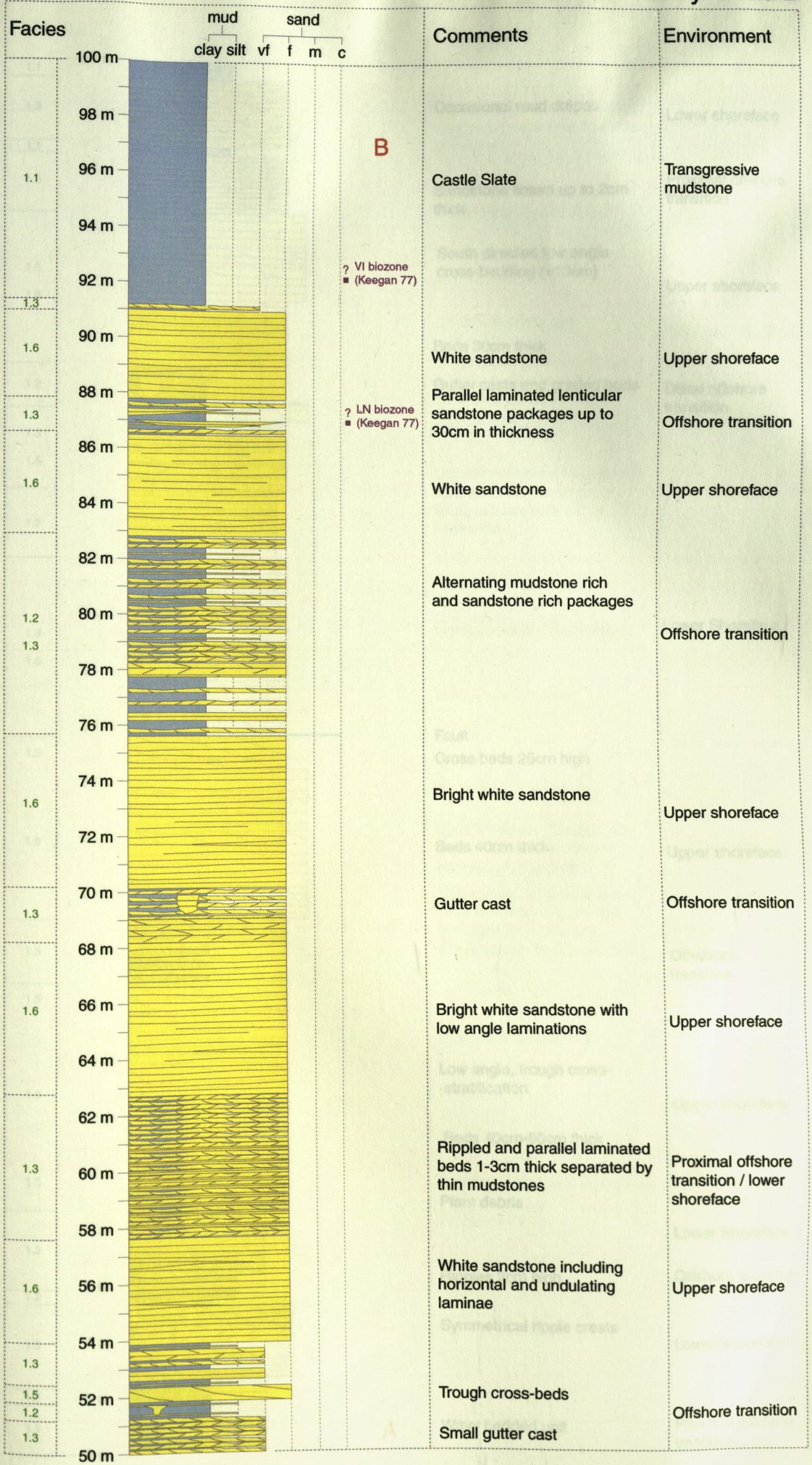


Plate 6.10 - Massive sandstone unit developed at the top of the Old Head Formation (Curraghbinny 4.5m).

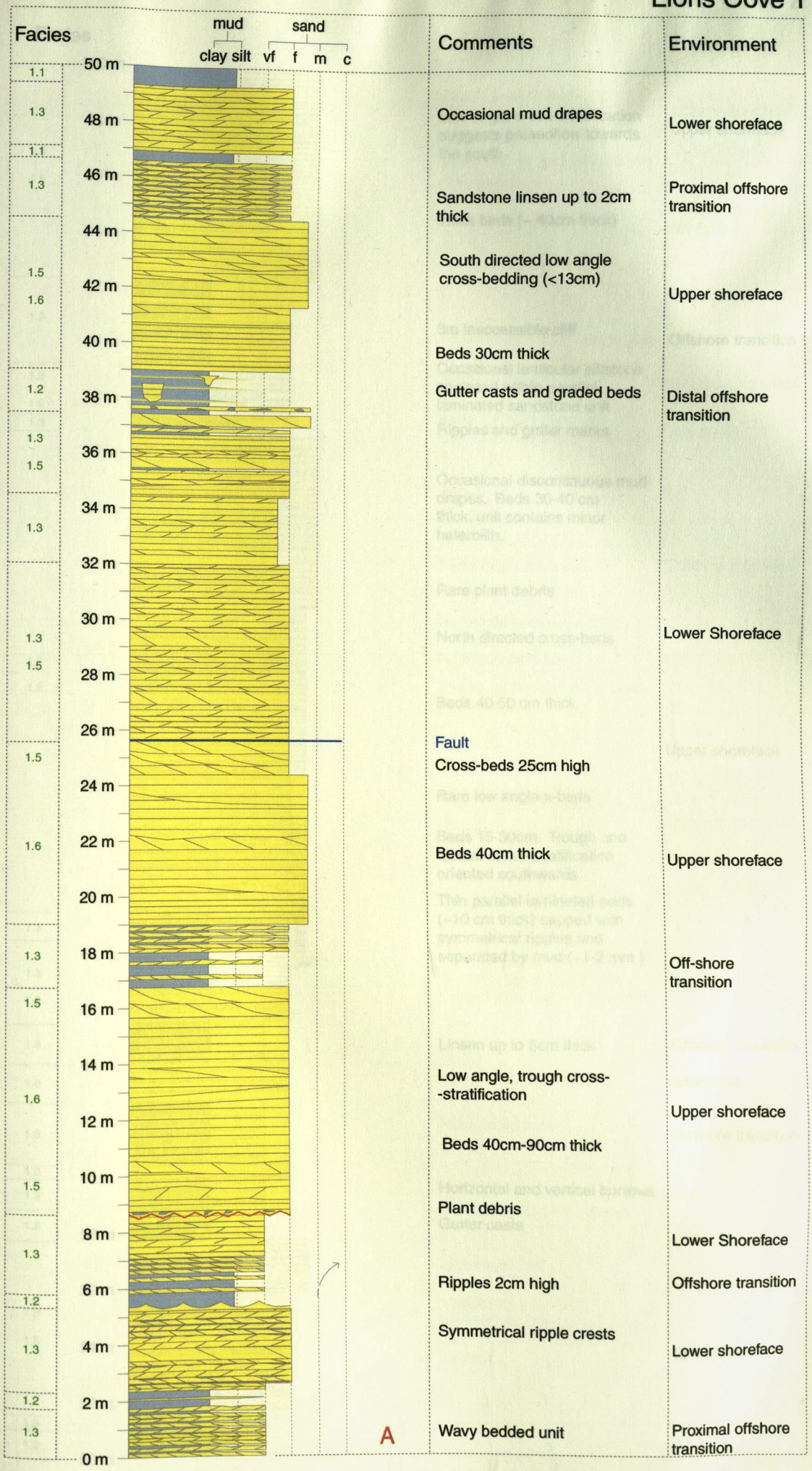
Galley Head 1



Galley Head 2



Lions Cove 1


Facies
mud
clay silt
sand
vf f m c
Comments
Environment
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46 m
44 m
42 m
40 m
38 m
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16 m
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10 m
8 m
6 m
4 m
2 m
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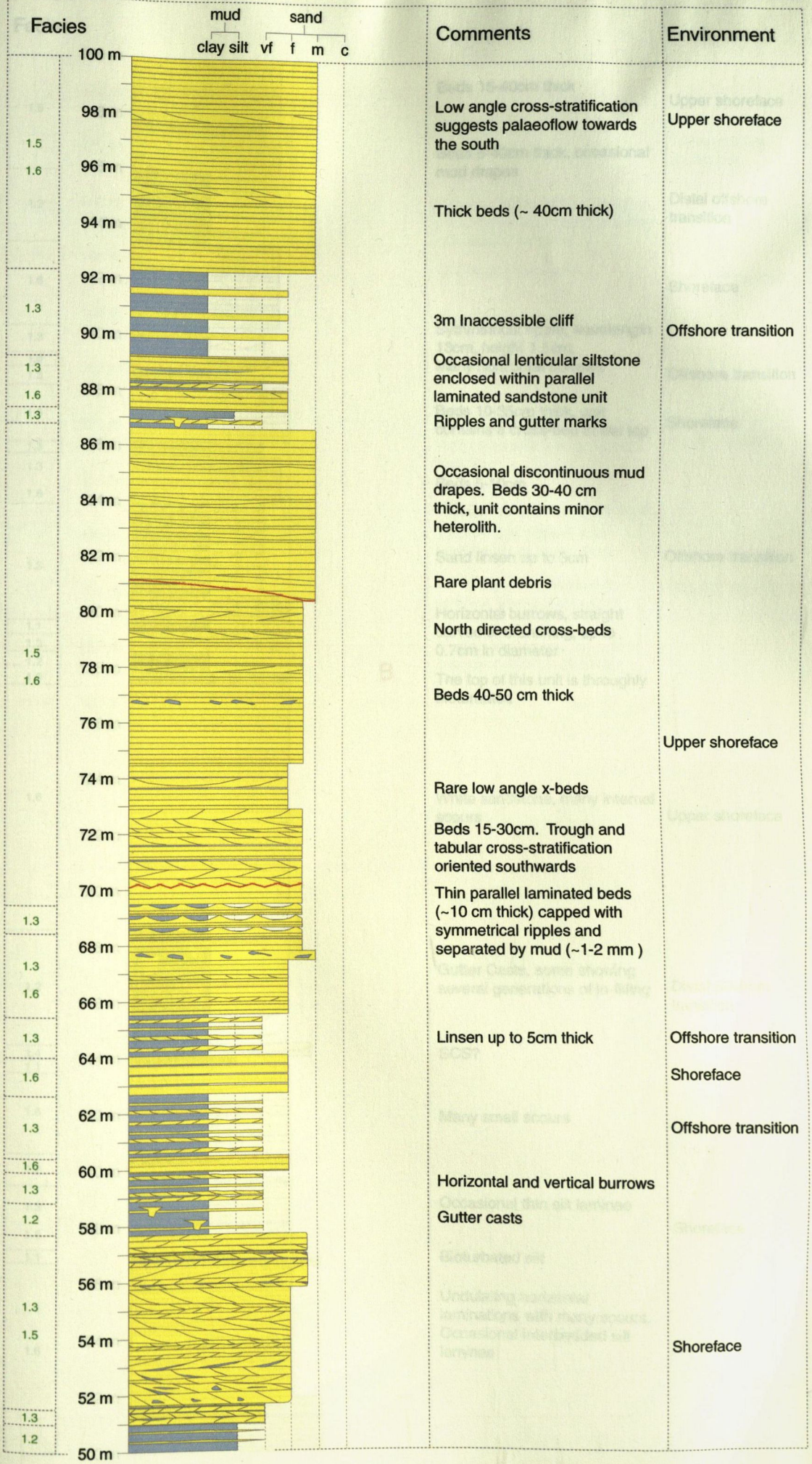
1.3
1.1
1.3
1.5
1.6
1.2
1.3
1.5
1.3
1.3
1.5
1.5
1.6
1.3
1.5
1.6
1.5
1.3
1.2
1.3
1.2
1.3
Occasional mud drapes
Lower shoreface
Sandstone linsen up to 2cm thick
Proximal offshore transition
South directed low angle cross-bedding (<13cm)
Upper shoreface
Beds 30cm thick
Gutter casts and graded beds
Distal offshore transition
Lower Shoreface
Fault
Cross-beds 25cm high
Beds 40cm thick
Upper shoreface
Off-shore transition
Low angle, trough cross--stratification
Upper shoreface
Beds 40cm-90cm thick
Plant debris
Lower Shoreface
Ripples 2cm high
Offshore transition
Symmetrical ripple crests
Lower shoreface
Wavy bedded unit
Proximal offshore transition
A

Lions Cove 2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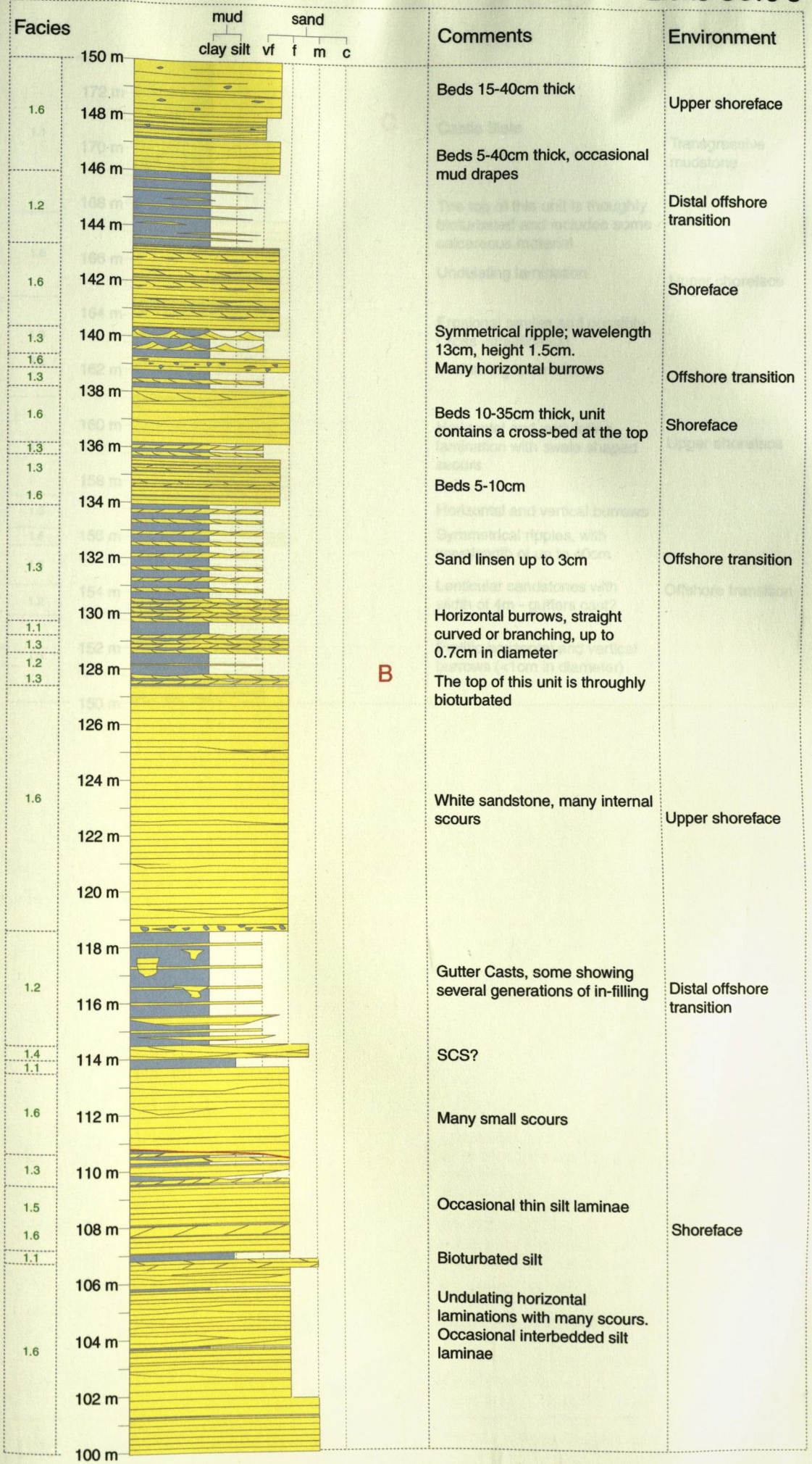
80 m
78 m
76 m
74 m
72 m
70 m
68 m
66 m
64 m
62 m
60 m
58 m
56 m
54 m
52 m
50 m
1.5
1.6
1.3
1.3
1.6
1.3
1.5
1.6
1.3
1.3
1.6
1.3
1.6
1.3
1.6
1.3
1.2
1.3
1.5
1.3
1.2
Comments
Low angle cross-stratification suggests palaeoflow towards the south
Thick beds (~ 40cm thick)
3m Inaccessible cliff
Occasional lenticular siltstone enclosed within parallel laminated sandstone unit
Ripples and gutter marks
Occasional discontinuous mud drapes. Beds 30-40 cm thick, unit contains minor heterolith.
Rare plant debris
North directed cross-beds
Beds 40-50 cm thick
Rare low angle x-beds
Beds 15-30cm. Trough and tabular cross-stratification oriented southwards
Thin parallel laminated beds (~10 cm thick) capped with symmetrical ripples and separated by mud (~1-2 mm)
Linsen up to 5cm thick
Horizontal and vertical burrows
Gutter casts
Environment
Upper shoreface
Offshore transition
Upper shoreface
Shoreface
Offshore transition
Shoreface

Lions Cove 3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clay silt
sand
vf f m c
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146 m
144 m
142 m
140 m
138 m
136 m
134 m
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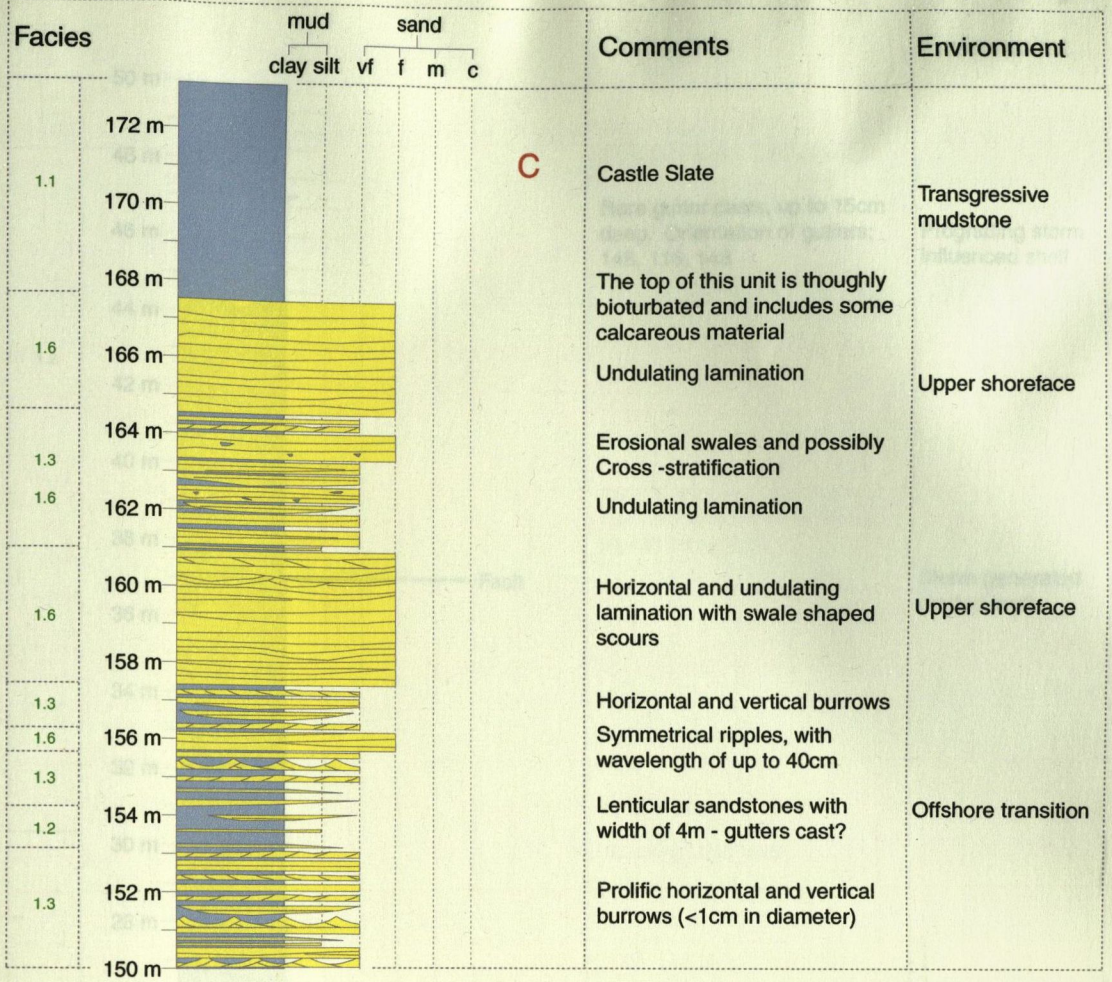
128 m
126 m
124 m
122 m
120 m
118 m
116 m
114 m
112 m
110 m
108 m
106 m
104 m
102 m
100 m
1.6
1.2
1.6
1.3
1.6
1.3
1.6
1.3
1.3
1.6
1.3
1.1
1.3
1.2
1.3
1.6
1.2
1.4
1.1
1.6
1.3
1.5
1.6
1.1
1.6
B
Comments
Beds 15-40cm thick
Beds 5-40cm thick, occasional mud drapes
Symmetrical ripple; wavelength 13cm, height 1.5cm.
Many horizontal burrows
Beds 10-35cm thick, unit contains a cross-bed at the top
Beds 5-10cm
Sand linsen up to 3cm
Horizontal burrows, straight curved or branching, up to 0.7cm in diameter
The top of this unit is throughly bioturbated
White sandstone, many internal scours
Gutter Casts, some showing several generations of in-filling
SCS?
Many small scours
Occasional thin silt laminae
Bioturbated silt
Undulating horizontal laminations with many scours.
Occasional interbedded silt laminae
Environment
Upper shoreface
Distal offshore transition
Shoreface
Offshore transition
Shoreface
Offshore transition
Upper shoreface
Distal offshore transition
Shoreface

Lions Cove 4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clay silt
sand
vf f m c
Comments
Environment
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166 m
164 m
162 m
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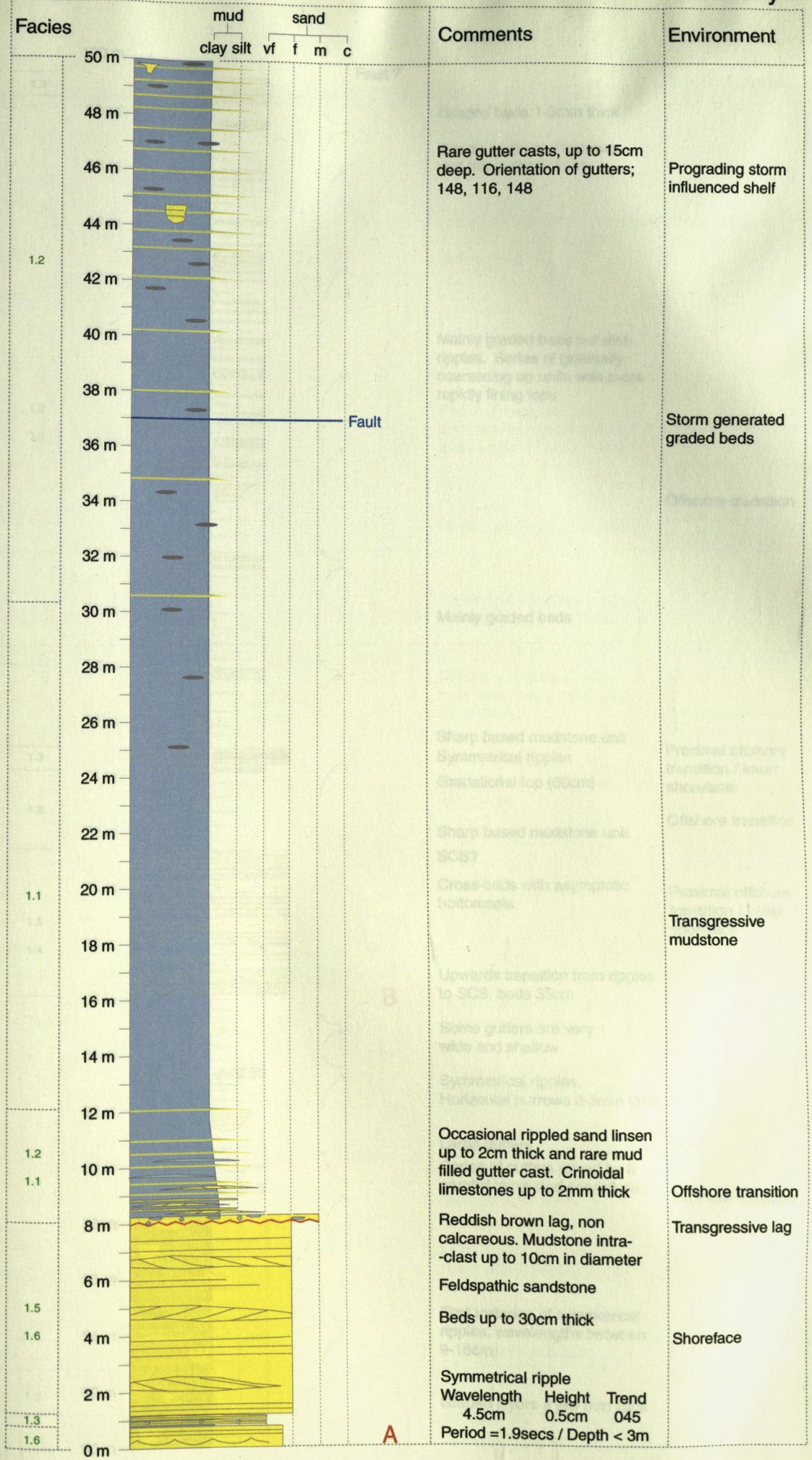
156 m
154 m
152 m
150 m
1.1
1.6
1.3
1.6
1.6
1.3
1.6
1.3
1.2
1.3
C
Castle Slate
Transgressive mudstone
The top of this unit is thoughly bioturbated and includes some calcareous material
Undulating lamination
Upper shoreface
Erosional swales and possibly Cross -stratification
Undulating lamination
Horizontal and undulating lamination with swale shaped scours
Upper shoreface
Horizontal and vertical burrows
Symmetrical ripples, with wavelength of up to 40cm
Lenticular sandstones with width of 4m - gutters cast?
Offshore transition
Prolific horizontal and vertical burrows (<1cm in diameter)

Dunworly 1


Facies
mud
clay silt
sand
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50 m
48 m
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38 m
36 m
34 m
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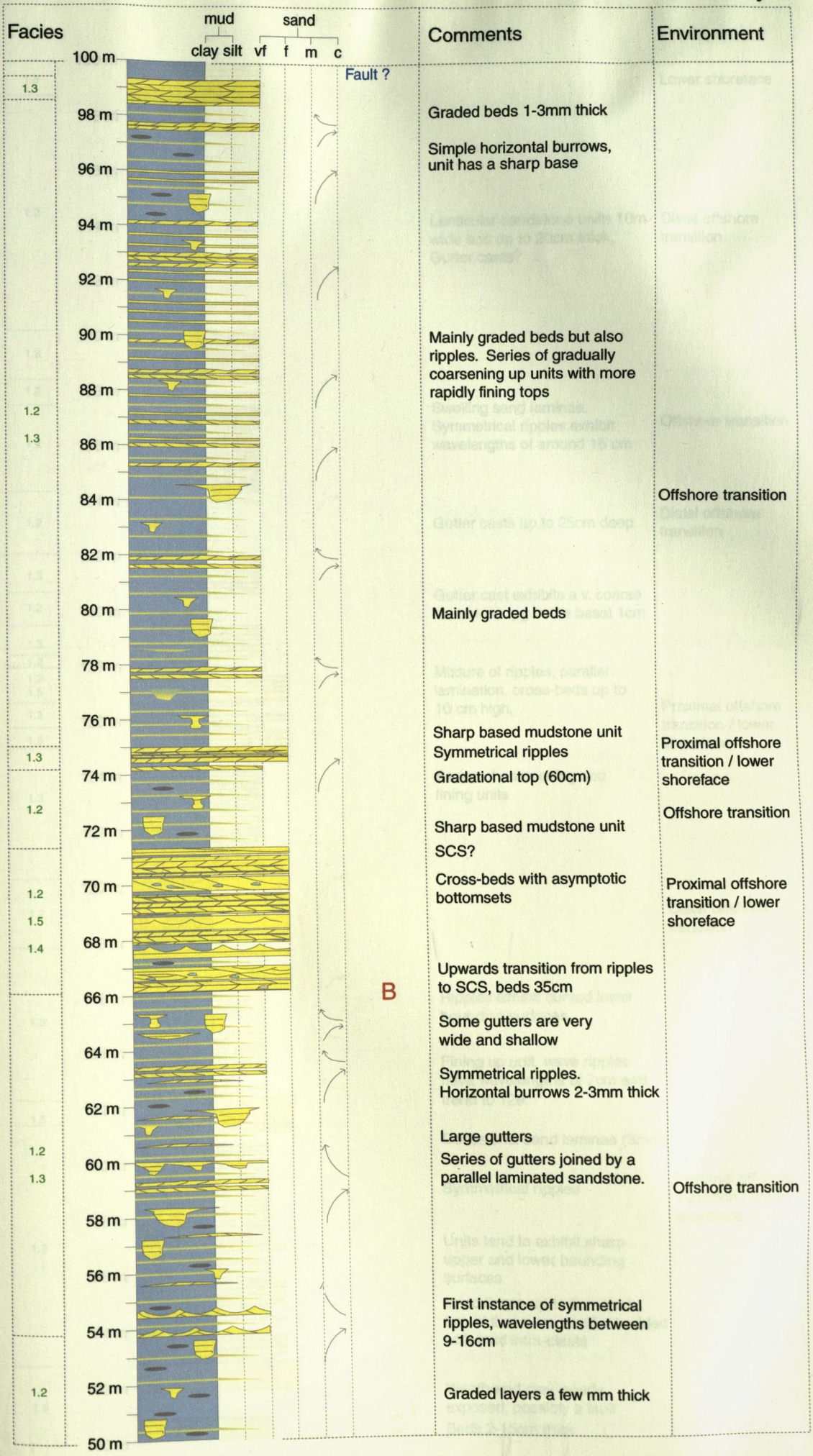
30 m
28 m
26 m
24 m
22 m
20 m
18 m
16 m
14 m
12 m
10 m
8 m
6 m
4 m
2 m
0 m
1.2
1.1
1.2
1.1
1.5
1.6
1.3
1.6
Fault
A
Comments
Rare gutter casts, up to 15cm deep. Orientation of gutters; 148, 116, 148
Occasional rippled sand linsen up to 2cm thick and rare mud filled gutter cast. Crinoidal limestones up to 2mm thick
Reddish brown lag, non calcareous. Mudstone intra--clast up to 10cm in diameter
Feldspathic sandstone
Beds up to 30cm thick
Symmetrical ripple
Wavelength 4.5cm
Height 0.5cm
Trend 045
Period =1.9secs / Depth < 3m
Environment
Prograding storm influenced shelf
Storm generated graded beds
Transgressive mudstone
Offshore transition
Transgressive lag
Shoreface

Dunworly 2


Facies
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sand
vf f m c
Comments
Environment
100 m
98 m
96 m
94 m
92 m
90 m
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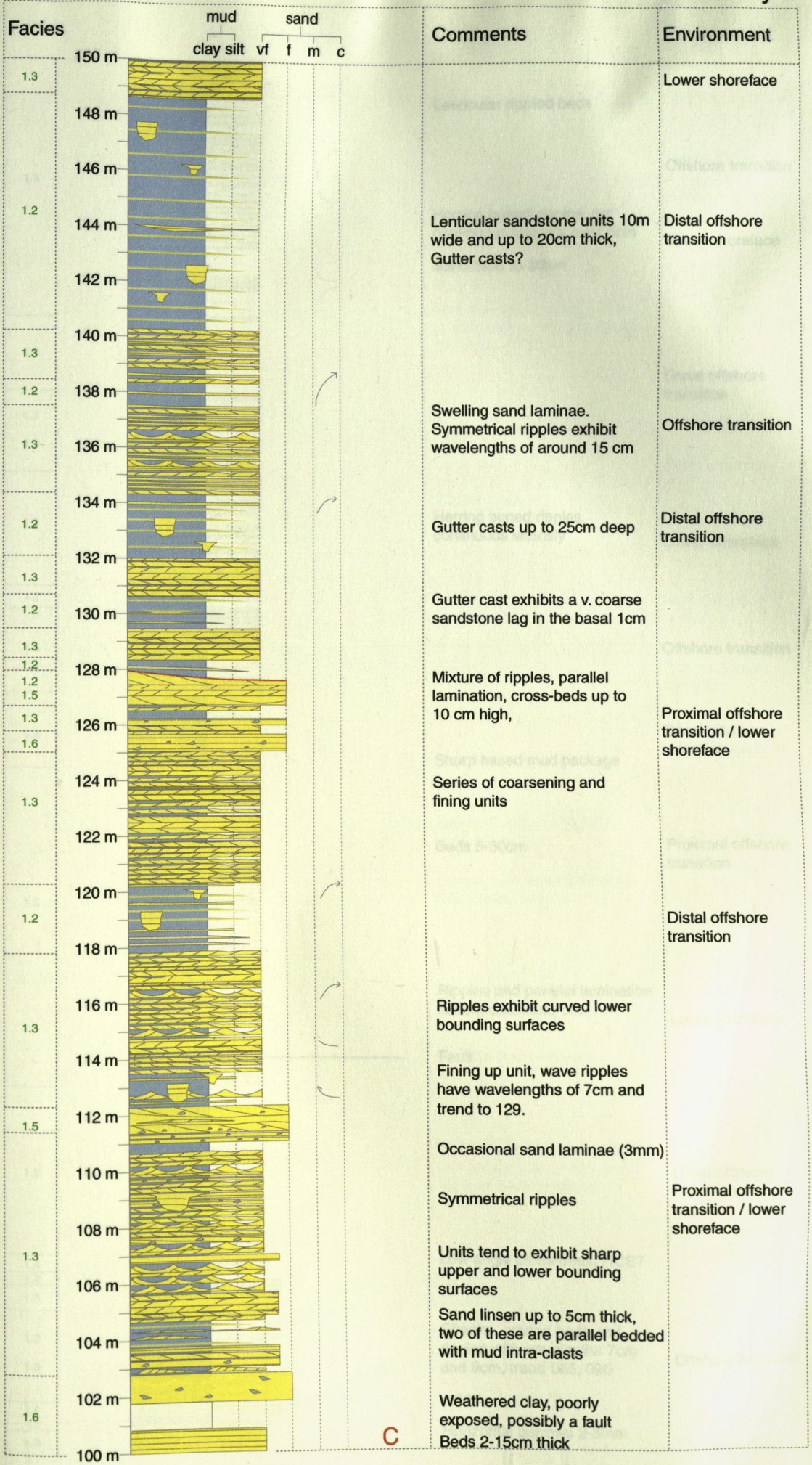
82 m
80 m
78 m
76 m
74 m
72 m
70 m
68 m
66 m
64 m
62 m
60 m
58 m
56 m
54 m
52 m
50 m
1.3
1.2
1.3
1.3
1.2
1.2
1.5
1.4
1.2
1.3
1.2
Fault ?
B
Graded beds 1-3mm thick
Simple horizontal burrows, unit has a sharp base
Mainly graded beds but also ripples. Series of gradually coarsening up units with more rapidly fining tops
Offshore transition
Mainly graded beds
Sharp based mudstone unit
Symmetrical ripples
Gradational top (60cm)
Proximal offshore transition / lower shoreface
Offshore transition
Sharp based mudstone unit
SCS?
Cross-beds with asymptotic bottomsets
Proximal offshore transition / lower shoreface
Upwards transition from ripples to SCS, beds 35cm
Some gutters are very wide and shallow
Symmetrical ripples. Horizontal burrows 2-3mm thick
Large gutters
Series of gutters joined by a parallel laminated sandstone.
Offshore transition
First instance of symmetrical ripples, wavelengths between 9-16cm
Graded layers a few mm thick

Dunworly 3


Facies
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sand
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Comments
Environment
150 m
148 m
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132 m
130 m
128 m
126 m
124 m
122 m
120 m
118 m
116 m
114 m
112 m
110 m
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106 m
104 m
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100 m
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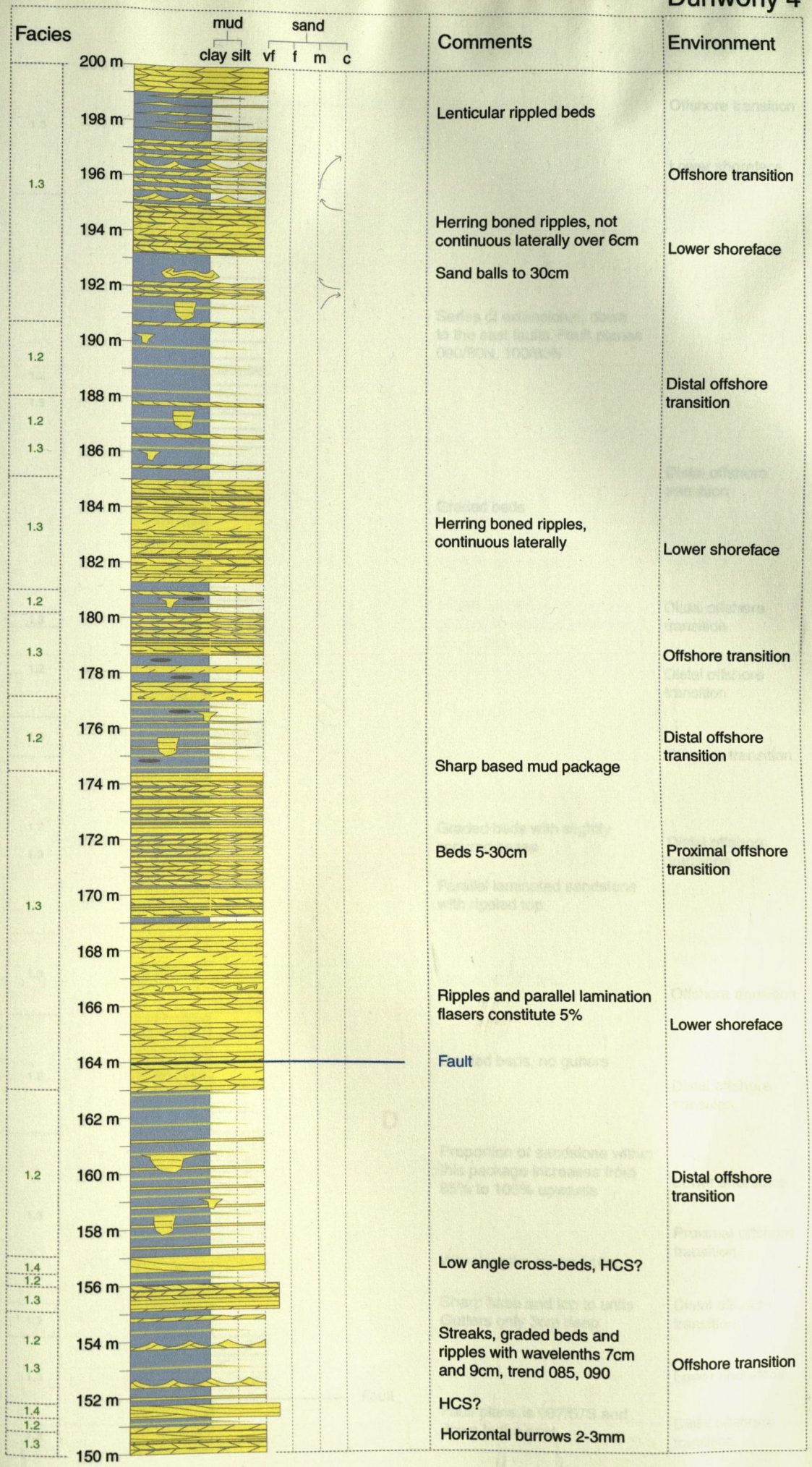
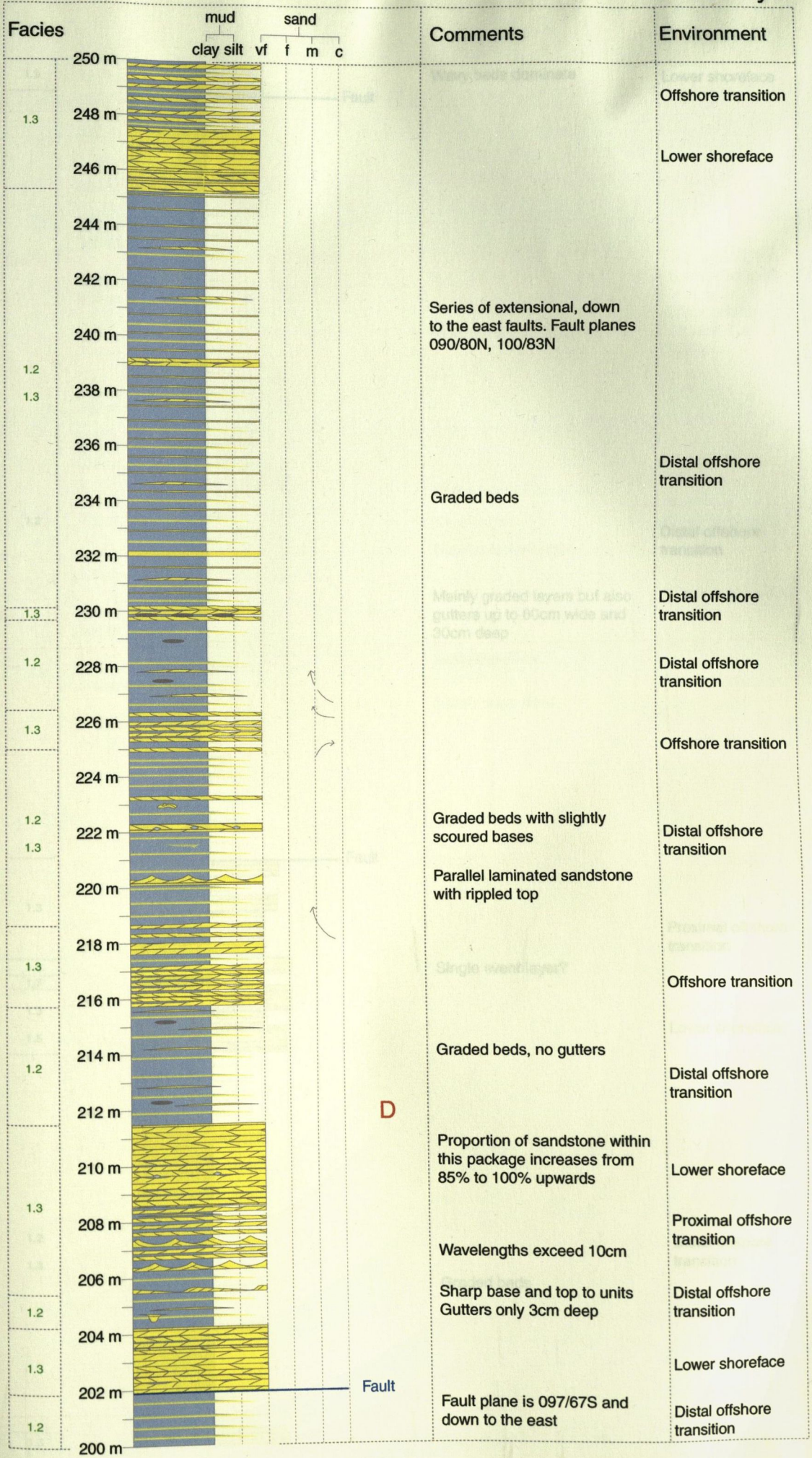
1.2
1.3
1.2
1.3
1.2
1.3
1.2
1.2
1.5
1.3
1.6
1.3
1.2
1.3
1.5
1.3
1.6
Lower shoreface
Lenticular sandstone units 10m wide and up to 20cm thick, Gutter casts?
Distal offshore transition
Swelling sand laminae. Symmetrical ripples exhibit wavelengths of around 15 cm
Offshore transition
Gutter casts up to 25cm deep
Distal offshore transition
Gutter cast exhibits a v. coarse sandstone lag in the basal 1cm
Mixture of ripples, parallel lamination, cross-beds up to 10 cm high,
Proximal offshore transition / lower shoreface
Series of coarsening and fining units
Distal offshore transition
Ripples exhibit curved lower bounding surfaces
Fining up unit, wave ripples have wavelengths of 7cm and trend to 129.
Occasional sand laminae (3mm)
Symmetrical ripples
Proximal offshore transition / lower shoreface
Units tend to exhibit sharp upper and lower bounding surfaces
Sand linsen up to 5cm thick, two of these are parallel bedded with mud intra-clasts
Weathered clay, poorly exposed, possibly a fault
Beds 2-15cm thick
C

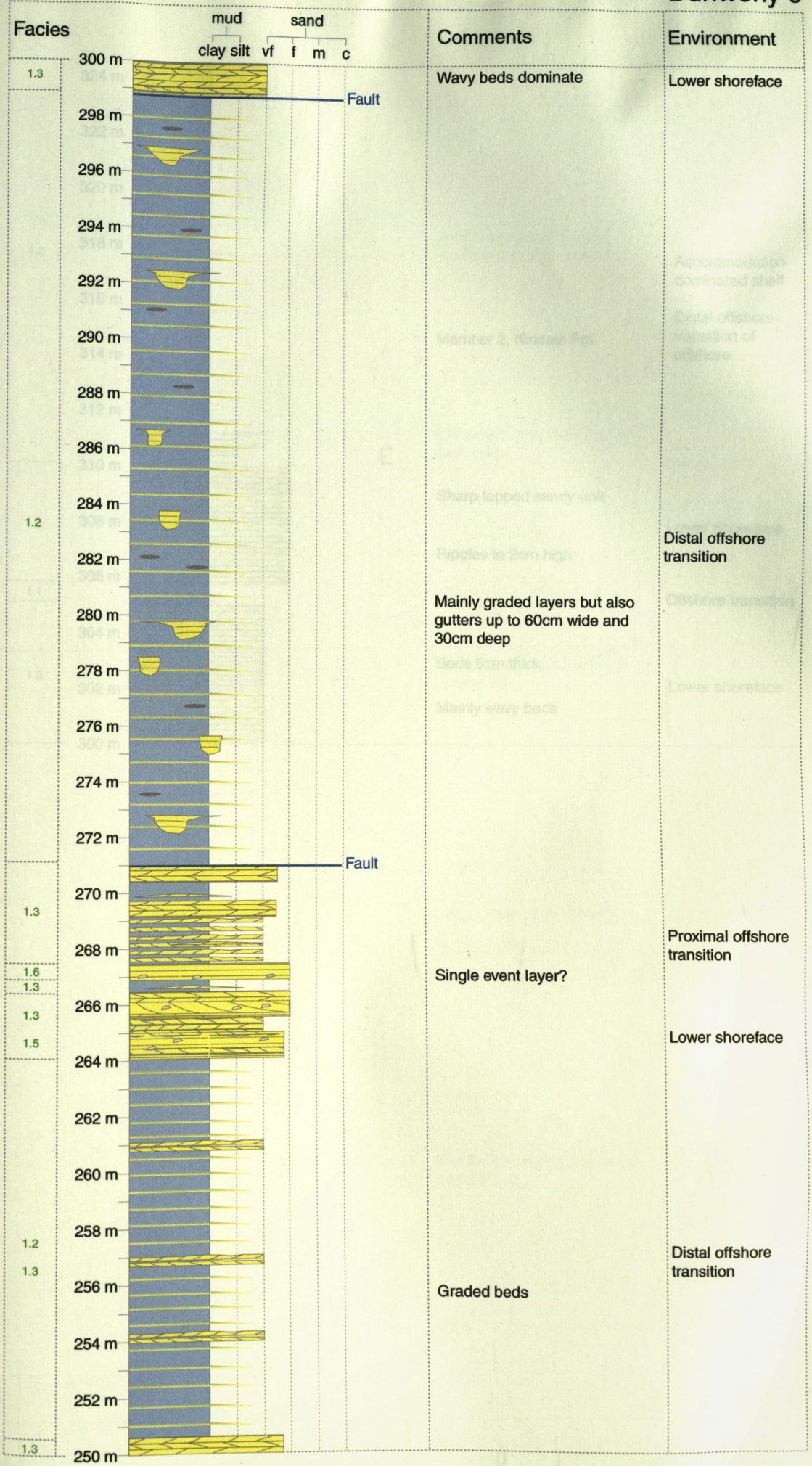
Dunworly 4


Facies
mud
clay silt
sand
vf f m c
200 m
198 m
196 m
194 m
192 m
190 m
188 m
186 m
184 m
182 m
180 m
178 m
176 m
174 m
172 m
170 m
168 m
166 m
164 m
162 m
160 m
158 m
156 m
154 m
152 m
150 m
1.3
1.2
1.2
1.3
1.3
1.2
1.3
1.2
1.3
1.2
1.4
1.2
1.3
1.2
1.3
1.4
1.2
1.3
Comments
Lenticular rippled beds
Herring boned ripples, not continuous laterally over 6cm
Sand balls to 30cm
Herring boned ripples, continuous laterally
Sharp based mud package
Beds 5-30cm
Ripples and parallel lamination flasers constitute 5%
Fault
Low angle cross-beds, HCS?
Streaks, graded beds and ripples with wavelenths 7cm and 9cm, trend 085, 090
HCS?
Horizontal burrows 2-3mm
Environment
Offshore transition
Lower shoreface
Distal offshore transition
Lower shoreface
Offshore transition
Distal offshore transition
Proximal offshore transition
Lower shoreface
Distal offshore transition
Offshore transition

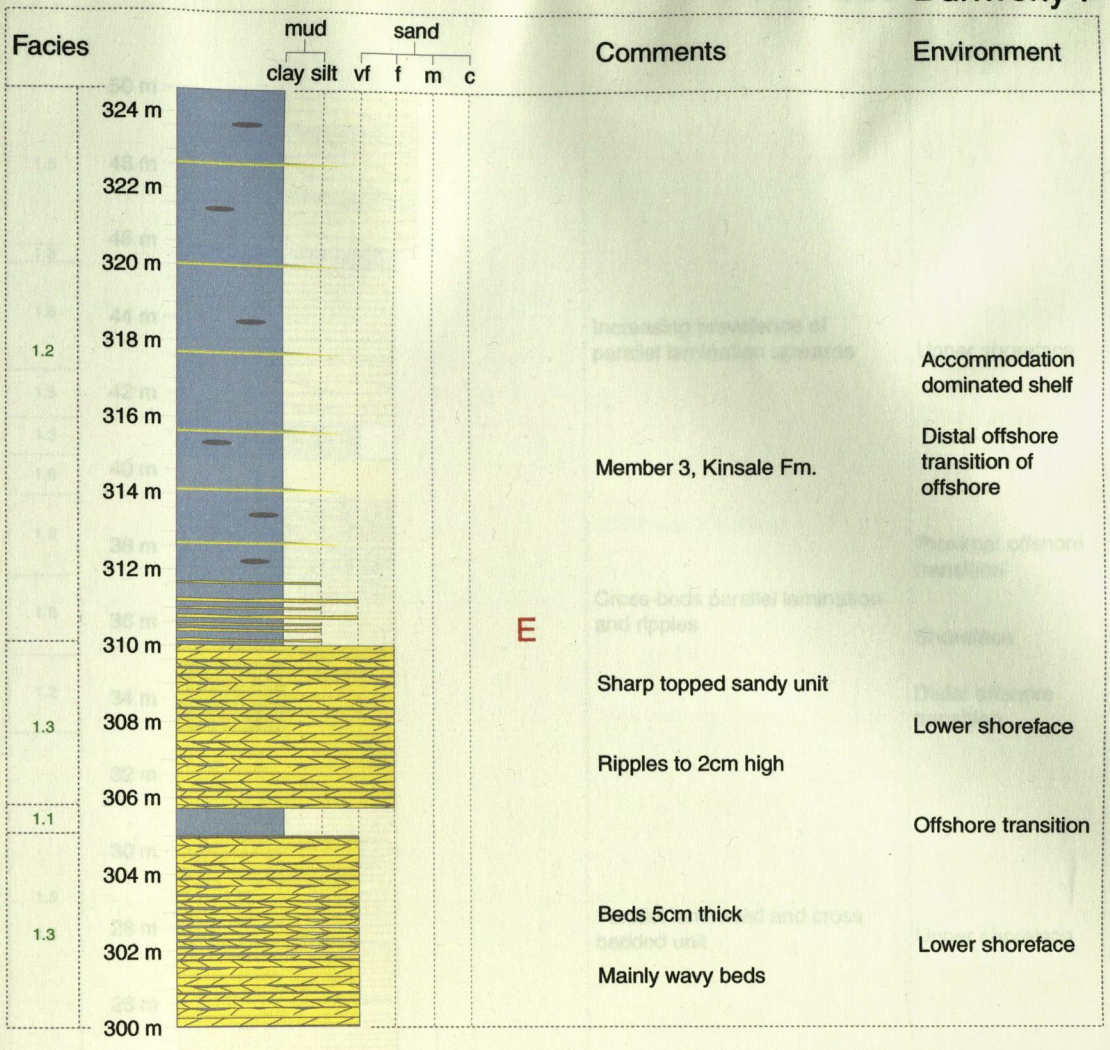
Dunworly 5


Facies
mud
clay silt
sand
vf f m c
250 m
248 m
246 m
244 m
242 m
240 m
238 m
236 m
234 m
232 m
230 m
228 m
226 m
224 m
222 m
220 m
218 m
216 m
214 m
212 m
210 m
208 m
206 m
204 m
202 m
200 m
1.3
1.2
1.3
1.2
1.3
1.2
1.3
1.3
1.2
1.3
1.2
1.3
1.2
D
Fault
Comments
Environment
Offshore transition
Lower shoreface
Series of extensional, down to the east faults. Fault planes 090/80N, 100/83N
Distal offshore transition
Graded beds
Distal offshore transition
Distal offshore transition
Offshore transition
Graded beds with slightly scoured bases
Distal offshore transition
Parallel laminated sandstone with rippled top
Offshore transition
Graded beds, no gutters
Distal offshore transition
Proportion of sandstone within this package increases from 85% to 100% upwards
Lower shoreface
Proximal offshore transition
Wavelengths exceed 10cm
Sharp base and top to units Gutters only 3cm deep
Distal offshore transition
Lower shoreface
Fault plane is 097/67S and down to the east
Distal offshore transition

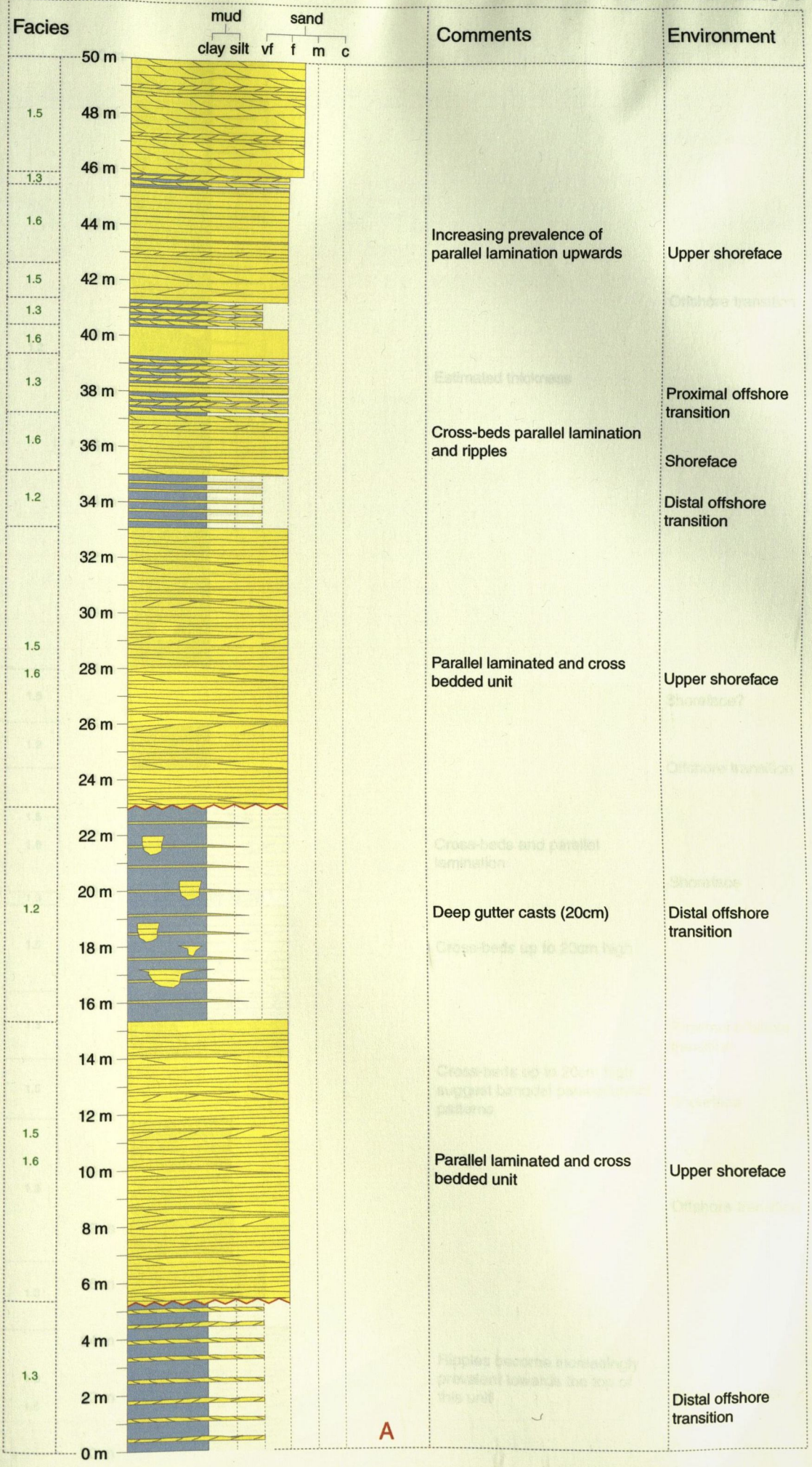
Dunworly 6


Facies
mud
clay silt
sand
vf f m c
Comments
Environment
300 m
298 m
296 m
294 m
292 m
290 m
288 m
286 m
284 m
282 m
280 m
278 m
276 m
274 m
272 m
270 m
268 m
266 m
264 m
262 m
260 m
258 m
256 m
254 m
252 m
250 m
1.3
1.2
1.6
1.5
Fault
Fault
Wavy beds dominate
Lower shoreface
Distal offshore transition
Mainly graded layers but also gutters up to 60cm wide and 30cm deep
Proximal offshore transition
Single event layer?
Lower shoreface
Distal offshore transition
Graded beds

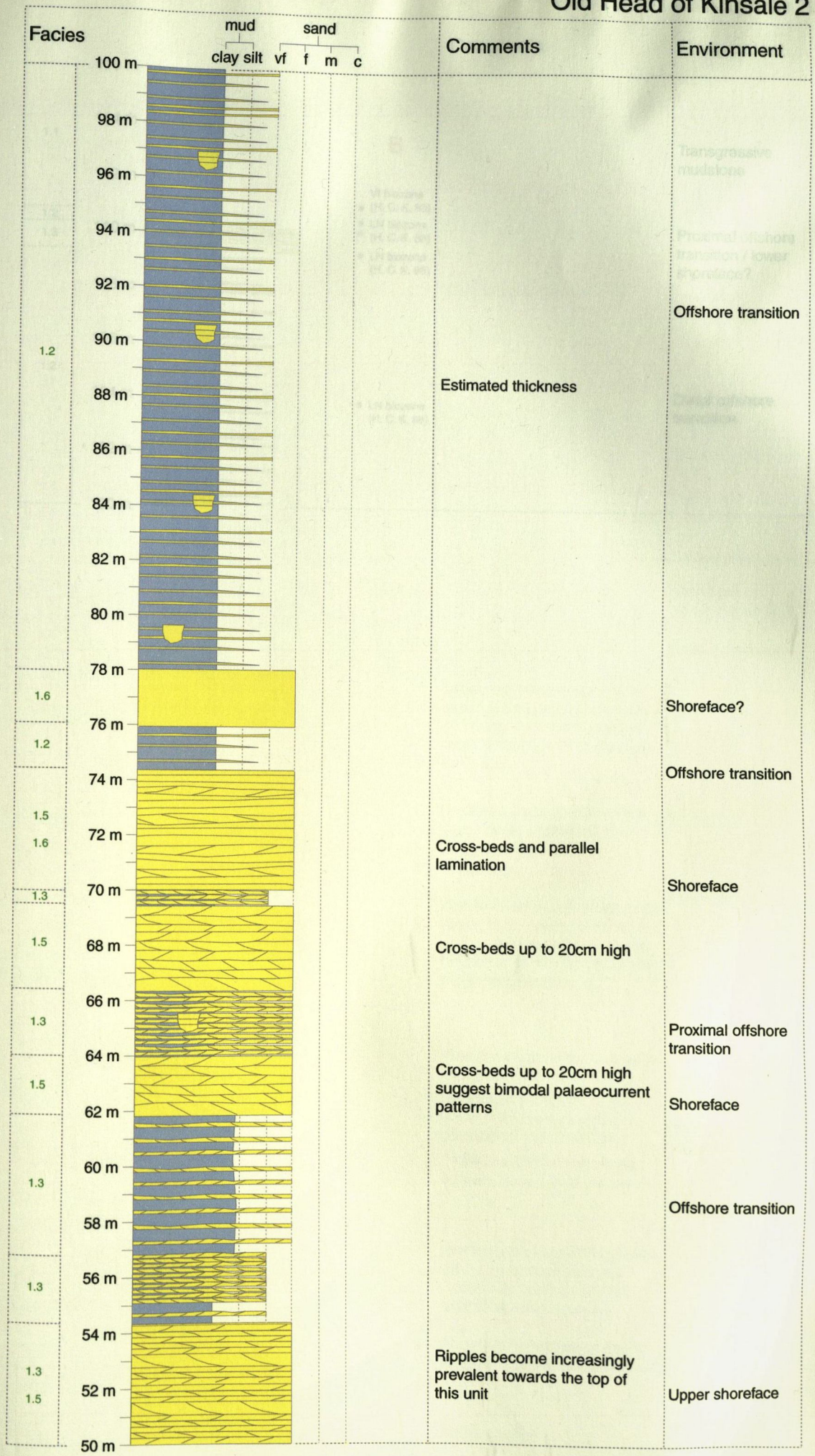
Dunworly 7


Facies
mud
clay silt
sand
vf f m c
Comments
Environment
324 m
322 m
320 m
318 m
316 m
314 m
312 m
310 m
308 m
306 m
304 m
302 m
300 m
1.2
1.3
1.1
1.3
Accommodation dominated shelf
Distal offshore transition of offshore
Member 3, Kinsale Fm.
E
Sharp topped sandy unit
Lower shoreface
Ripples to 2cm high
Offshore transition
Beds 5cm thick
Lower shoreface
Mainly wavy beds

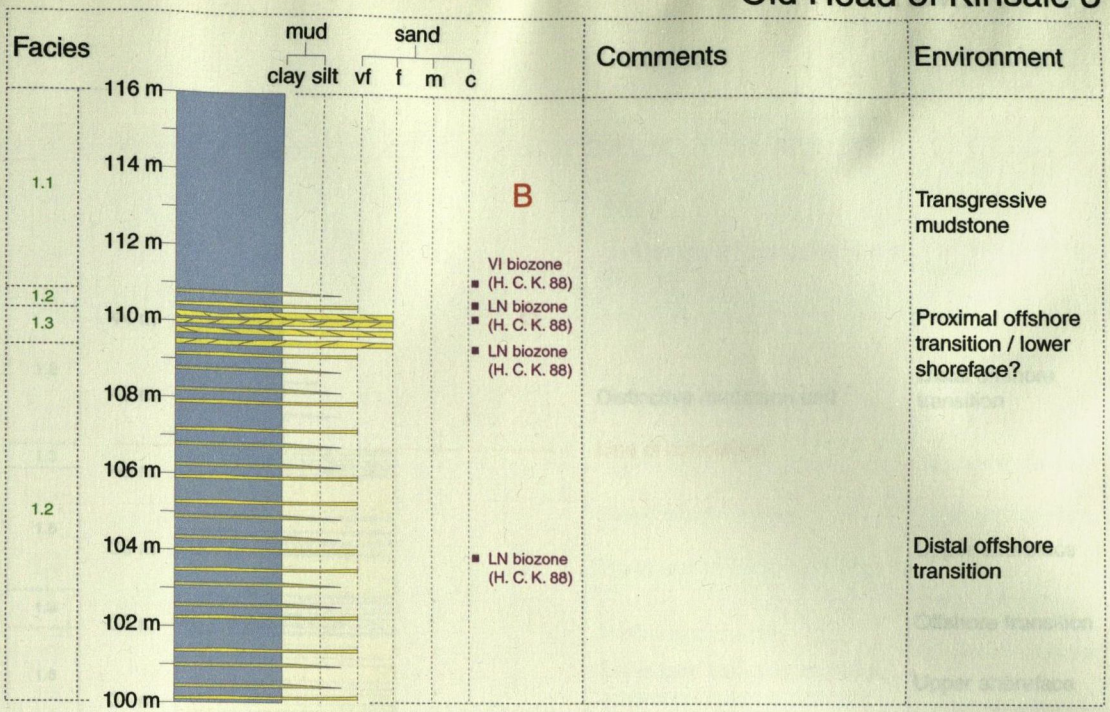
Old Head of Kinsale 1



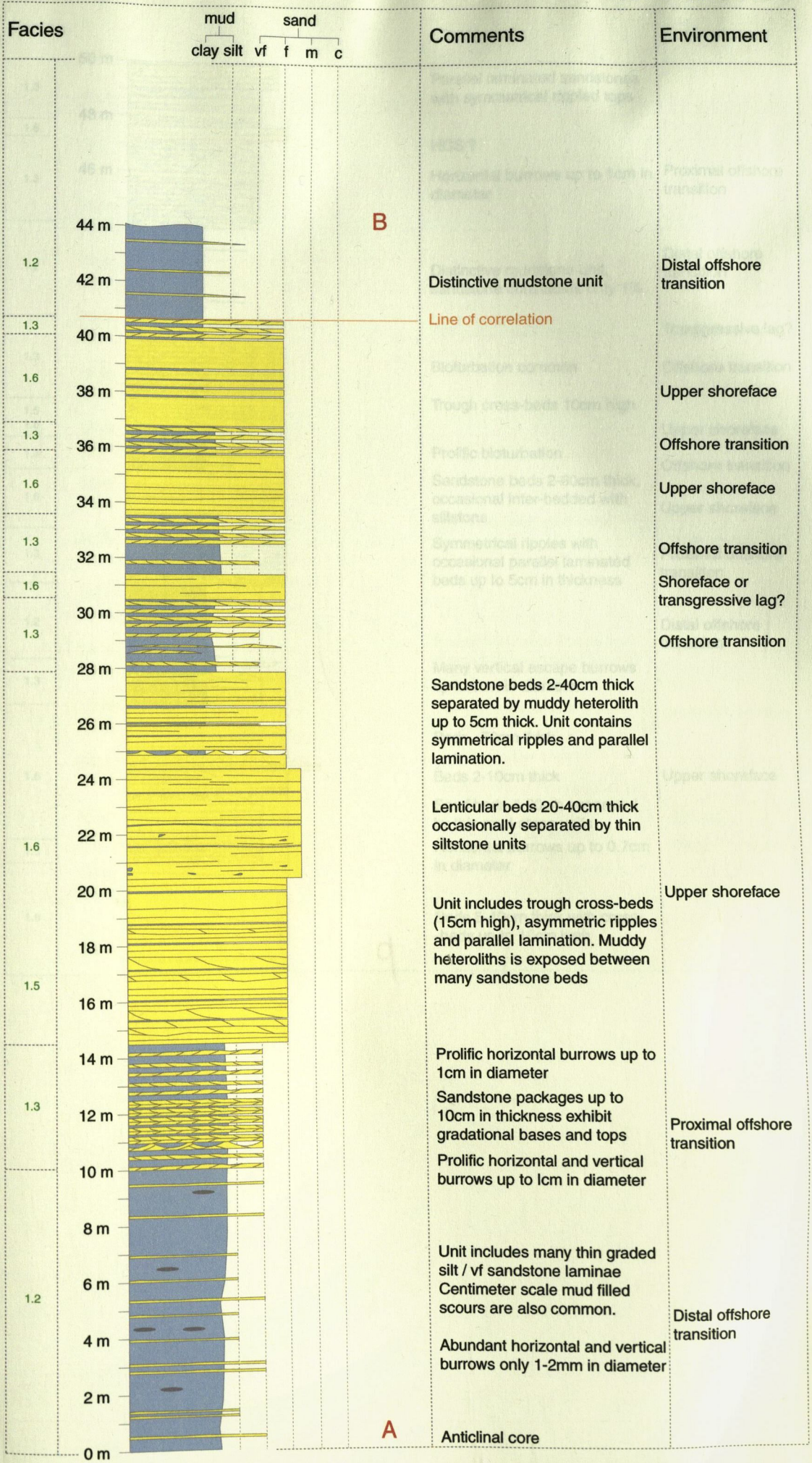
Old Head of Kinsale 2



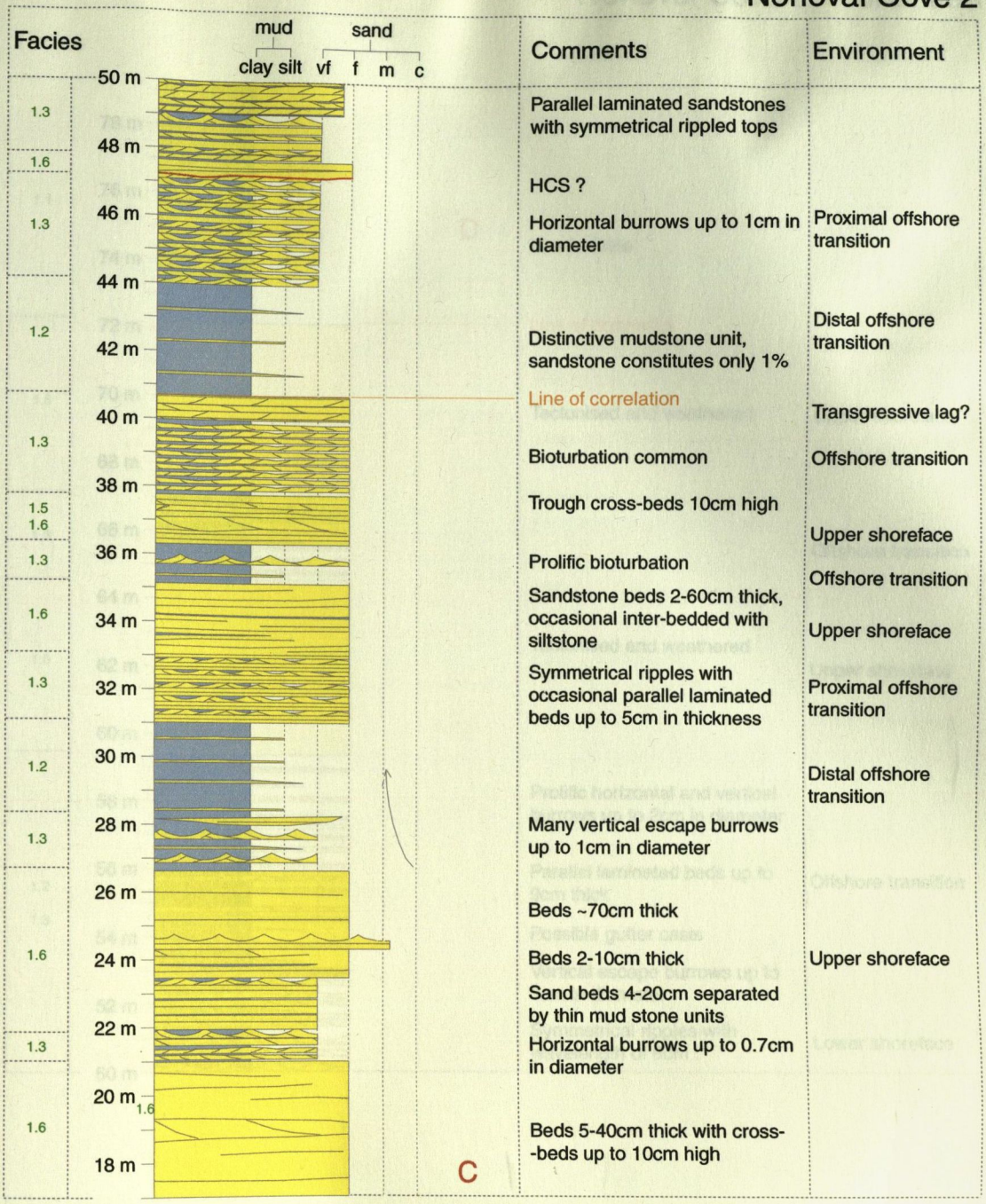
Old Head of Kinsale 3



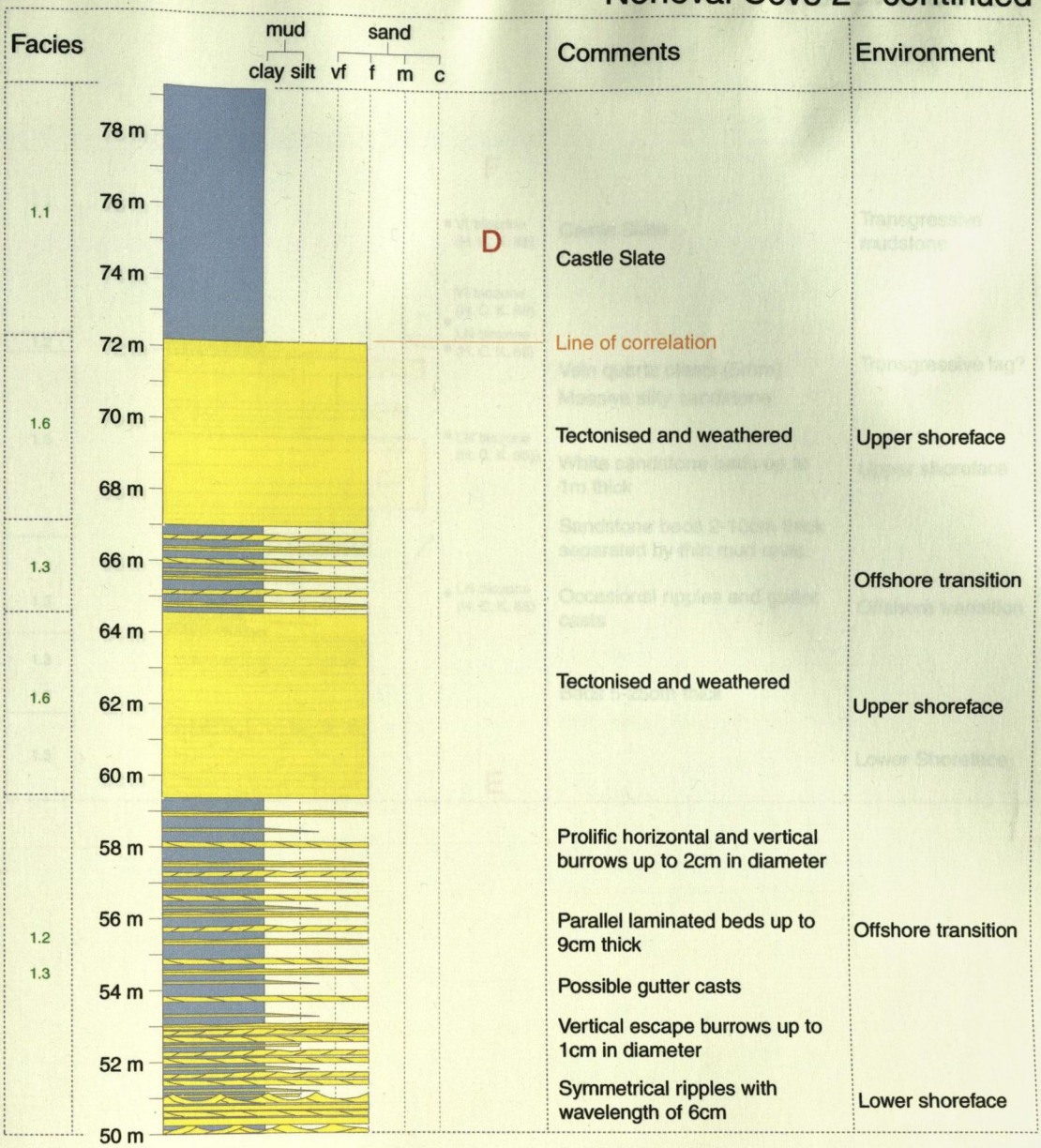
Nohoval Cove 1



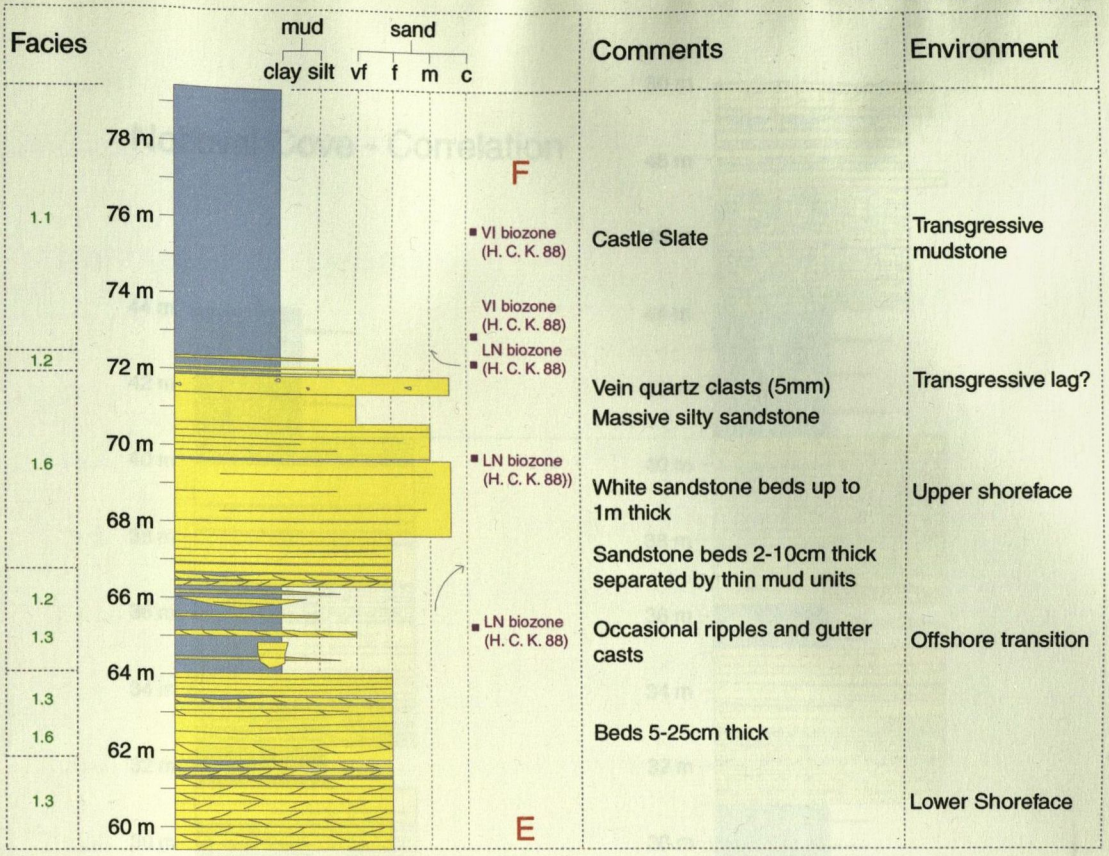
Nohoval Cove 2



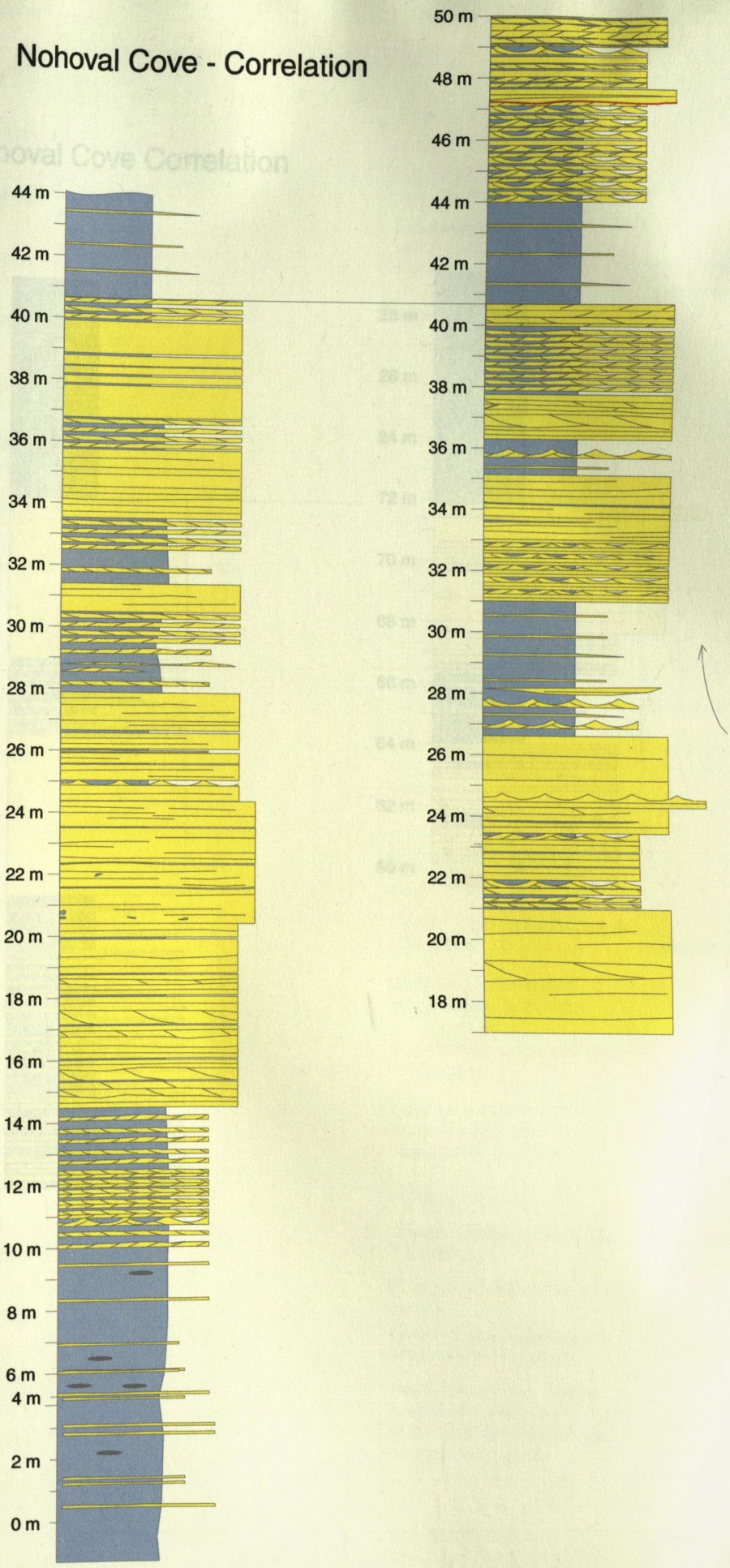
Nohoval Cove 2 - continued



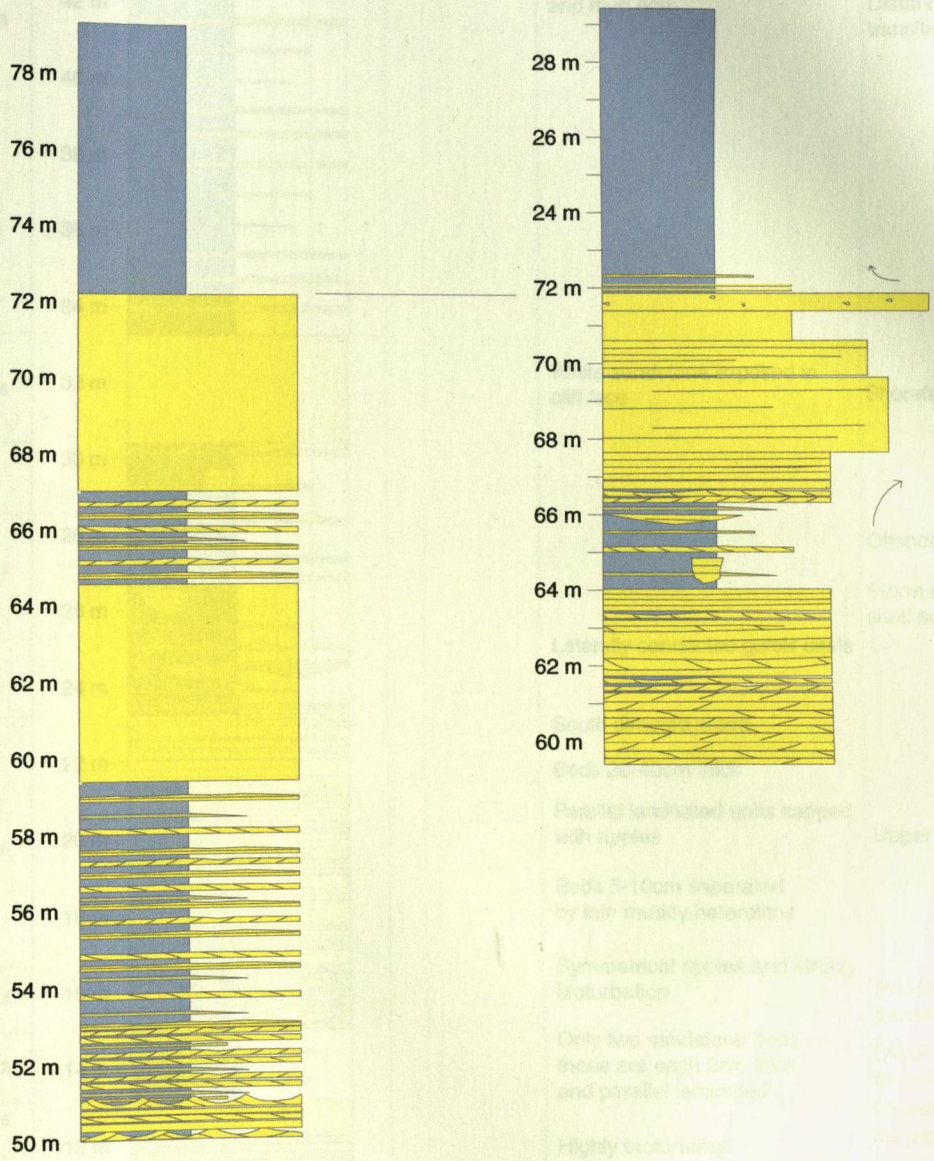
Nohoval Cove 3



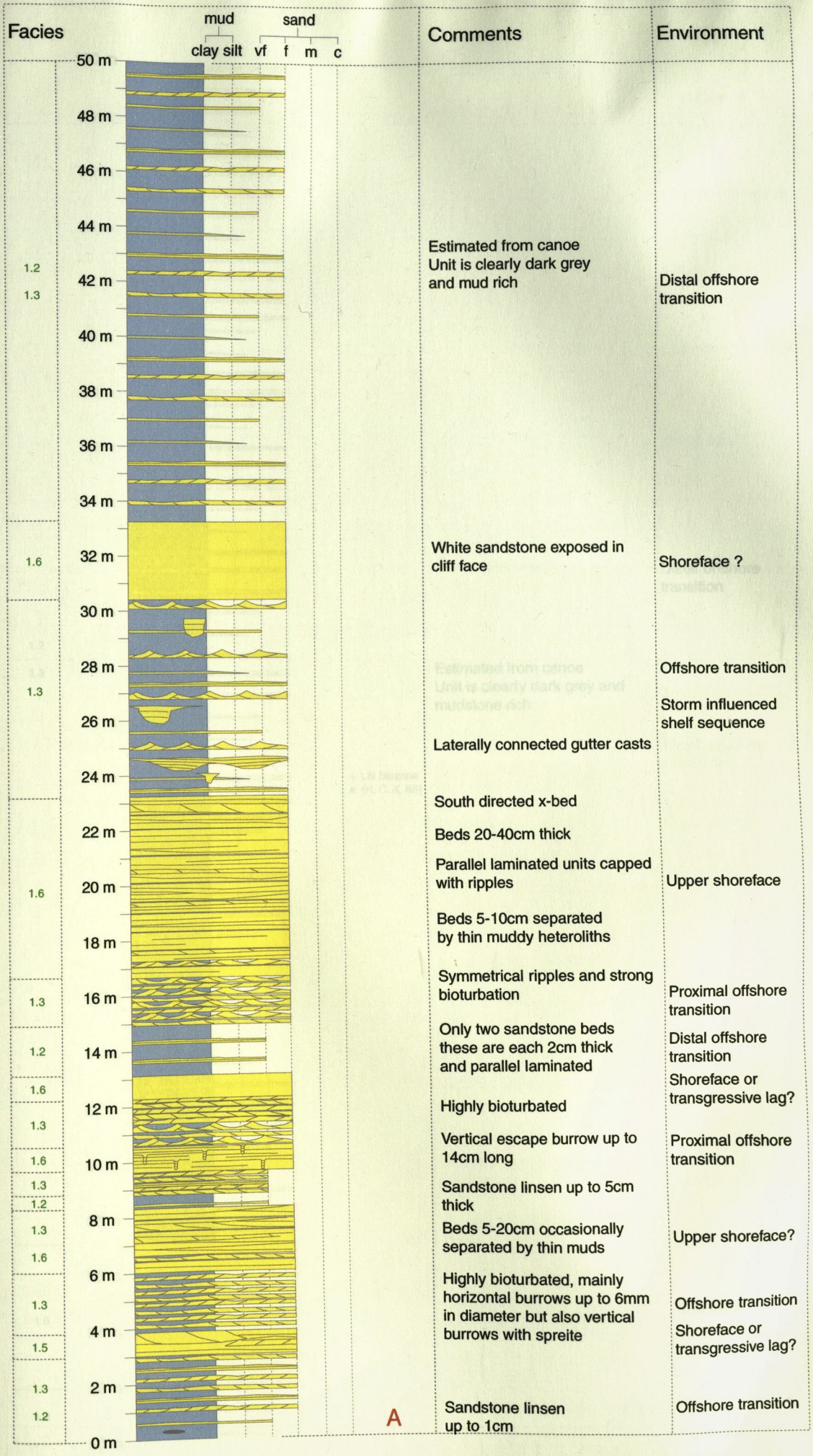
Nohoval Cove - Correlation



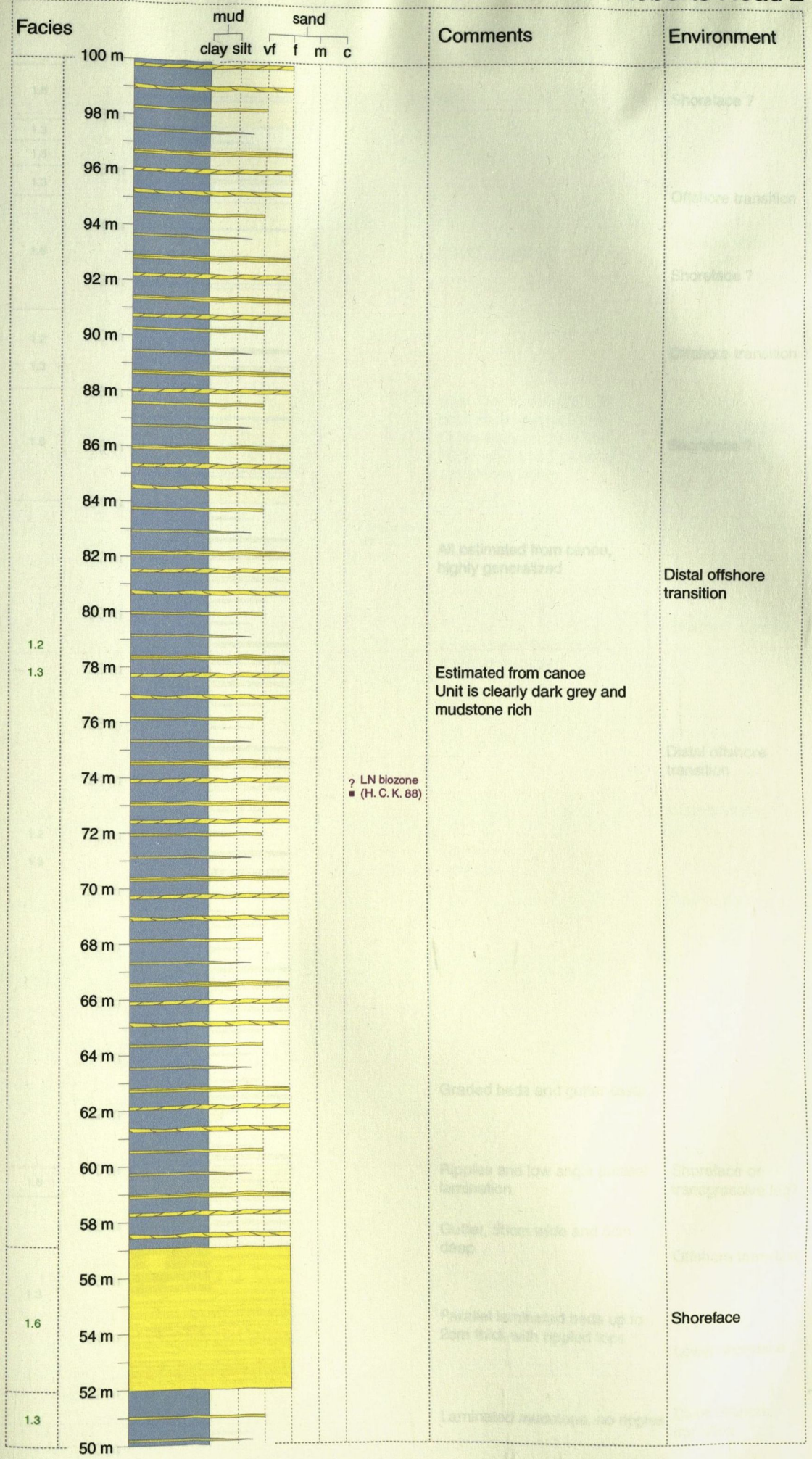
Nohoval Cove Correlation



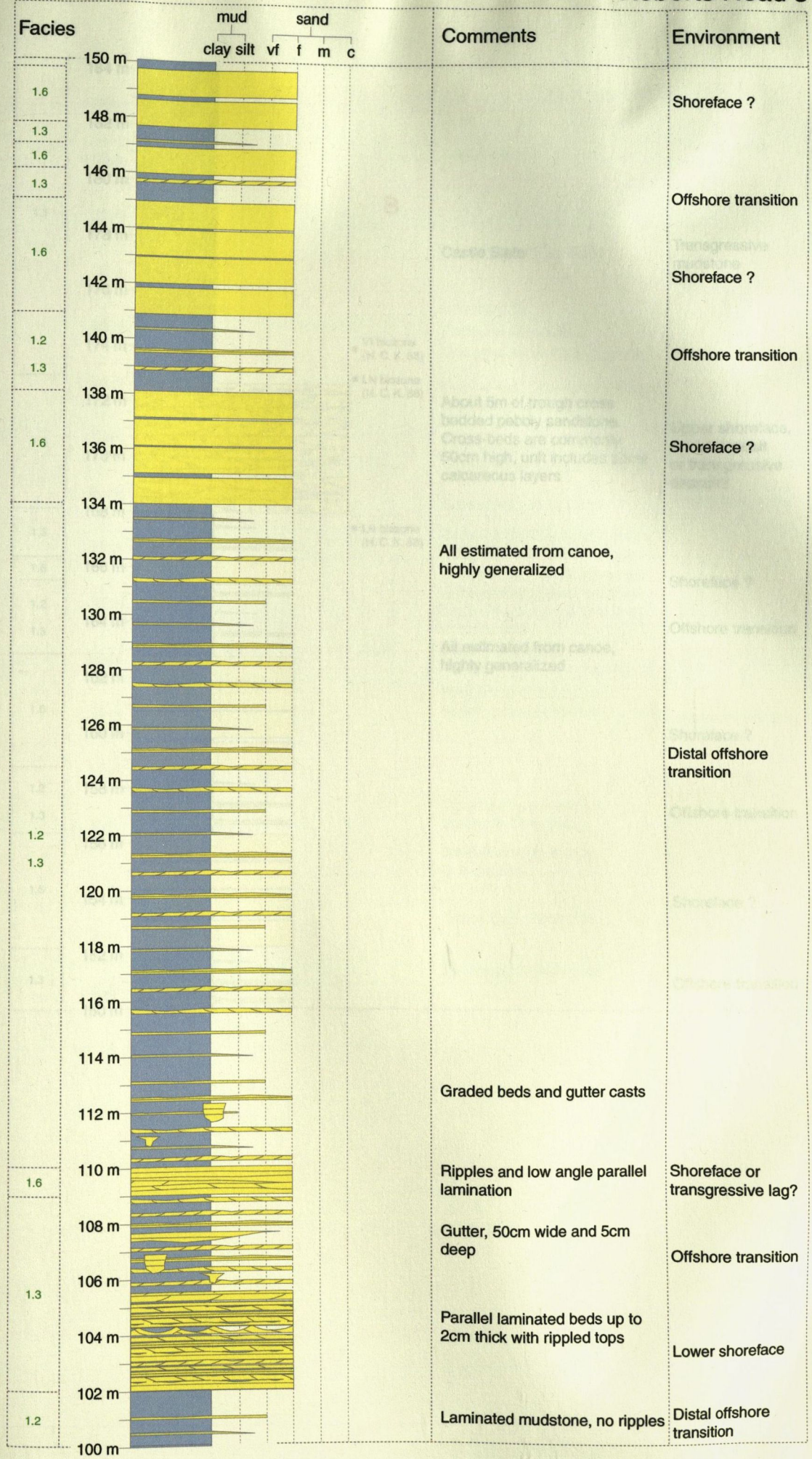
Roberts Head 1



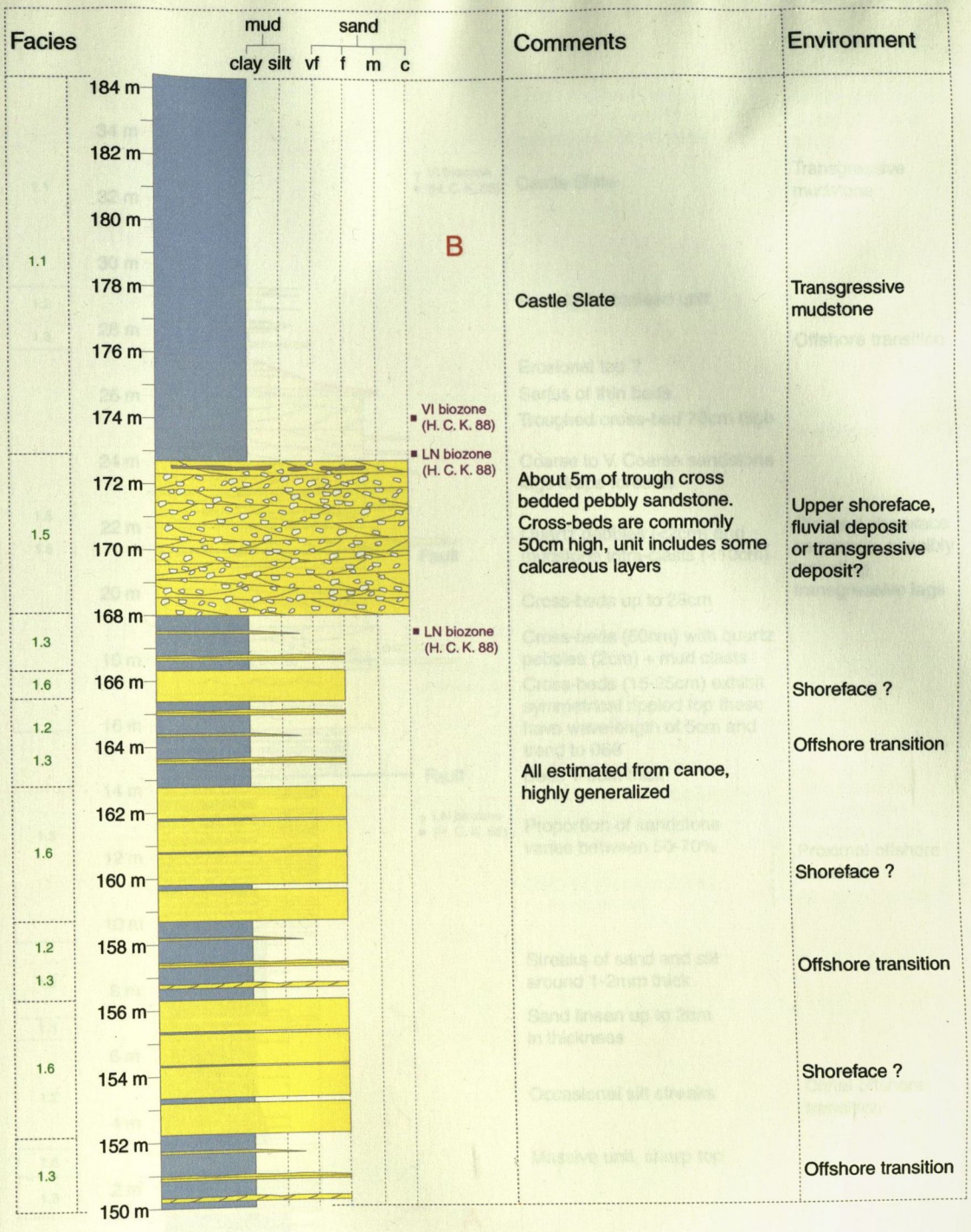
Roberts Head 2



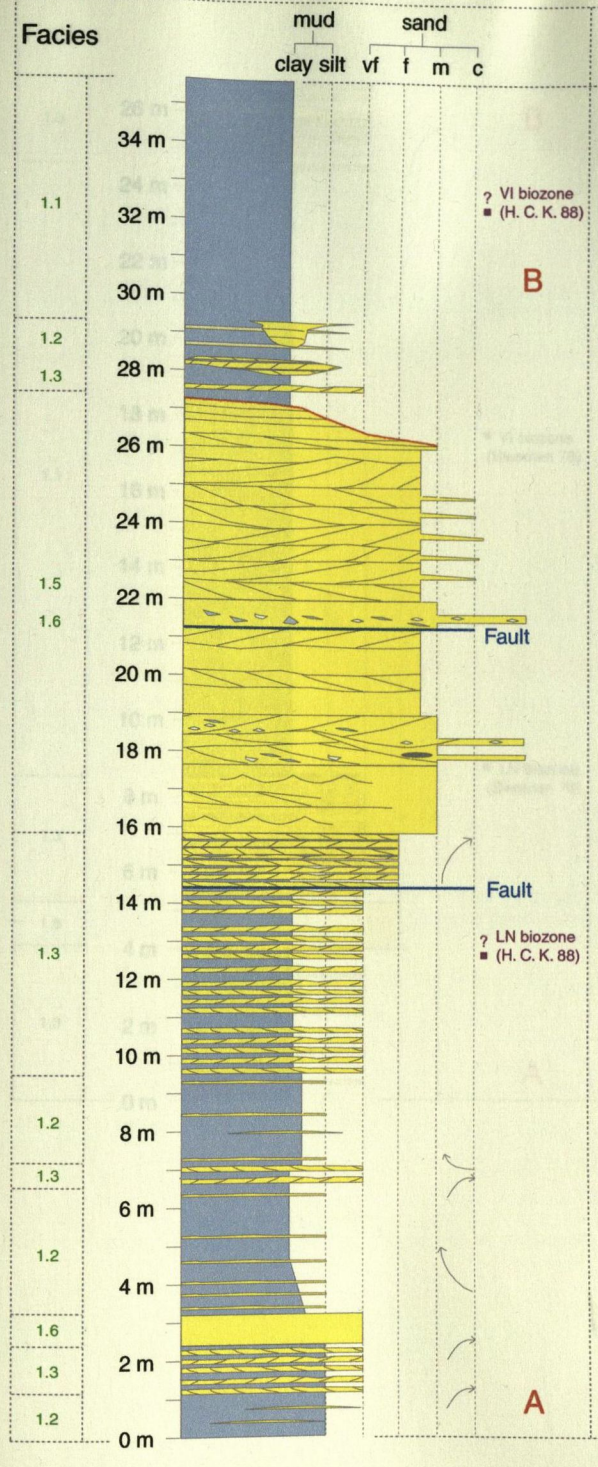
Roberts Head 3



Roberts Head 4

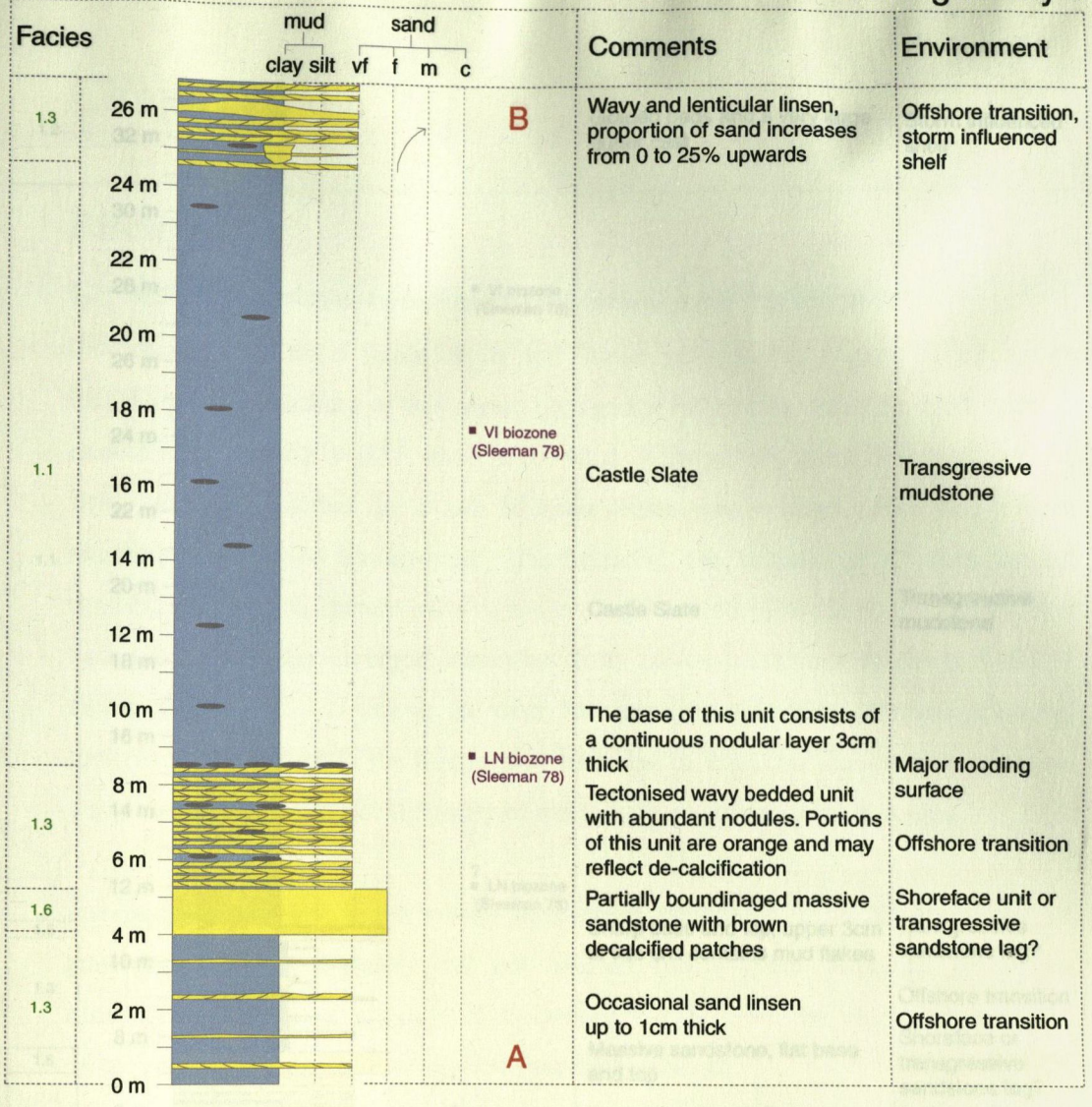


Myrtleville 1

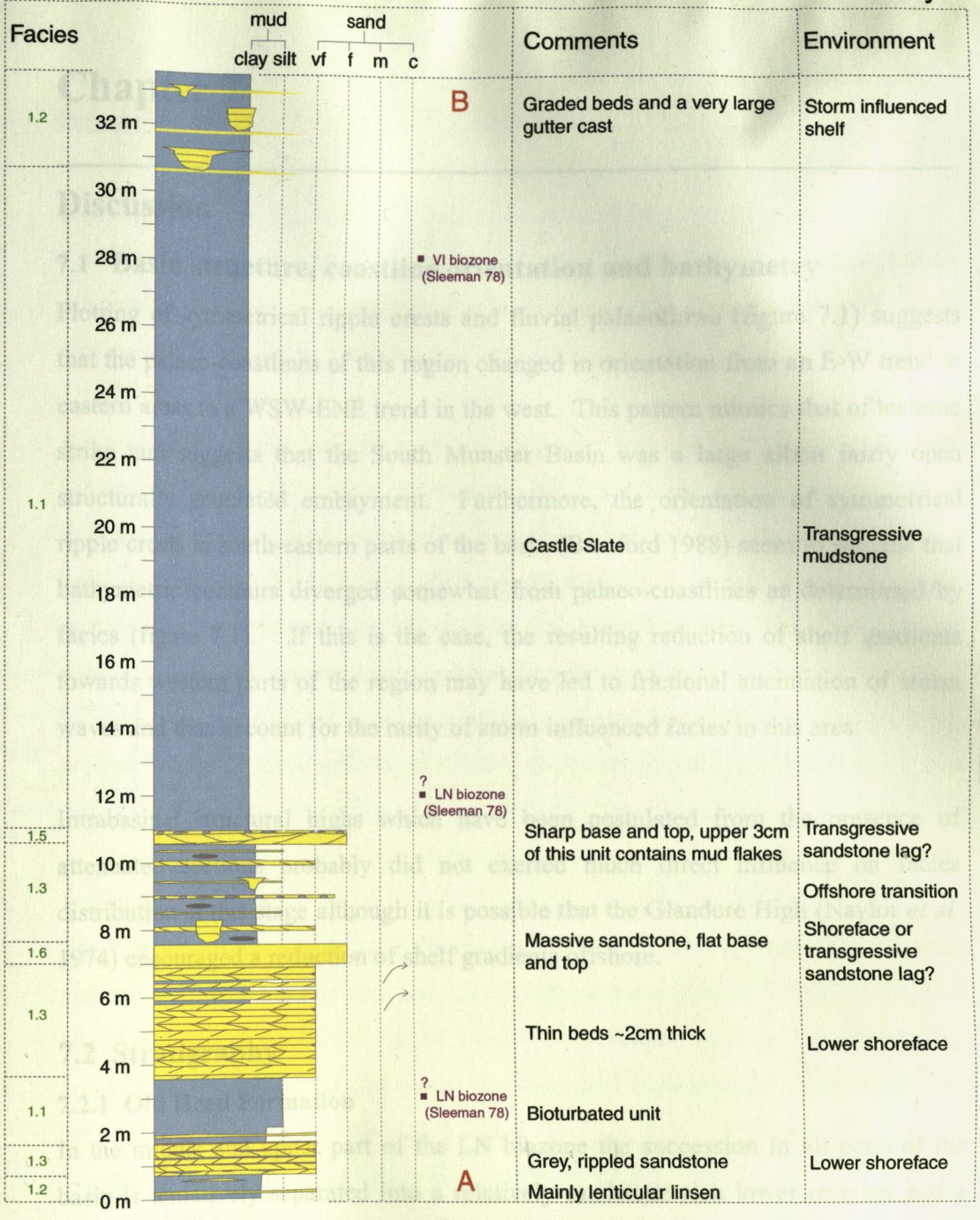


Facies	Comments	Environment
1.1	Castle Slate	Transgressive mudstone
1.2	Partially tectonised unit	
1.3	Erosional top ?	Offshore transition
	Series of thin beds	
	Troughed cross-bed 70cm high	
	Coarse to V. Coarse sandstone lags drape foresets	
1.5		
1.6	Quartz pebbles (<2cm) and mudstone intra-clasts (<10cm)	Stacked shoreface sequence, possibly including transgressive lags
	Cross-beds up to 25cm	
	Cross-beds (60cm) with quartz pebbles (2cm) + mud clasts	
	Cross-beds (15-25cm) exhibit symmetrical rippled top these have wavelength of 5cm and trend to 066	
	Beds 1-5cm thick	
1.3	Proportion of sandstone varies between 50-70%	Proximal offshore transition
1.2	Streaks of sand and silt around 1-2mm thick	
1.3	Sand linsen up to 2cm in thickness	
1.2	Occasional silt streaks	Distal offshore transition
1.6	Massive unit, sharp top	
1.3		
1.2		

Curraghbinny 1



Cuskinny 1


Facies
mud
clay silt
sand
vf f m c
Comments
Environment
1.2
32 m
30 m
28 m
26 m
24 m
22 m
1.1
20 m
18 m
16 m
14 m
12 m
1.5
10 m
1.3
8 m
1.6
6 m
1.3
4 m
1.1
2 m
1.3
1.2
0 m
B
A
VI biozone (Sleeman 78)
? LN biozone (Sleeman 78)
? LN biozone (Sleeman 78)
Graded beds and a very large gutter cast
Storm influenced shelf
Castle Slate
Transgressive mudstone
Sharp base and top, upper 3cm of this unit contains mud flakes
Transgressive sandstone lag?
Offshore transition
Massive sandstone, flat base and top
Shoreface or transgressive sandstone lag?
Thin beds ~2cm thick
Lower shoreface
Bioturbated unit
Grey, rippled sandstone
Mainly lenticular linsen
Lower shoreface

Chapter 7

Discussion

7.1 Basin structure, coastline orientation and bathymetry

Plotting of symmetrical ripple crests and fluvial palaeoflows (figure 7.1) suggests that the palaeo-coastlines of this region changed in orientation from an E-W trend in eastern areas to a WSW-ENE trend in the west. This pattern mimics that of tectonic strike and suggests that the South Munster Basin was a large albeit fairly open structurally generated embayment. Furthermore, the orientation of symmetrical ripple crests in south-eastern parts of the basin (Bamford 1988) seem to suggest that bathymetric contours diverged somewhat from palaeo-coastlines as determined by facies (figure 7.1). If this is the case, the resulting reduction of shelf gradients towards western parts of the region may have led to frictional attenuation of storm waves and thus account for the rarity of storm influenced facies in this area.

Intrabasinal structural highs which have been postulated from the presence of attenuated sections probably did not exerted much direct influence on facies distribution at this stage although it is possible that the Glandore High (Naylor *et al.* 1974) encouraged a reduction of shelf gradients offshore.

7.2 Stratigraphy

7.2.1 Old Head Formation

In the middle and upper part of the LN biozone the succession in all parts of the basin is tentatively separated into a relatively sandstone rich lower member and a more mudstone rich upper member (figure 1.5). This division was first reported in the Roberts Head section (Naylor 1969; Van Gelder 1974) and these units named the Daunt Member and the Tower Member (Van Gelder 1974). Subsequent study has shown that these units may also be found in sections situated on the basin margin area north of Roberts Head although in this case the units were termed the Whitebay and Glanagow Members (MacCarthy *et al.* 1978). This study illustrates that this division probably also exists in the South Bantry Bay section (at 202m) and the Dooneen section (at 131m) in the west of the basin and in the Galley Head, Seven

Heads and Old Head of Kinsale sections situated on the present day south coast region.

Daunt Member

Although the Daunt Member has not been studied in much detail, brief reconnaissance of the unit suggests that it includes a higher sandstone content and less storm influence than the overlying Tower Member.

Analysis of the Daunt Member in the South Bantry Bay (up to 202m) and Dooneen (up to 131m) sections in the north-western part of the basin suggest that deposition varied between tide influenced coastal settings and more mudstone rich, wave influenced shallow shelf settings. Variation between these settings probably reflects relative sea-level fluctuation with mudstone rich shallow shelf deposits generated during periods of higher relative sea-level than the sandstone rich coastal packages. In the eastern part of the basin this package is sandstone rich and was probably deposited within a wave influenced shallow shelf setting, perhaps adjacent to a major distributary system.

Tower Member

The Tower Member was deposited during the late LN biozone and generally contains more mudstone rich facies than the underlying marine sequence. However this unit also includes many sharply bound sandstone packages. These are particularly prevalent at the top of the unit across the basin and throughout the unit in sections exposed along the present day south coast. Most of these sandstone packages are interpreted to reflect deposition within falling or lowstand stage shoreface settings. As with mudstone rich facies, they are normally wave and tide influenced in the north-west of the basin but wave and storm influenced in more exposed distal sections to the south and upon the eastern basin margin where shelf gradients were perhaps steeper (figure 7.1).

The abundance of sharply-bound shoreface sandstone bodies in positions well to the south of the northern basin margin (figure 7.2) clearly indicates repeated episodes of regression and transgression. These were probably generated by fluctuation of relative sea-level. During phases of reduced relative sea-level, the coastline probably

migrated rapidly basinward until the rate of eustatic fall was reduced sufficiently to enable wave erosion to cut a new shoreline profile through erosional shoreface retreat (Johnson and Baldwin 1996). This was followed by progradation of shoreface deposits as sediment flux, supplied by rejuvenated fluvial systems, exceeded accommodation. This rapid transition from erosion to deposition thus generated the sharp lower surfaces so common to these packages. The sharp upper surfaces were generated by a combination of sub aerial erosion and upper shoreface erosion during subsequent transgression and together; these processes were usually capable of removing all evidence of fluvial plain or upper shoreface strata. As the shoreline-shelf profile approached equilibrium with the contemporaneous sea-level, erosion at the top of these sandstone units was reduced but depositional rates probably initially remained low because ongoing transgression continued to create accommodation in marginal regions. This allowed physical and biological reworking of the top of some of these sandstone bodies (see Kuijpers 1972; Graham 1975) as well as accumulation of shell material (thus calcareous cements). Intraclasts, which are also sometimes encountered in the uppermost part of these units, were probably liberated from older deposits as transgressive upper shoreface incision migrated northward. Subsequent mud deposition probably only recommenced when relative sea-level had risen sufficiently to establish an accretionary shoreline-shelf profile but then persisted until the next phase of relative sea-level fall. The thickness of the resultant sequences is variable and depends on subsidence rate, proximity to the coastline, sediment supply and the frequency of relative sea-level changes. Nevertheless, most of these are between 3-30m thick.

Despite considerable evidence to suggest that these sandstone bodies reflect shoreface sequences, their abundance in the south coast region but rarity in sections landward of this is rather puzzling. One possible explanation is that the palaeo-shelf steepened in the south coast region (shelf-break) and thus provided the additional accommodation necessary for repeated shoreline stabilisation in this area (figure 7.2). Furthermore, the absence of these deposits in north-western parts of the basin (other than at the top of the Old Head Formation) may be slightly illusive in that there is evidence that these sections were periodically emergent and it is possible that shoreface packages in this low-wave energy region were most commonly mud dominant. In the Roberts Head section where wave and storm energy was

significantly higher, the absence of shoreface sandstone packages probably results from removal of thin falling stage shoreface deposits during subsequent transgressive shoreface retreat. An alternative explanation for the presence of so many sandstone rich units in the south coast region is that there was a lateral variation in sediment supply (see Posamentier and Norris 2000). Indeed the detached nature of lowstand sandstone bodies suggested by figure 7.2 need not depict the stratification style directly north of the south coast sections (rather than north-east) where the principal distributary may have been situated (see McMurray and Gawthorpe 2000).

Several features displayed by the sandstone bodies encountered within the Tower Member are incompatible with genesis within offshore bar forms as has been suggested by MacCarthy (1987) and Bamford (1988). The most important of these are the sharp basal surfaces that these units display and their thickness in vertical section. Indeed the whole 'offshore bar model' has major difficulties (Walker 1984). In particular, it is hard to understand why sand was transported such distances offshore only to be concentrated in bar forms of very limited extent. Further, although MacCarthy (1987) compares the sandstone packages of the South Munster Basin, not unreasonably, to the isolated sandstone bodies of the Western Interior of the USA, many of these, although originally interpreted as offshore bars (Swagor *et al.* 1976; Tillman and Martinsen 1984, 1987; Bergman and Walker 1987, 1988) have been reinterpreted as lowstand shoreface deposits (Plint 1988, 1991, 1996; Plint and Norris 1991, Walker and Plint 1992; Nummedal *et al.* 1992, 1993, Ainsworth 1994; Tirsgaard 1996). Documentation of vertical rootlets preserved at the top of some of these units (Graham 1975) together with calculations suggesting water depths of (at least periodically) less than 5m (chapter 6) seem to give further credence to the shoreface model. Although the presence and abundance of these shoreface facies within relatively distal sections could also have been generated by the development of a barrier system in this area (Graham 1975) this would have been situated at unusually large distances from the palaeocoastline (80-100km) and would also have been unusually long lived.

The widespread sandstone package developed at the top of the Old Head Formation is the only shoreface sandstone body that consistently contains pebbles. The presence of these probably reflects rejuvenation of adjacent fluvial systems in

response to the widespread eustatic fall that is documented at this level by Wagner (2001) and is not thought to reflect tectonic uplift as postulated by MacCarthy (1971). Like Bamford (1988), this study finds no evidence to suggest along-shore derivation of these pebbles from the east.

In many sections throughout the basin, the uppermost shoreface sandstone body is overlain by a mudstone rich package containing limestone and/or siltstone linsen and this sometimes culminates in a thin sandstone bed or well-developed gutter cast prior to the transition into the Castle Slate Formation. This study concurs with MacCarthy (1987) in attributing these features to two (at least) pulses of transgression perhaps arising from superimposition of high frequency relative sea-level fluctuation (4th order?) upon a longer-term transgressive trend (3rd order?). The variability in distribution of siltstone and limestone stringers at this level was perhaps a symptom of basinward sediment transport pathways over an irregular sea-bed which perhaps included partly filled palaeo-valleys and relief arising from differential transgressive shoreface erosion.

7.2.2 Castle Slate Formation

The Castle Slate Formation is composed of homogenous mudstone and probably reflects deposition within distal offshore settings which were generated following the global rise of relative sea-level that is reported from this period (Wagner 2001). The base of the Castle Slate Formation is probably reasonably contemporaneous across the basin whilst the transition into the overlying Narrow Cove Formation, which is marked by the incoming of siltstone laminae, is probably older in regions where bathymetry was reduced and where sediment supply was high (e.g. north-west area). In contrast, it took much longer for lowering of relative sea-level to reduce storm wave base to the sea floor in more distal areas and as a result, deposition of mudstone persisted for longer in these areas and the Castle Slate Formation is thicker (62m - Old Head of Kinsale - Naylor 1969). Unfortunately, palynological evidence for this diachroniety is rather sparse, but it is worth noting that an HD miospore assemblage has been recorded from low in the Narrow Cove Formation on the Old Head of Kinsale, whereas VI assemblages appear to range relatively higher in this unit near the margin of the basin in the east (Sevastopulo 2001).

Despite this however, it should be noted that there are exceptions to the general pattern of offshore thickening (South Dunmanus, Galley Head and Dunworly) and, although this can sometimes be attributed to the influence of intra-basinal highs (reduced subsidence) or out of strike faulting, there is sometimes little conclusive proof of this (particularly the latter).

7.2.3 Narrow Cove Formation

The term Narrow Cove Formation (Naylor 1966) is extended in usage to all parts of the basin and refers to the relatively sandstone rich succession sandwiched between the mudstone rich Castle Slate and Pigs Cove Formations. Three basin-wide members are identified within the unit and are termed the Ardaturrish, Reenagough and Black Ball Members.

Ardaturrish Member

The mixed mudstone and sandstone rich Ardaturrish Member at the base of the Narrow Cove Formation is recognised across the basin and represents a basinward shift of facies following deposition of the Castle Slate Formation. As indicated in the previous section, the contact with the underlying Castle Slate Formation is probably oldest in marginal regions where water depths were reduced. Above this contact, the reintroduction of sandstone is usually characterised by stepped rather than gradational increases in sandstone content (figure 7.3). This probably means that this part of the sequence is composed of a series of basin stepping, small-scale sequences that probably reflect superimposition of high frequency relative sea-level fluctuation (4th order?) upon a longer term regressive trend (3rd order?). In most parts of the basin, this early mudstone rich part of the Ardaturrish Member is characterised by storm influenced facies and the presence of these in north-western parts of the basin in particular, indicates that relative sea-levels initially remained relatively high following the Castle Slate transgression. This style of deposition was quickly replaced by more sandstone rich, wave and tide influenced facies in north western areas.

Although this unit reflects a marked increase in sandstone content compared to the underlying Old Head Formation in the north-west of the basin, in the south coast region it is the Old Head Formation that is more sandstone rich. This pattern

obviously marks a major switch in the locus of sand deposition from the east during the late Devonian to the west in the early Carboniferous and probably reflects an avulsion of the principal distributary system westwards. This may have been encouraged by the increased rates of accommodation generation associated with the Castle Slate transgression as this would have led to decreases in fluvial gradient and in-filling of entrenchment in marginal areas.

In relatively distal sections, the Ardaturrish Member is composed of repeated vertical alternations between particular facies which presumably reflects repeated fluctuation of relative sea-level. This pattern is best seen in the South Bantry Bay and Dooneen sections where tidally influenced coastal strata are repeatedly inter-bedded with shallow marine intervals. However these cyclical changes are also found in the more distal Dunworly section where numerous metre scale coarsening up and coarsening then fining up cycles are encountered. These coarsening up cycles are probably common because regressive events are associated with a higher sediment flux to shelf settings than transgressive phases. Unfortunately, such repeated changes in facies are less conspicuous in marginal sections in the north-west of the basin, probably because the range of possible water depth variation was more limited. For instance, although the Cahermore section suggests continuous deposition within tidal flat and shallow marine settings, it is clear from the development of shoreface sediments in sections to the south, that this succession must actually contain numerous exposure surfaces.

The upper part of the Ardaturrish Member on the north side of Bantry Bay and in the Kenmare River region is composed of fine grained terrestrial strata that probably reflects deposition within flood plain settings. The upper surface of this unit is a marine flooding surface.

Reenagough Member

The sandstone rich Reenagough Member represents a basin-ward shift in facies relative to the enclosing Ardaturish and Black Ball Members and in western areas (adjacent to a major distributary system?) includes exceptional thicknesses of sandstone rich paralic and shallow marine strata (figure 7.3). Like other large scale changes in rock type throughout this succession, the Reenagough Member probably

reflects a change in background relative sea-level (3rd order?) although a change in sediment flux to the basin cannot be ruled out and large-scale vertical changes are indeed encountered within fluvial strata exposed to the north (Khan 1955; Capewell 1957a,b; Doran 1970; Prendergast 1972; Doran *et al.* 1973; Colthurst 1978; Penney 1980; Bridge *et al.* 1980; Bridge and Diemer 1983; Diemer *et al.* 1987).

Like other units within the succession, the Reenagough Member is composed of stacked, small-scale sequences each reflecting a cycle of relative sea-level change and associated coastal migration (figures 7.4 and 7.5). The evidence for these repeated fluctuations of relative sea-level is best demonstrated in more distal sections where variation in palaeo-water depth was greatest. In the Dunworly section for instance, the unit is composed of repeated alternations between relatively sandstone rich facies deposited in proximal offshore transitional settings and mudstone rich strata deposited in more distal settings. This pattern of repeated vertical alternation in facies is duplicated in the more proximal Dooneen section where repeated alternation between shallow shelf and coastal facies is encountered. Further landward, sections on the north side of Bantry Bay exhibit more subtle evidence for relative sea-level change in the form of alternation between distributary channels reflecting coastal settings and tabular shelf sandstones deposited when relative sea-level was slightly higher. Whilst in the most proximal sections situated on the Kenmare River, fluctuation of relative sea-level is suggested by brief phases of flood plain accretion or accumulation of tidal flat facies which interrupt an otherwise sandstone rich sequence.

These features suggest that when relative sea-level was at its peak, the palaeocoastline was normally situated in the Kenmare River region adjacent to the basin margin. This encouraged tidal influence within the distributary channels of this region whilst increased rates of accommodation generation facilitated the preservation potential of flood plain strata. During subsequent relative sea-level fall, the coastline regressed rapidly southward because shelf gradients were low. This was accompanied by reduced rates of accommodation generation and is thus often poorly represented in the sediment record. However the preservation potential of the falling stage sequence probably increased offshore as the rate of relative sea-level fall began to slow and the coastline stabilised (figure 7.4). The sharp-based

sandstone and mudstone rich shoreface packages found in offshore sections (e.g. Dooneen and Dunworly sections) were probably deposited during this stage and subsequent lowstands and were storm influenced in the south-east of the basin (e.g. Dunworly) but wave and tide influenced in the west (e.g. Dooneen). This probably corresponds to shelf geometry (figure 7.1).

As relative sea level then began to rise again, accommodation generation upon the exposed shelf sometimes enabled accumulation of a thin veneer of fluvial strata (Dooneen?) although the low gradient of the shelf and subsequent erosive shoreface retreat (particularly in areas of storm influence where this process is much more active) normally restricted the preservation of these deposits to marginal areas. Indeed in most cases, the phases of shelf exposure are probably only represented by inauspicious planar erosion surface. Despite this however, coastal strata did accumulate when transgressive shoreface retreat was slower, for instance towards the end of a phase of relative sea-level rise or when sediment supply was particularly high (adjacent to point sources). In these instances, strata deposited during the previous highstand of relative sea-level are found overlain (often across a tidal ravinement surface) by estuarine/deltaic deposits and these in turn are overlain by shelf deposits (across a wave ravinement surface).

Black Ball Member

The top of the Narrow Cove Formation is only exposed in three of the sections analysed (Ballycrovane, Cahermore and Dunworly) but in each case exhibits a significant increase in the proportion of mudstone rich strata compared to the underlying Reenagough Member. Although originally included as part of the Reenagough Member (Naylor *et al.* 1969, 1974, 1983; Jones 1974; McAfee 1992; Sadler 1992; Williams *et al.* 1989; Pracht 1994) this study terms this part of the stratigraphy the Black Ball Member.

The transition between the Reenagough and Black Ball Members is only exposed in the Dunworly section in the south-east of the basin and in this case consists of a rather disparate increase in mudstone rich strata. Above this in all of the sections analysed, the unit is dominated by mudstone rich facies which reflect deposition within offshore and offshore transitional settings. However, these sediments are

inter-bedded with sharply bound shoreface sandstone packages which were deposited during phases of reduced relative sea-level (figures 7.3 and 7.5).

The top of the Black Ball Member in each of the sections studied is marked by an increase in sandstone content. In the Ballycrovane section this occurs gradually and reflects a change from distal offshore transitional settings to more proximal offshore transitional and perhaps lower shoreface settings. In contrast, this level in the Cahermore section to the south is marked by a series of thick, channelised sandstone units reflecting deposition within coastal settings. As this thick coastal succession is enclosed by shelf mudstone and has no obvious correlatives within the proximal Ballycrovane section (other than a much thinner conglomeratic unit) we can speculate that deposition progressed during a lowstand of relative sea-level and that this period is marked in more proximal sections by a depositional hiatus. The presence of a sharp-based shoreface sandstone package at the top of the Black Ball Member in the Dunworly section is perhaps further testimony to the extent of shoreline retreat during this event. In each of the sections analysed the transition into the overlying Pigs Cove Formation is rapid and reflects a phase of pronounced relative sea-level rise.

7.2.4 Pigs Cove Formation

The term Pigs Cove Formation is extended in usage to encompass western parts of the basin whilst the term Ardnamanagh Formation (Naylor *et al.* 1969, 1974, 1983; Jones 1974; McAfee 1992; Williams *et al.* 1989; Pracht 1994) is abandoned.

The Pigs Cove Formation is dominated by mudstone rich facies and was probably deposited within storm influenced offshore transitional and offshore settings. The lack of thick sandstone bodies throughout the package perhaps indicates that the palaeo-coastline had migrated significantly northward by this stage and in the western part of the basin at least, had probably considerably overstepped the northern basin margin. Transgression over the northern margin region may have followed the onset of regional subsidence in this area (thermal or flexural) or a eustatic sea-level rise.

It is interesting that the encroachment of the coastline beyond the western basin margin was associated with replacement of wave by storm influenced facies as this also occurred in eastern parts of the basin following drowning of the eastern basin margin (during deposition of the Old Head Formation). It is also interesting that in both cases this overstepping event seems to have stymied further development of thick shallow marine sequences in the adjacent basinal areas. This may have been linked to an associated rise of accommodation generation across the northern platform region (figure 1.4), as this region probably then soaked up much of the sediment supply originally destined for the basin and therefore allowed deepening of the basin. Increased accommodation upon the basin margin region probably also introduced more instability to point source positioning as the scope for fluvial entrenchment was reduced (see section 7.3).

7.3 The origin of unusually thick shallow marine sequences

This study suggests that tectonic style, the presence of a large and mature sediment flux and the development of unusually low shelf gradients were the principal factors contributing to the genesis of unusually thick shallow marine sequences within the South Munster Basin. However, these packages do not reflect prolonged phases of continuous shallow marine deposition as might initially be supposed, but rather multiple stacking of individual small-scale sequences, each separated by a sequence boundary (figure 7.4). The range of coastline positions generated during repeated fluctuation of relative sea-level was therefore maintained in space, time and again, and it was this phenomenon, more than any other, that led to the accumulation of these unusually thick deposits.

The most important factors facilitating the development of this unusual style of stacking pattern was the close juxtaposition of a rapidly subsiding basin with an isostatically stable basin margin region together with the presence of a large transverse sediment flux. One crucial manifestation of these features, was that the low level of accommodation generation upon the northern platform area to the north of the basin prevented migration of the coastline beyond this structurally defined margin. This therefore pinned the maximum landward extent of palaeo-coastline migration during successive cycles of relative sea-level change and thus led to

stacking of successive sedimentary sequences. This tectonic framework may also have encouraged the development of the unusually thick sandstone rich deposits (e.g. Reenagough Member in the west of the basin) because the development of these was probably dependant upon proximity to the major distributary system. The thickness of the sand rich successions may therefore testify to an unusually low number of avulsion events and this in turn probably arose from fluvial entrenchment upon the basin margin.

With these factors in mind, it is interesting to note that basins where the locus of subsidence (and therefore accommodation generation) migrates through time (i.e. low angle detachment style extensional basins, thermal stage basins and flexural basins) will be less conducive to the genesis of these deposits. Yet despite this, it is clear that thick paralic and shallow marine successions are also rare within rift basins. Perhaps the main reason for this is that rifting events themselves are often associated with regional uplift caused by ascent of the asthenosphere. This commonly elevates the basin floor above relative sea-level during the rifting phase and thus precludes development of shallow marine strata. Rift basins are also often associated with thermally generated marginal uplift and this tends to repel regional scale drainage networks. Only where the pre-extensional crust was already thin or where 'passive' rifting processes were dominant might the basin floor develop below relative sea-level and marginal uplift remain small enough to allow transverse passage of major drainage networks. In the South Munster Basin, the lack of locally derived 'immature' sediment suggests that marginal uplift was indeed minimal whilst crustal thickness may have been reduced following evolution of the earlier Munster Basin. Furthermore, the low level of igneous activity associated with rifting suggests that passive type rifting processes were indeed operative. The tensional stresses controlling this may have originated in response to roll-back in the Rheic ocean to the south.

As previously mentioned, the thickness, lateral extent and fine grain size of the shallow marine strata within the South Munster Basin suggest the presence of a large and mature sediment flux to the basin (although qualitative analysis of fluvial strata to the north suggest discharges of only $180m^3\ s^{-1}$ - Bridge and Diemer 1983). The large size of this system was probably of crucial importance to the development of

the unusually thick shallow marine deposits within the South Munster Basin as it provided the capacity to generate thick sedimentary sequences. Indeed it is possible that this kind of deposit is so dependent upon the presence of large-scale drainage systems that they are limited to palaeo-continental landmasses large enough to host such systems. This dependency probably also means that these successions are restricted in lateral extent along individual rift systems - although this may be countered in regions of along-shelf sediment transport (Anderton 1976; Levell 1980). It is interesting to note therefore, that the structural embayment postulated in section 7.1 may have exerted a considerable influence on the long-term positioning of such a system.

A further factor that may have been influential to the development of this kind of deposit was the presence of low shelf gradients as these probably resulted in wide facies belts and thus encouraged the preservation potential of particular facies in vertical section. A more subtle manifestation of these low shelf gradients is that they are likely to have encouraged rapid migration of the coastline during phases of relative sea-level change and thus inhibited the preservation potential of fluvial strata in sections situated away from the basin margin. The main evidence for low shelf gradients comes from wave ripple orientations (figure 7.1), the development of wide facies belts and the restriction of storm influence to offshore sections. Low shelf gradients were probably encouraged by the positioning of the shelf upon the rift floor where there was no natural increase in subsidence offshore and where, with the influence of sediment loading, the reverse was probably true. This is in stark contrast to many thermal or flexural style basins where basin structure encourages increasing subsidence offshore and therefore further emphasises the relationship between this kind of deposit and rift type settings. Low shelf gradients were probably also encouraged by the large structural embayment within which the majority of sections fall (figure 7.1) and by the fine grain size of the sediment flux to the basin which presumably facilitated basinward reworking.

Finally, it is interesting to note that the factors that were influential to the accumulation of the Reenagough Member seem to have varied in some respects from those responsible for genesis of similar thick sandstone rich deposits of Precambrian to Cambrian age. In these older examples, Johnson and Baldwin (1996) demonstrate

that a combination of high energy shelf hydraulics, non vegetated braid-plains and repeated transgression over sand rich fluvial deposits led to unusually high sand delivery and that this in turn encouraged thick sandstone rich deposits. However, like the South Munster Basin, these examples seem to have developed within rift type settings with a large transverse sediment delivery (Levell 1980) and may also have been characterised by low shelf gradients. It may therefore be these factors that are of most importance to genesis of this kind of succession.

7.4 Are SCS and gutter casts the same bedform?

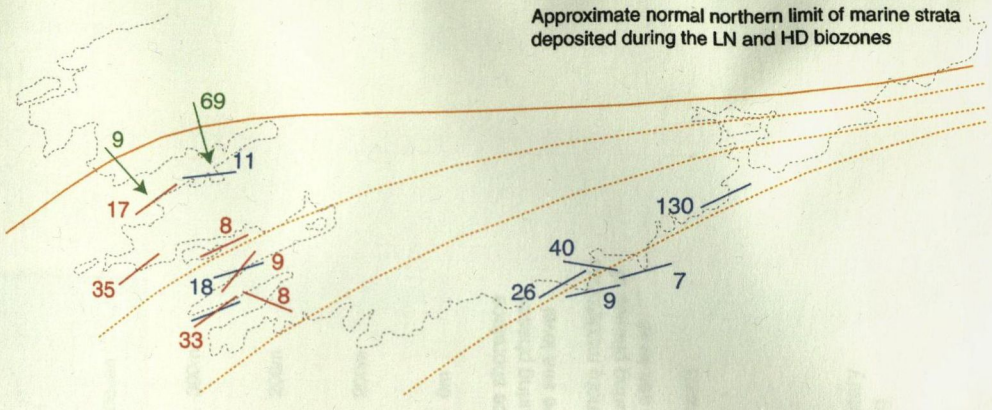
SCS, HCS and gutter casts are almost ubiquitous in ancient storm influenced shelf successions but their genesis, despite much research and speculation, remains poorly understood (Allen 1985; Allen and Underhill 1989; Swift and Nummedal 1986; Duke 1986; Duke *et al.* 1991; Klein and Marsaglia 1986; Nottvedt and Kreisa 1987; Winn 1990; Martel and Gibling 1994; Myrow and Southard 1996). One aspect that does generate some consensus however, is the distribution of these structures upon ancient coast to shelf profiles, namely that SCS (Leckie and Walker 1982) appears to form in more proximal settings than HCS (Harms *et al.* 1975) and that gutter-casts seem to increase in size offshore (Johnson and Baldwin 1996). Yet despite this, both HCS and SCS are only formed in sand, what happens when the zone of HCS or SCS generation falls upon a muddy sea-floor (a common phenomenon during periods of forced regression)? This is particularly interesting for the case of SCS (but probably also many instances of HCS) because genesis of this bedform clearly involves phases of erosion. Although it is far from clear what impact such swale generating mechanism might have had upon muddy substrates, perhaps the most likely consequence is that gutter casts would have formed. It is interesting to note therefore, that there are striking similarities between the gutter-casts of this study and SCS generally, over and above the obvious geometrical differences. Most importantly, the genesis of both bedforms appears to have involved alternating phases of scour generation and more quiescent episodes of scour fill, note that most of the sandstone filled gutter-casts in this study contain several generations of fill. This suggests some kind of repeated instability in the flow overlying these bedforms that periodically interrupted deposition, usually of parallel laminated sandstone. It is also interesting that many of the medium sized gutter-casts analysed in this study

include a saucer shaped scour at their top which resembles the swale shaped scours of SCS in all but scale (which may be restricted by substrate consistency). Moreover, the main differences between these bedforms, mainly that gutter casts are elongate in an offshore direction whereas erosional swales are more symmetrical, can perhaps be explained by subsequent erosion of gutter casts which unlike SCS, are not immediately blanketed with sand following generation (and therefore preserved in their original state?). With this in mind, it also seems likely that the geometry of gutter casts themselves, which varies from swale shaped depressions to swale shaped depressions with steeply down-cutting central portions, depends largely upon the degree to which the initial saucer shaped depression is reworked. Although this probably depended on a number of factors, reworking was perhaps greatest in offshore sections (hence largest gutter casts in these areas) because low sediment supply to these regions meant that the sea-bed did not aggrade. In contrast, the rapid accumulation of sand during storm events in more proximal settings caused distribution of swale structures throughout the body of individual storm sand beds thus forming SCS and probably also HCS (see following section).

If gutter casts are generated by the same type of flow instability that leads to the development of SCS, might this also be responsible for the development of HCS which forms between SCS and gutter-casts in the coast to shelf profile? In the majority of cases, the answer to this question is probably yes although accretionary, hummock shaped bedforms have been generated experimentally (Arnott and Southard 1990) and probably do exist in natural settings (figure 2.5). Yet the majority of what is called HCS in the sedimentary record (and which should perhaps be called SCS) contains numerous erosive swales into which sandstone laminae thicken and shallow but only very rarely exhibit any evidence for accretionary up-building. Furthermore, parting lineation is often found on bedding plane exposure of HCS/SCS (Brenchley 1985; Leckie and Krytinik 1989) thus surely indicating deposition within upper rather than lower flow conditions. This is further emphasised by the studies of Leckie (1988). This study therefore attributes the majority of HCS to scour and fill process (Bourgeois 1983) and thus speculates that in most cases, SCS, HCS and gutter-casts arise from the same generative mechanism rather than from migration of bedforms (Swift *et al.* 1983; Duke 1985; 1987; Nottvevedt and Kreisa 1987).

If these assertions are correct, then the relationship between parallel laminated sandstone and SCS/HCS is perhaps less clear than previously suggested because both bedforms were deposited within upper flow regime settings. This is particularly interesting in the case of tempestite beds where HCS/SCS overlies a parallel laminated basal interval because traditionally these units are attributed to waning flow. However, the evidence for waning flow is actually fairly unclear. For instance, although the grain fabric studies of Cheel (1990) suggest that offshore-directed unidirectional currents were dominant during genesis of the basal, parallel laminated part of these beds and that oscillatory currents came to dominate during deposition of the overlying HCS/SCS part, this could reflect either a decrease in unidirectional component (waning flow) or increase in oscillatory component (waxing flow). On the other hand, the offshore thickening of the basal plane bedded part of tempestite beds relative to the overlying HCS/SCS component (Johnson and Baldwin 1996), the presence of erosional scours in HCS/SCS and the sequence symmetry exhibited by many storm beds (i.e. upward transition from parallel lamination to HCS/SCS and back to a thin parallel laminated unit before culminating in a rippled top) are most easily explained if these units reflect waxing then waning of the storm event. It is also difficult to envisage how the volume of sediment required to generate many ancient tempestite beds could have been suspended in the water column until after the storm peak had passed as would be required if these units were generated during the waning part of the storm (see Swift *et al.* 1983).

If the parallel laminated portion of tempestite beds does reflect lower energy conditions than SCS/HCS then successions dominated by this structure, like the South Munster Basin during deposition of the Old Head Formation, may reflect lower levels of storm energy rather than increased prominence of combined flow as suggested by Arnott (1993). If this is the case, then the abundance of HCS/SCS in early Carboniferous strata in sections situated on the eastern basin margin (Cotter 1985) is interesting because it suggests higher energy storm conditions, perhaps enabled by deepening of the basin following the Castle Slate transgression.



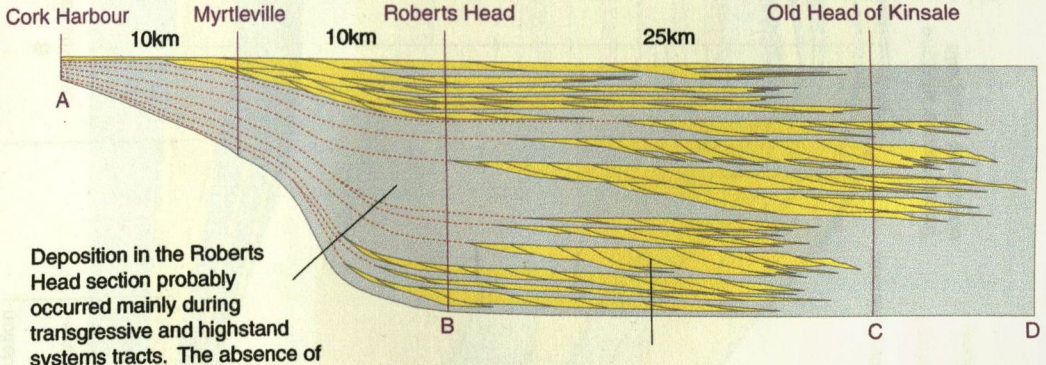
11 Orientation of wave generated ripple crests from within the Old Head Fm. (with number of measurements)

17 Orientation of wave generated ripple crests from within the Narrow Cove Fm. (with number of measurements)

Orientation of bathymetric contours estimated from symmetrical ripple crest orientation.

9 Orientation of fluvial palaeoflow from strata of equivalent age to the Old Head and Narrow Cove Formations

Figure 7.1 - Position and orientation of symmetrical ripple crests and fluvial palaeoflow during deposition of the Old Head and Narrow Cove Formations. These are useful because they allow rough estimation of the orientation of the palaeoshoreline and palaeobathymetric contours. Data for the eastern part of the basin is taken from Bamford (1988). This figure also indicates the position of normal maximum marine encroachment northward (solid orange line). It is interesting that the orientation of symmetrical ripples appears to diverge westward away from this thus causing an increasingly lower gradient shelf towards the west. This may have been of considerable importance to the restriction of storm influenced facies to more distal parts of the basin and to the eastern basin margin where shelf gradients appear to have been steeper.



Deposition in the Roberts Head section probably occurred mainly during transgressive and highstand systems tracts. The absence of shoreface sandstone within this section is perhaps a consequence of low shelf gradients which discouraged stabilisation of the coastline in this region.

Sharply bound shoreface sandstone packages were deposited during falling stage and lowstand systems tracts.

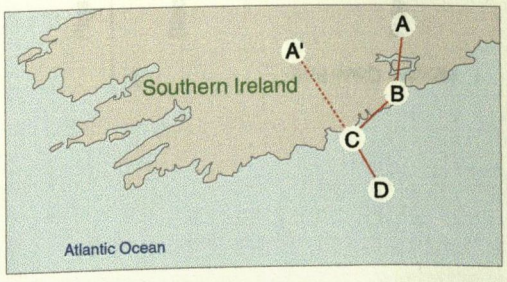


Figure 7.2 - Cartoon section thought the Tower Member (not to scale). Although this emphasizes the detached nature of the shoreface sandstone packages it is possible that other sections, for instance one running south from A', would be charatcerised by a series of attached rather than detached, basin stepping sandstone packages. This would probably depend on increased local sediment supply. Unfortunately however, poor exposure and limited dating means little is known about inland sections.

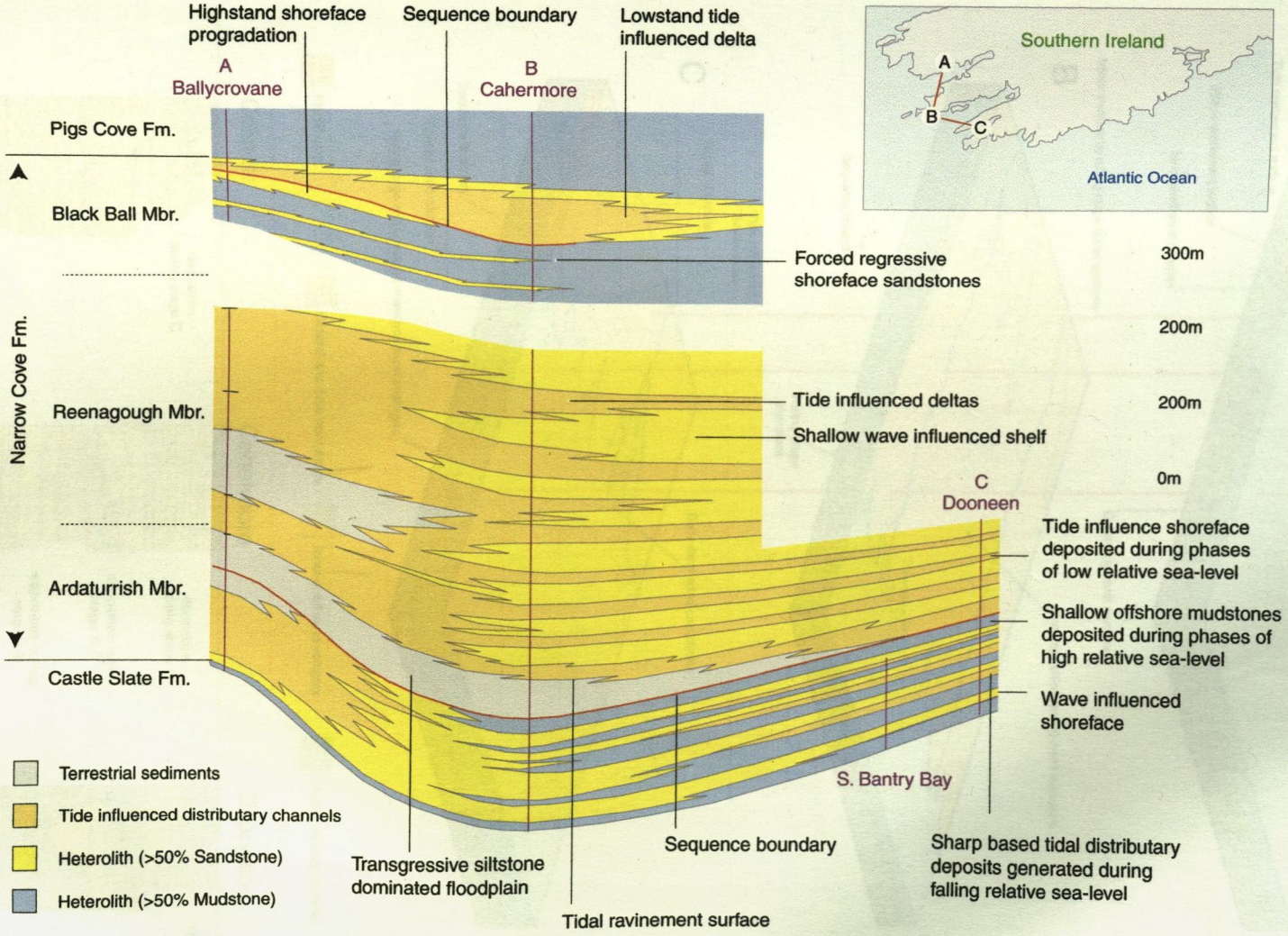


Figure 7.3 - Onshore to offshore section stretching from Ballycrovane to Cahermore to Dooneen.

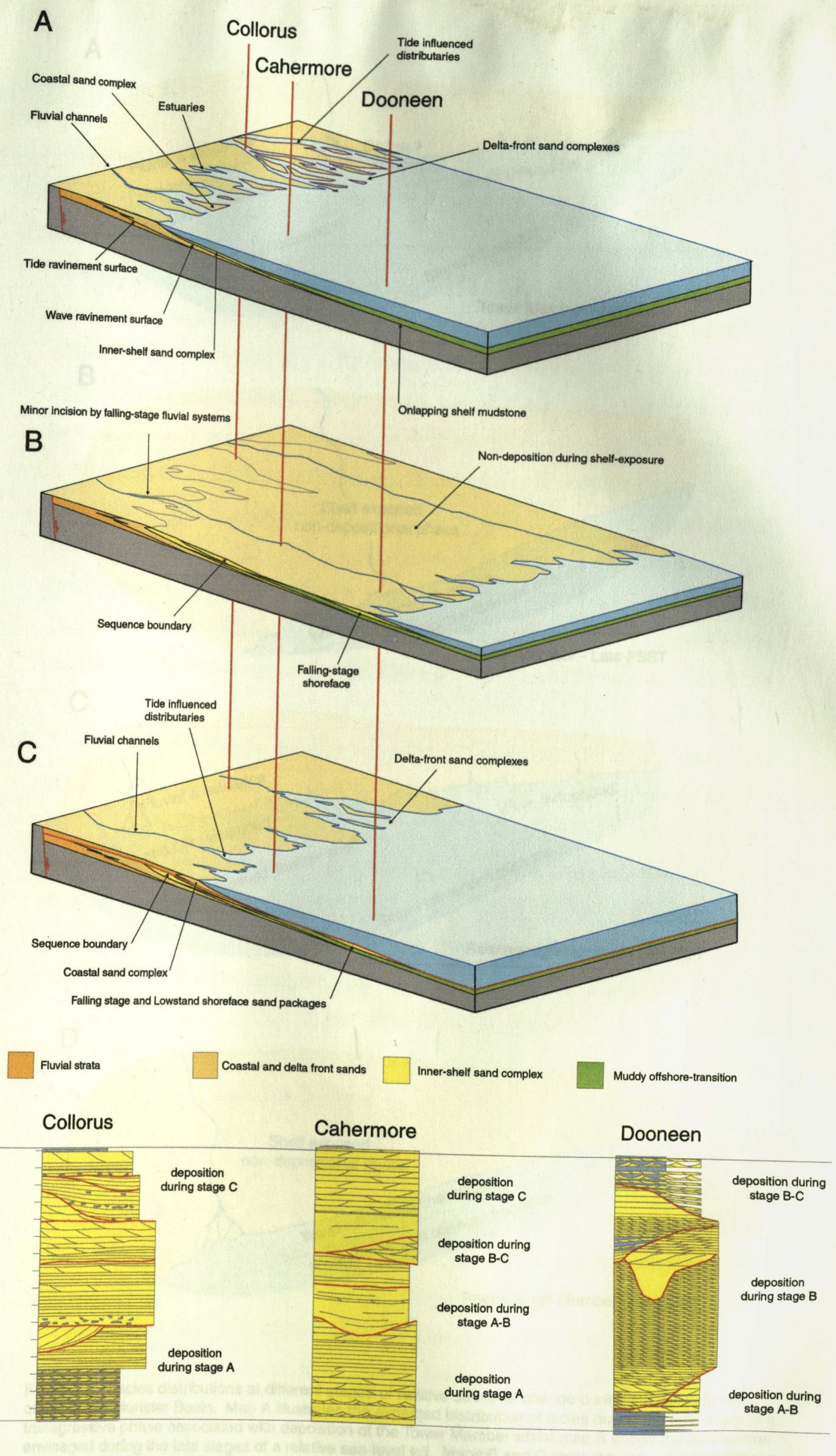


Figure 7.4 - Sections illustrate the sequential stratigraphic and environmental development of a single high frequency sequence within the Reenagough Member together with the resultant vertical facies profiles generated in both proximal and distal sections. Note that deposition in distal sections (Dooneen) occurred predominantly when relative sea-level was low or falling whilst deposition in proximal sections occurred preferentially when sea-levels were rising or high.

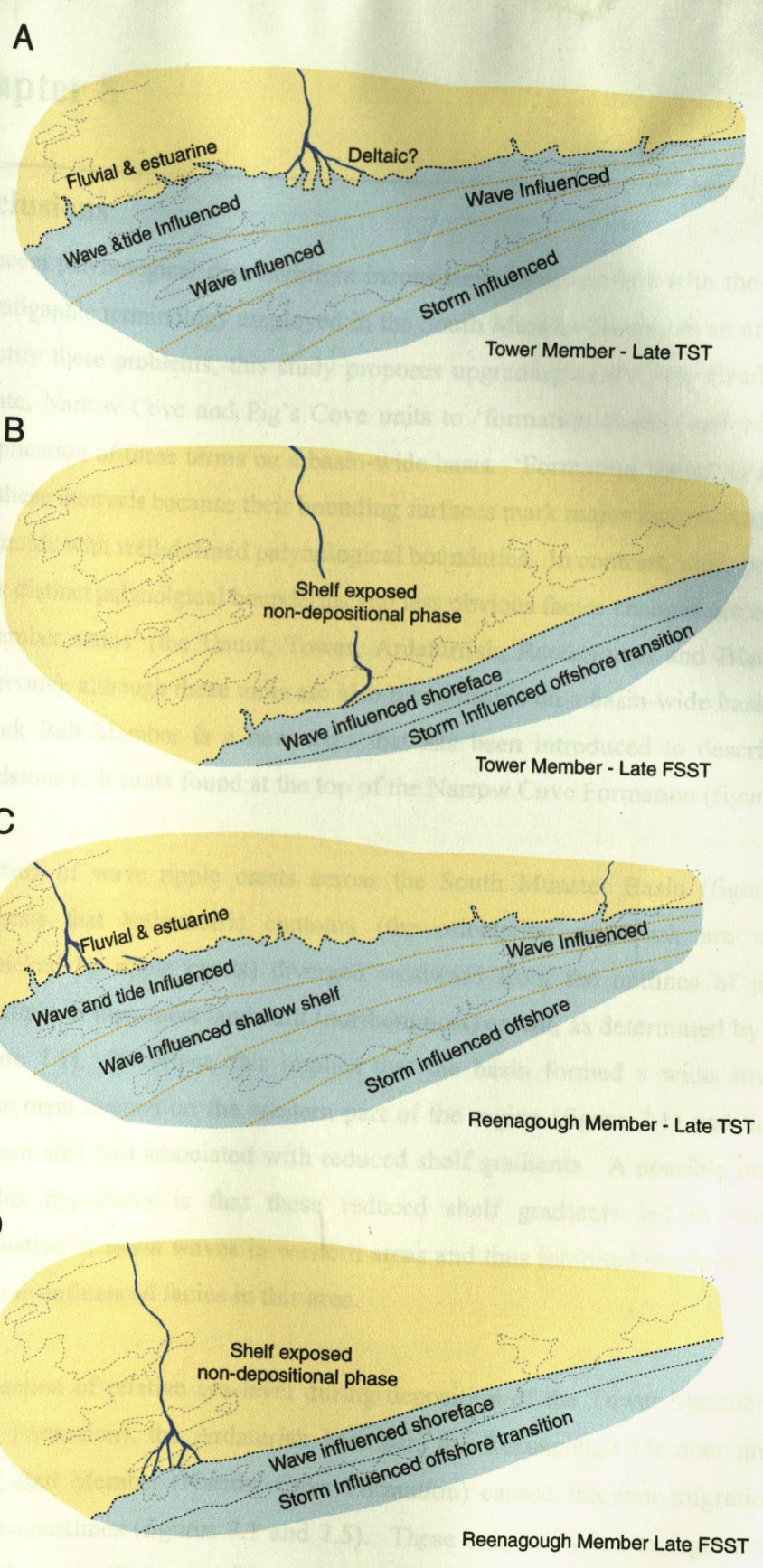


Figure 7.5 - Facies distributions at different stages of relative sea-level change during the development of the South Munster Basin. Map A illustrates the expected distribution of facies during the late stages of a transgressive phase associated with deposition of the Tower Member whilst map B shows the distributions envisaged during the late stages of a relative sea-level fall. Maps C and D show the corresponding changes associated with deposition of the Reenagough Member. Note that regressions of the palaeo-coastline seem to have extended further to the south during accumulation of the Tower Member and that the principal sediment source seems to have moved westward through time.

Chapter 8

Conclusions

(1) Recent palynological data highlight inconsistencies associated with the existing stratigaphic terminology employed in the South Munster Basin. In an attempt to rectify these problems, this study proposes upgrading of the Old Head, Castle Slate, Narrow Cove and Pig's Cove units to 'formation status' and advocates application of these terms on a basin-wide basis. 'Formation status' is ascribed to these intervals because their bounding surfaces mark major facies changes and coincide with well-defined palynological boundaries. In contrast, units bound by less distinct palynolgical boundaries and less obvious facies changes are ascribed 'member status' (the Daunt, Tower, Ardaturrish, Reenagough and Black Ball intervals), although these units are also recognisable on a basin-wide basis. The Black Ball Member is a new term that has been introduced to describe the mudstone rich strata found at the top of the Narrow Cove Formation (figure 1.5).

(2) Plotting of wave ripple crests across the South Munster Basin (figure 7.1) suggests that bathymetric contours (the orientation of which are usually mimicked by ripple crests) diverged westward from the outlines of palaeo-coastlines at their most landward (northernmost) extent, as determined by facies (figure 7.1). If correct, this implies that the basin formed a wide structural embayment centred on the western part of the region (figure 7.1) and that this western area was associated with reduced shelf gradients. A possible outcome of this hypothesis is that these reduced shelf gradients led to frictional attenuation of storm waves in western areas and thus inhibited the development of storm-influenced facies in this area.

(3) Fluctuation of relative sea-level during deposition of the Tower Member (Old Head Formation), the Ardaturish Member, the Reenagough Member and the Black Ball Member (Narrow Cove Formation) caused frequent migrations of palaeo-coastlines (figures 7.1 and 7.5). These commonly led to regressions of the palaeo-coastline to positions south of Dunmanus Bay and at certain stages, beyond the present-day south coast region. During phases characterised by these

regressions, deposition was dominated by the generation of sharp-based shoreface packages whilst subsequent transgressive phases caused erosional shoreface retreat followed by accumulation of muddy strata in distal sections. In more proximal sections, the accommodation associated with these transgressive phases enabled accumulation of fluvial and paralic strata.

(4) The unusually thick shallow marine sequences encountered within the South Munster Basin reflect the establishment of a long-term balance between subsidence and sediment supply but resulted from multiple stacking of individual high frequency sequences rather than from continuous vertical accumulation (figure 7.4). This vertical stacking pattern was facilitated by the close juxtaposition of an isostatically stable basin margin region and a rapidly subsiding basin as this arrangement produced a rapid increase in accommodation ('accommodation jump') that 'pinned' the maximum landward extent of palaeo-coastline migrations during successive sea-level changes. This in turn led to stacking of successive high frequency sequences and therefore also of facies types. The absence of pronounced uplift or down-warp in the basin marginal region was also important because it encouraged prolonged fluvial entrenchment thus encouraging long-term 'stability' of the sediment entry points to the basin. It also allowed transverse passage of a voluminous and mature sediment flux.

(5) Study of tempestite deposits within the South Munster Basin suggests that similar hydrodynamic processes may have led to the generation of both gutter casts and swaley cross-stratification (and perhaps also many instances of hummocky cross-stratification). This process seems to have involved instantaneous scouring events that impacted differently upon the sea floor depending on the frequency of the scouring episodes, the substrate consistency and the rates at which sedimentation progressed. As these factors tend to vary offshore in a repeatable pattern, this interpretation helps to explain the spatial distribution that these bed-forms typically exhibit within ancient shelf sequences. Furthermore, as this model suggests sand-deposition (in marginal regions) during both the waxing and waning parts of the storm-event, the large thickness of many ancient SCS / HCS beds is made easier to understand.

References

Ainsworth, R. B., and Pattison, S. A. J., 1994, Where have all the lowstands gone? Evidence for attached lowstand systems tracts in the Western Interior of North America: Geology, v. 22, p. 415-418.

Allen, J. R. L., 1979, A model for the interpretation of wave ripple marks using their wavelength, textural composition, and shape: J. geol. Soc. London, v. 136, p. 673-682.

Allen, P. A., 1981, Wave generated structures in the Devonian lacustrine sediments of south-east Shetland and adjacent wave conditions: Sedimentology, v. 28, p. 369-379.

Allen, P. A., 1981, Some guidlines in reconstructing ancient sea conditions from wave ripplemarks: Marine Geology, v. 43, p. 59-67.

Allen, P. A., 1984, Reconstruction of ancient sea conditions with an example from the Swiss Molasse: Marine Geology, v. 60, p. 455-473.

Allen, P. A. H., P., 1984., Evolution and mechanics of a Miocene tidal sandwave.: *Sedimentology*, v. **31**, p. 63-81.

Allen, P. A., 1985, Hummocky cross-stratification is not produced purely under progressive gravity waves.: Nature, v. 313, p. 562-564.

Allen, P. A., and Underhill, J. R., 1989, Swaley cross-stratification produced by unidirectional flows, Bencliff Grit (Upper Jurassic), Dorset, UK.: Journal of the Geological Society of London, v. 146, p. 241-252.

Arnott, W. R., and Southard, J. B., 1990, Exploratory flow-duct experiments on combined-flow bed configurations, and some implications for interpreting storm-event stratification: Journal of Sedimentary Petrology, v. 60, p. 211-219.

Arnott, R. W. C., 1993, Quasi-Planar-laminated sandstone beds of the Lower Cretaceous Bootlegger Member North-Central Montana: evidence of combined-flow sedimentation: Journal of Sedimentary petrology, v. 63, p. 488-494.

Bagnold, R. A., 1946, Motion of waves in shallow water, interactions between waves and sand bottoms: Proceedings of the Royal Society of London, p. 1-18.

Bamford, M. L. F., 1988, The sedimentological and structural geology of the Old Head Sandstone formation of County Cork.: Unpub. Phd thesis (unpubl) thesis, U.C.C.

Bamford, L. F., and Ford, M., 1990, Flexural shear in a periclinal fold from the Irish Variscides: *J. Struct Geol.*, v. 12, p. 59-67.

Banerjee, I., 1996, Populations, trends and cycles in combined flow bedforms.: J. Sed. Res., v. 66, p. 868-874.

Boersma, J. R., and Terwindt, J. H. J., 1981, Neap-spring tide sequences of intertidal shoal deposits in a mesotidal estuary: Sedimentology, v. 28, p. 151-170.

Bourgeois, J., 1980, A transgressive shelf sequence exhibiting hummocky stratification: The Cape Sebastian Sandstone (Upper Cretaceous), southwestern Oregon.: Journal of Sedimentary Petrology, v. 50, p. 681-702.

Brenchley, P. J., 1989, Storm Sedimentation: Geology Today, v. July-August, p. 133-137.

Bresser, G., and Hilgers, C., 1996, Struktur- und Metamorphoseentwicklung im SW-irischen Aubenvariszikum am Beispiel eines geologischen Profils von Killarney nach Bantry: Unpub. Unpublished diploma thesis thesis, RWTH.

Bromley, R. G., 1996, Trace Fossils: Biology, taphonomy and applications: London, Chapman and Hall.

Browne, G. H., 1994, Pot and gutter casts from the Chapel Island Formation, southeast Newfoundland-Discussion: Journal of Sedimentary Research, v. A64, p. 706-707.

Bucher, W. H., 1919, On ripples and related sedimentary surface forms and their palaeogeograhic interpretations: American Journal of science, v. 47, p. 149-210, 241-269.

Cacchione, D. A., Grant, W. D., and Tate, G. B., 1984, Rippled scour depressions on the inner continental shelf off Central California.: Journal of Sedimentary Petrology, v. 54, p. 1280-1291.

Capewell, J. G., 1957, The stratigraphy and sedimentation of the Old Red Sandstone of the Comeragh Mountains and adjacent areas, County Waterford, Ireland.: Quarterly Journal of the Geol. Soc. of London, v. cxii, p. 393-412.

Capewell, J. G., 1957b, The stratigraphy and structure of the country around Sneem, County Kerry: Proceedings of the Royal Irish Academy, v. 58B, p. 167-183.

Capewell, J. G., 1965, The Old Red Sandstone of Slieve Mish, Co. Kerry: Proc. Roy. Dublin Soc., v. 64, p. 165-174.

Chakraborty, C., 1995, Gutter casts from the Proterozoic Bijaygarh Shale Formation, India: their implication for storm induced circulation in shelf settings: Geological Journal, v. 30, p. 69-78.

Cheel, R. J., 1991, Grain fabric in hummocky cross-stratified storm beds: genetic implications: Journal of Sedimentary Petrology, v. 61, p. 102-110.

Clayton, G., Higgs, K., Gueinn, K. J. & Van Gelder, A., 1974, Palynological

correlations in the Cork Beds (Upper Devonian -? Upper Carboniferous) of southern Ireland.: *Proc. R. Ir. Acad*, v. **74(B)**, p. 145-155.

Clayton, G., Colthurst, J. R. L., Higgs, K., Jones, G. L., and Keegan, J. B., 1977, Tournaisian Miospores and Conodonts from County Kilkenny: Geol. Surv. Ireland Bull., v. 2, p. 99-106.

Clayton, G. H., K., 1979, The Tournaisian marine transgression.: *J. Earth Sci. R. Dubl. Soc*, v. 2, p. 1-10.

Clayton, G., Graham, J. R., Higgs, K., Holland, C. H. & Naylor, D., 1980, Devonian Rocks in Ireland: a review.: *J. Earth Sci. R. Dubl. Soc*, v. 2, p. 161-183.

Clayton, G. G., J. R., Higgs, K. Sevastopulo, G. D. & Welsh, A., 1986, Late Devonian and early Carboniferous palaeogeography of southern Ireland and south-west Britain.: Ministry of Economic Affairs, Adm. Of Mines, Belgian Geological Survey, v. Special Volume- April., p. 103-111.

Clifton, H. E., Hunter, R. E., and Phillips, R. L., 1971, Depositional structures and processes in the non-barred high energy nearshore: J. Sed. Pet., v. 41, p. 651-670.

Clifton, H. E., 1976, Wave formed sedimentary structures - a conceptual model.: Beach and Nearshore Sedimentation, v. Special Publication 24, Society of Economic and Petroleum Geology, 126-148 p.

Clifton, H. E., 1981, Progradational sequences in Miocene shoreline deposits, south-eastern Caliente Range, California: Journal of Sedimentary Petrology, v. 51, p. 165-184.

Collinson, J. D., and Thompson, D. B., 1982, Sedimentary Structures, George Allen & Unwin.

Colthurst, J. R. J., 1978, Old Red Sandstone rocks surrounding the Slievenamon Inlier, Counties Tipperary and Kilkenny.: J. Earth Sci. R. Dubl. Soc., v. 1, p. 77-103.

Cooper, M. A., Collins, D. A., Ford, M., Murphy, F. X., and Trayner, P. M., 1984, Structural style, shortening estimates and the thrust front of the Irish Variscides, *in* Hutton, D. H. W., and Sanderson, D. J., eds., Variscan tectonics of the north Atlantic region, Geological Society of London Special Publications, p. 167-175.

Cooper, M. A., Collins, D. A., Ford, M., Murphy, F. X., Trayner, P. M., and O'Sullivan, M., 1986, Structural evolution of the Irish Variscides: Journal of the Geological Society of London, v. 143, p. 53-61.

Cotter, E., 1985, Gravel topped offshore bar sequences in the Lower Carboniferous of southern Ireland .: *Sedimentology*, v. 32, p. 195-213.

Cotter, E., and Graham, J. R., 1991, Coastal plain sedimentation in the late Devonian of southern Ireland; hummock cross-stratification in fluvial deposits?: *Sedimentary Geology*, v. 72, p. 201-224.

De Raaf, J. F. M., 1970, Environmental studies concerning Upper Devonian (and Lower Carboniferous) coastal sections of South County Cork.: Geologie en Mijnbouw, v. 49, p. 247-248.

De Raaf, J. F. M., and Boersma, J. R., 1971, Tidal Deposits and their sedimentary structures (seven examples from Western Europe): Geologiie en Mijnbouw, v. 50, p. 479-504.

De Raaf, J. F. M., Boersma, J. R., and Van Gelder, A., 1977, Wave-generated structures and sequences from a shallow marine succession, Lower Carboniferous, County Cork, Ireland.: Sedimentology, v. 24, p. 451-483.

Diemer, J. A., Bridge J. S. & Sanderson D. J., 1987, Revised geology of Kerry Head, County Kerry.: *Irish Journal of Earth Science*, v. 8, p. 113-138.

Doran, R. J. P., 1970, Palynological evidence for th age of the Old Red Sandstone near Cappagh White, Co. Tipperary.: Sci. Proc. Roy. Dub. Soc., v. Series A, Vol. 3, p. 343-351.

Doran, R. J. P., Holland, C. H. & Jackson, A.A., 1973, The Sub-Old Red Sandstone surface in southern Ireland.: *Proc. R. Ir. Acad*, v. 73B, p. 8-28.

Duke, W. L., 1986, Hummocky cross stratification, tropical storms, and intense winter storms: Reply.: Sedimentology, v. 34, p. 344-359.

Duke, W. L., Arnott, R. W. C., and Cheel, R. J., 1991, Shelf sandstone and hummocky cross-stratification: New insights on a stormy debate: Geology, v. 19, p. 625-628.

Fitzgerald, D., M. , and Van Heteren, S., 1999, Classification of Paraglacial barrier systems: coastal New England, USA.: Sedimentology, v. 46, p. 1083-1108.

Ford, M., 1987, Practical application of the sequential balancing technique: an example from the Irish Variscides: Journal of the Geological Society of London, v. 144, p. 885-891.

Ford, M., 1990, The stratigraphy and structure of the Galley Head culmination zone; an area of enhanced shortening related to basin geometry within the Irish Variscides: Geological Journal, v. 25, p. 145-159.

Franke, W., 1989, Tectonostratigraphic units in the Variscan belt of Central Europe, *in* Dallmeyer, R. D., ed., Terranes in the Circum-Atlantic Palaeozoic Orogens, Geological Society of America Special Papers, p. 221-228.

Frey, R. W., and Pemberton, S. G., 1985, Biogenic structures in outcrops and cores. 1. Approaches to ichnology: Bulletin of Canadian Petroleum Geology, v. 33, p. 72-115.

Frey, R. W., Howard, J. D, Sang-Joon, H., Byong-Kwon Park., 1989, Sediments and sedimentary sequences on a modern microtidal flat, Inchon, Korea.: *Journ. of Sed.*

Pet., v. 59, p. 28-44.

Friend, P. F., Williams, B. P. J., Ford, M., and Williams, E. A., 2000, Kinematics and dynamics of Old Red Sandstone Basins, *in* F., F. P., and Williams, B. P. J., eds., New perspectives on the Old Red Sandstone, Geological Society of London Special Publications, p. 29-60.

Gardiner, P. R. R. H., R. R., 1972, The Devonian and Lower Carboniferous clastic correlatives of southern Ireland.: *Geol. Surv. Ireland, Bull.*, v. 1, p. 335-366.

Gardiner, P. R. R. M., I. A. J., 1981, The Late Palaeozoic evolution of southern Ireland in the context of tectonic basins and their transatlantic significance., *in* Kerr, J. W. F., A. J., ed., Geology of the North Atlantic borderlands, Canadian Society of Petroleum Geologists, p. 683-725.

Gardiner, P. R. R. S., 1981, Tectonic framework of the Celtic Sea and Adjacent areas with special reference to the location of the Variscan Front.: *J. Struct Geol.*, v. 3, p. 317-331.

Gastaldo, R. A., Allen, G. P., and A.-Y., H., 1995, The tidal character of the fluvial sediments of the modern Mahakam River delta, Kalimantan, Indonesia, *in* Flemming, B. W., and Bartholoma, A., eds., Tiidal signatures in modern and ancient sediments, Special Publication of the International Association of Sedimentologists.

George, T. N., Johnson, G. A. L., Mitchell, M., Prentice, J. E., Ramsbottom, W. H. C., Sevastopulo, G. D., and Wilson, J. B., 1976, A correlation of Dinantian rocks in the British Isles: Geological Society of London Special Report, v. 7, p. 87.

Graham, J. R., & Reilly, T. A., 1972, The Sherkin Formation (Devonian) of south-west County Cork.: *Geol. Surv. Ireland, Bull.*, v. 1, p. 281-300.

Graham, J. R., 1975, Analysis of an Upper Palaeozoic transgressive sequence in south-west County Cork, Eire.: *Sedimentary Geology*, v. 13, p. 267-290.

Graham, J. R., 1975, Deposits of a near-coastal fluvial plain - the Toe Head Formation (Upper Devonian) of south-west Cork, Ireland.: *Sedimentary Geology*, v. 14, p. 45-61.

Graham, J. R., & Reilly, T. A., 1976, The stratigraphy of the area around Clonakilty Bay, South County Cork.: *Proc. R. Ir. Acad.*, v. 76, p. 379-391.

Graham, J. R., Richardson, J. B., and Clayton, G., 1983, Age and significance of the Old Red Sandstone around Clew Bay, NW Ireland: Transactions of the Royal Society of Edinburgh: Earth Sciences, v. 73.

Graham, J., 1988, Collection and analysis of field data, *in* Tucker, M., ed., Techniques in sedimentology, p. 5-62.

Graham, J. R., James, A. & Russell, K. J., 1992, Basin history deduced from subtle changes in fluvial style: a study of distal alluvium from the Devonian of southwest

Ireland.: *Trans R Soc. Edinburgh*, v. 70, p. 655-667.

Graham, J. R., Russell, K. J. & Stillman, C. J., 1995, Late Devonian magmatism in West Kerry and its relationship to the development of the Munster Basin.: *Irish Journal of Earth Sciences*, v. 14, p. 7-23.

Graham, 2001 (in press), The Devonian, *in* Holland, C. H., ed., The Geology of Ireland, Dunedin Academic Press.

Hammond, T. D., and Collins, M. B., 1979, On the threshold of transport of sand sized sediment under the combined influence of unidirectional and oscillatory flow.: Sedimentology, v. 26, p. 795-812.

Hampson, G. J., 2000, Discontinuity surfaces, clinoforms, and facies architechture in a wave-dominated, shoreface-shelf parasequence: Journal of Sedimentary Research, v. 70, p. 325-340.

Harris, P. T., Pattiaratchi, C. B., Collins, M. B., and Dalrymple, D. W., 1995, What is bedload parting?, *in* Flemming, B. W., and Bartholoma, A., eds., Tidal signatures in modern and ancient sediments, Special publication of the International Association of Sedimentologists.

Hart, B. S., Vantfoort, R. M., and Plint, G., 1990, Is there evidence for geostrophic currents preserved in the sedimentary record of inner to middle shelf deposits? - Discussion.: Journal of Sedimentary Petrology, v. 60, p. 633-635.

Higgs, K., 1975, Upper Devonian and Lower Carboniferous miospore assemblages from Hook Head, C ounty Wexford, Ireland.: Micropaleontolgy, v. 4, p. 393-419.

Higgs, K. R., K. J., 1981, Upper Devonian microfloras from south-east Iveragh, County Kerry, Ireland.: *Geol. Surv. Ireland, Bull.*, v. 3, p. 17-50.

Higgs, K., 1983, Palynological evidence for Carboniferous strata in two wells drilled in the Celtic Sea Area.: *Geol. Surv. Ireland, Bull.*, v. 3, p. 107-112.

Higgs, K., Clayton, G., and Keegan, J. B., 1988, Stratigraphic and systematic palynology of the Tournaisian rocks of Ireland, v. 7, Special Paper of the Geological Survey of Ireland.

Higgs, R., 1990, Is there evidence for geostrophic currents preserved in the sedimentary record of inner to middle shelf deposits? - Discussion.: Journal of Sedimentary Petrology, v. 60, p. 630-632.

House, M. R., 1968, Continental drift and the Devonian System, University of Hull.

Howard, J. D., and Reineck, H. E., 1981, Depositional facies of high energy beach to offshore sequence; comparison with low energy sequence: Bulletin of the American Association of Petroleum Geologists, v. 65, p. 807-830.

Hunter, R. E., Clifton, H. E., and Phillips, R. L., 1979, Depositional processes,

sedimentary structures and predicted vertical sequeces in barred near-shore systems, southern Oregon coast: Journal of Sedimenary Petrology, v. 49, p. 711 - 726.

Husain, S. M., 1957, The geology of the Kenmare Syncline, County Kerry, Ireland: Unpublished PhD thesis, University of London.

Inman, D. L., 1957, Wave generated ripples in nearshore sands: U.S. Technology Memo., Beach Erosion Board., v. 2, p. 42.

James, A., and Graham, J. R., 1995, Stratigraphy and structure of Devonian fluvial sediments, western Beara Peninsula, south-west Ireland.: Geological Journal, v. 30, p. 165-182.

Johnson, M. A., Stride, A. H., Belderson, R. H., and Kenyon, N. H., 1981, Predicted sand-wave formation and decay on a large offshore tidal-current sand sheet., *in* S. D. Nio, Shuttenhelm, R. T. E., and Weering, T. C. E. v., eds., Holocene marine sedimentation in the North Sea Basin, Spec. Publs int. Ass. Sediment., p. 247-256.

Johnson, H. D., and Baldwin, C. T., 1996, Shallow Clastic Seas, *in* Reading, H. G., ed., Sedimentary environments: processes, facies and stratigraphy, Blackwell Science.

Jones, P. C., 1974, Marine transgression and facies distribution in the Cork Beds (Devonian-Carboniferous) of west Cork and Kerry, Ireland.: Proceedings of the Geological Association, v. 85, p. 159-188.

Jopling, A. V., and Walker, R. G., 1968, Morphology and origin of ripple-drift cross lamination, with examples from the Peistocene of Massachusetts: J. Sed. Pet., v. 38, p. 971-984.

Keegan, J. B., 1977, Late Devonian and Early Carboniferous Miospores from the Galley Head - Leap Harbour region of south-west Ireland.: *Pollen et Spores*, v. Vol. xix.

Kelly, S. B., and Olsen, H., 1993, Terminal fans - a review with reference to Devonian examples: Sedimentary Geology, v. 85, p. 339-374.

Kelly, S. B., and Sadler, S. P., 1995, Equilibrium and response to climatic and tectonic forcing: a study of alluvial sequences in the Devonian Munster Basin, Ireland., *in* House, M. R., and Gale, A. S., eds., Orbital forcing timescales and cyclostratigraphy., Geological Society London Special Publication, p. 19-36.

Kenyon, N. H., Belderson, R. H., Stride, A. H., and Johnson, M. A., 1981, Offshore tidal sand-banks as indicators of net sand transport and as potential deposits, *in* Nio, S. D., Shuttenhelm, R. T. E., and van Weering, T. C. E., eds., Holocene marine sedimentation in the North Sea Basin, International Association of Sedimentologists, p. 257-268.

Khan, M. F. H., 1955, The Old Red Sandstone of the Kerry Head Anticline, County Kerry.: Procs. of the R. Ir. Acad., v. 57, p. 71-78.

Klein, G. H., and Marsaglia, K. M., 1986, Hummocky cross stratification, tropical storms, and intense winter storms: discussion.: Sedimentology, v. 34, p. 333-359.

Komar, P. D., 1976, Beach processes and sedimentation: Eaglewood Cliffs, New Jersey, Prentice Hall, 429 p.

Kuijpers, E. P., 1971, Preliminary note on the Breamrock Formation (Upper Devonian) County Cork, Ireland-an ancient tidal deposit.: *Sedimentary Geology*, v. 5, p. 83-89.

Kuijpers, E. P., 1972, Upper Devonian tidal deposits and associated sediments south and southwest of Kinsale.: Unpub Phd thesis, University of Utrecht.

Le Mehaute, B., Divoky, D., and Lin, A., 1969, Shallow water waves; a comparison of theories and experiments: American Society of Civil Engineering. Proceedings 11th Conference of Coastal Engineering., p. 86-96.

Leckie, D. A., and Walker, R. G., 1982, Storm and tide dominated shorelines in Cretaceous Moosebar-Lower Gates interval-outcrop equivelents of Deep Basin Gas Trap in Western Canada.: American Association of Petroleum Geologists Bulletin, v. 66, p. 138-157.

Leckie, D., 1988, Wave formed, coarse-grained ripples and their relationship to hummocky cross-stratification: Journal of Sedimentary Petrology, v. 58, p. 607-622.

Leckie, D. A., and Krystinik, L. F., 1989, Is there sedimentary evidence for geostrophic currents preserved in the sedimentary record of inner to middle-shelf deposits?: J. Sed. Pet., v. 59, p. 862-870.

Leckie, D. A., and Krystinik, L. F., 1990, Is there evidence for geostrophic currents preserved in the sedimentary record of inner to middle shelf deposits? - Reply.: Journal of Sedimentary Petrology, v. 60, p. 633-635.

Leckie, D. A., and Krystinik, L. F., 1991, Is there evidence for geostrophic currents preserved in the sedimentary record of inner- to middle-shelf deposits?-Discusssion: Journal of Sedimentary Petrology, v. 61, p. 152-154.

Leflef, D., 1974, Continental Sedimentation patterns at the Old Red Sandstone Border, South of Cork, Ireland.: Unpub. Phd (Unpubl.) thesis, University of Utrecht.

Leyshon, P. R., and J., L. R., 1996, Steriographic projection techniques in structural geology, Butterworth-Heinemann.

MacCarthy, I. A. J., 1974, The Upper Devonian and Lower Carboniferous stratigraphy of the Whitegate area, Co. Cork.: *Proc. R. Ir. Acad.*, v. **74(B)**, p. 313-330.

MacCarthy, I. A. J., Gardiner, P. R. R., and Horne, R. R., 1978, The lithostratigraphy of the Devonian-Early Carboniferous succession in parts of Counties Cork and Waterford, Ireland.: *Geol. Surv. Ireland, Bull.*, v. 2, p. 265-305.

MacCarthy, I. A. J., 1979, An early Carboniferous river dominated regressive facies in southern Ireland.: *Geology en Mijnbouw*, v. **58 (1)**, p. 39-48.

MacCarthy, I. A. J., 1983, Devonian facies in the southern and south-eastern part of the Munster Basin.: *Friends of the Devonian Field Meeting*.

MacCarthy, I. A. J., 1987, Transgressive facies in the South Munster Basin, Ireland.: *Sedimentology*, v. 34, p. 389-422.

MacCarthy, I. A. J., 1987, Dinantian Cyclicity: a case history from the Munster Basin of southern Ireland., *in* Miller, J., Adams, A. E. & Wright, V. P., ed., European Dinantian Environments, p. 199-237.

MacCarthy, I. A. J., 1990, Alluvial sedimentation patterns in the Munster Basin, Ireland.: *Sedimentology*, v. 37, p. 685-712.

Martel, A. T., and Gibling, M. R., 1994, Combined-flow generation of sole structures, including recurved groove casts,associated with Lower Carboniferous lacustrine storm deposits in Nova Scotia, Canada: Journal of Sedimentary Research, v. A64, p. 508-517.

Mathews, S. C., Naylor, D. & Sevastopulo, G. D., 1983, Palaeozoic sedimentary sequence as a reflection of deep structure in south-west Ireland.: *Sedimentary Geology*, v. 34, p. 83-95.

McAfee, A. M., 1992, Upper Devonian - Lower Carboniferous sedimentation patterns in the western parts of the South Munster Basin: Unpub. Unpublished PhD thesis thesis, National University of Ireland.

McCabe, A. M., 1985, Ireland, *in* Bowen, D. Q., ed., Correlation of Quaternary glaciations in England, Ireland, Scotland, and Wales, Quaternary Science Reviews, p. 312 - 318.

McCave, I. N., 1971, Wave effectiveness at the sea bed and its relationship to bed-forms and deposition of mud: Journal of Sedimentary Petrology, v. 41, p. 89-96.

McCave, I. N., 1985, Recent shelf clastic sediments, *in* Brenchley, P. J., and Williams, P. J., eds., Sedimentology: recent advances and applied aspects, Geological Society of London Special Publication, p. 49-65.

McCowan, J., 1894, On the highest wave of permanent type: Philos. Mag,, v. 5, p. 351-357.

McKerrow, W. S., MacNiocaill, C., Ahlberg, P. E., Clayton, G., Cleal, C. J., and Eagar, M. C., 2000, The late Palaeozoic relations between Gondwana and Laurussia, *in* Franke, W., Haak, V., Onken, O., and Tanner, D., eds., Orogenic processes: Quantification and Modelling in the Variscan Belt, Geological Society of London, Special Publications, p. 9-20.

McMurray, L. S., and Gawthorpe, R. L., 2000, Along strike variability of forced regressive deposits: late Quaternary, northern Peloponnesos, Greece, *in* Hunt, D., and Gawthorpe, R. L., eds., Sedimentary Responses to Forced Regressions, Geological Society of London, Special Publication, p. 363-378.

Meere, P. A., 1995, The structural evolution of the Irish Variscides: Tectonophysics, v. 246, p. 97-112.

Metivier, F., and Gaudemer, Y., 1999, Stability of output fluxes of large rivers in South East Asia during the last 2 million years: implications on flood plain processes: Basin Research, v. 11, p. 293-304.

Miche, R., 1944, Undulatory movements of the sea in constant and decreasing depth: Ann. Ponts Chauss, v. May-June, July-August,, p. 25-78, 131-164, 270-292,369-406.

Midtgaard, H. H., 1996, Inner-shelf to lower shoreface hummocky sandstone bodies with evidence for geostrophic influenced combined flows, Lower Cretaceous, West Greenland: Journal of Sedimentary Research, v. 66, p. 343-353.

Miller, M. C., and Komar, P. D., 1980, A field investigation of the relationship between oscillating ripple spacing and the near-bottom water orbital motions.: J. Sed. Pet., v. 50, p. 183-191.

Miller, M. C., and Komar, P. D., 1980, Oscillation sand ripples generated by laboratory apparatus: J. Sed. Pet., v. 50, p. 173-182.

Morton, R. A., 1981, Formation of Storm deposits by wind forced currents in the Gulf of Mexico and the North Sea, *in* S. D. Nio, Shuttenhelm, R. T. E., and Weering, T. C. E. v., eds., Holocene marine sedimentation in the North Sea Basin., Special publication of the international Association of Sedimentologists, p. 385-396.

Morton, R. A., Paine, J. G., and Blum, M. D., 2000, Responses of stable bay-margin and barrier island systems to Holocene sea-lvel highstands, western Gulf of Mexico.: Journal of Sedimentary Research, v. 70, p. 478-490.

Myrow, P. M., and Southard, J. B., 1991, Combined-flow model for vertical stratification sequences in shallow marine storm-deposited beds: Journal of Sedimentary Petrology, v. 61, p. 202-210.

Myrow, P. M., 1992, Pot and gutter casts from the Chapel Island Formation, Southeast Newfoundland: Journal of Sedimentary Petrology, v. 62, p. 992-1007.

Myrow, P. M., 1994, Pot and gutter casts from theChapel Island Formation, southeast Newfoundland-Discussion: Journal of sedimentary Petrology, v. A64, p. 708-709.

Myrow, P. M., and Southard, J. B., 1996, Tempestite deposition: J. Sed. Res., v. 66, p. 875-887.

Naylor, D., 1964, The Upper Devonian and Lower Carboniferous stratigraphy of

South County Cork, Ireland.: Unpub. Phd (Unpubl.) thesis, University of Dublin.

Naylor, D., 1966, The Upper Devonian and Carboniferous Geology of the Old Head of Kinsale, Co. Cork.: *Sci. Proc. Roy. Dublin Soc*, v. 2, p. 229-249.

Naylor, D., 1969, Facies change in upper Devonian and Lower Carboniferous rocks of southern Ireland.: *Geol. Journal*, v. 6, p. 307-328.

Naylor, D., Jones, P. C. & Clarke, M. J., 1969, The stratigraphy of the Cork Beds (Upper Devonian and Carboniferous) in south-west Ireland.: *Sci. Proc. Roy. Dublin Soc.*, v. 3, p. 171-191.

Naylor, D., Jones, P. C. & Mathews, S. C., 1974, Facies relationships in the Upper Devonian - Lower Carboniferous of southwest Ireland and adjacent regions.: *Geological Journal*, v. 9, p. 77 -58.

Naylor, D., 1975, Upper Devonian-Lower Carboniferous Stratigraphy along the south coast of Dunmanus Bay, Co. Cork.: *Proc. R. Ir. Acad.*, v. **75(B)**, p. 317-337.

Naylor, D., Higgs, K., & Boland, M. A., 1977, Stratigraphy of the north flank of the Dunmanus Syncline, West Cork.: *Geol. Surv. Ireland, Bull.*, v. 2, p. 143-157.

Naylor, D., 1978, A structural section across the Irish Variscan fold belt: J. Earth Sci. R. Dubl. Soc., v. 1, p. 63-70.

Naylor, D., and Sevastopulo, G. D., 1979, The Hercynian "Front" in Ireland: Krystalinkum, v. 14, p. 77-90.

Naylor, D. H., K., 1980, The geology of the coastline east of Kinsale Harbour, County Cork.: *Geol. Surv. Ireland, Bull*, v. 2, p. 371-388.

Naylor, D. R., T. A.., 1981, The Kinsale Formation, north-east Seven Heads, County Cork.: *Geol. Surv. Ireland, Bull.*, v. 3, p. 1-8.

Naylor, D., and Shannon, P. M., 1982, The geology of offshore Ireland and west Britain, London, Graham and Trotman.

Naylor, D., Reilly, T. A. & Sevastopulo, G. D., 1983, Stratigraphy and structure in the Irish Variscides., *in* Hancock, P., ed., *The Variscan Fold Belt*, Bristol, Adam Hilger, p. 20-46.

Naylor, D., Higgs T. A., Reilly, T. A & Sevastopulo G. D., 1987, Dinantian and Namurain stratigraphy, Seven Heads Peninsula, County Cork.: *Irish Journal of Earth Sciences*, v. 9, p. 1-17.

Naylor, D., Sevastopulo, G. D. & Sleeman, A. G., 1989, Subsidence history of the South Munster Basin, Ireland., *in* Arthurson R. S., G. P. N. S. C., ed., The role of tectonics in Devonian and Carboniferous sedimentation in the British Isles., The Yorkshire Geological Society, p. 99-110.

Naylor, D., 1992, The post-Variscan history of Ireland, *in* Parnell, J., ed., Basins on the Atlantic Seaboard: Petroleum Geology, Sedimentology and Basin Evolution, Geological Society Special Publication, p. 255-275.

Naylor, D. S., G. D., 1993, The Reenydonagan Formation (Dinantian) of the Banty and Dunmanus Synclines, County Cork.: *Irish Journal of Earth Sciences*, v. 12, p. 191-203.

Naylor, D., Sevastopulo, G. D. & Sleeman, A. G., 1996, Contemporaneous erosion and reworking within the Dinantian of the South Munster Basin., *in* Strogen, P., Somerville, I. D. & Jones G., ed., Recent Advances in Lower Carboniferous Geology, *Geological Society Special Publication*, p. 331-343.

Neumann, G., 1953, On ocean wave spectra and a new way of forecasting wind-generated sea: U.S. Army Corps Eng., Beach |Erosion Board, Tech. Mem., v. 43, p. 42.

Neves, R., Gueinn, K. J., Clayton, G., Ioannides, N., and Neville, R. S. W., 1972, A scheme of miospore zones for the British Dinantian: 7th Cong. Advanc. Etud. Stratigr. Geol. Carb., v. 347-353.

Newton, R. S., 1968, Internal structure of wave-formed ripple marks in the nearshore: Sedimentology, v. 11, p. 275-292.

Nottvedt, A., and Kreisa , R. D., 1987, Model for the combind-flow origin of hummocky cross-stratification.: Geology, v. 15, p. 357-361.

O'Liathain, M., 1992, The stratigraphic palynology and palynofacies of the Upper Devonian- Lower Carboniferous successions in the South Munster Basin, Ireland and North Devon, England.: Unpub. Phd (Unpubl.) thesis, University College Cork.

Otvos, E. G., 1981, Barrier Island formation through nearshore aggradation - stratigraphic and field evidence: Marine Geology, v. 43, p. 195-243.

Pemberton, S. G., MacEachern, J. A., and Frey, R. W., 1992, Trace fossil facies models: environmental and allostratigraphic significance, *in* Walker, R. G., and James, N. P., eds., Facies models - Responses to sea level change, Ottawa, Geological Association of Canada.

Penney, R. P., 1980, A new look at the Old Red Sandstone succession of the Comeragh Mountains, County Waterford.: J. Earth Sci. R. Dubl. Soc., v. 3, p. 155-178.

Phillips, S. J. L., 1985, The stratigraphy and structure of southwest Count Cork, Ireland: Unpub. Phd (unpubl.) thesis, Queens University.

Plint, A. G., and Nummedal, D., 2000, The falling stage systems tract: recognition and importance in sequence stratigraphic analysis, *in* Hunt, D., and Gawthorpe, R. L., eds., Sedimentary Responses to Forced Regressions, Geological Society of London, p. 1-18.

Posamentier, H. W., Allen, G. P., James, D. P., and Tesson, M., 1992, Forced regressions in a sequence stratigraphic framework: concepts, examples and exploration significance: Bulletin of the American Association of Petroleum Geologists, v. 76, p. 1687-1709.

Posamentier, H. W., and Morris, W. R., 2000, Aspects of the stratal architechture of forced regressive deposits, *in* Hunt, D., and Gawthorpe, R. L., eds., Sedimentary Responses to Forced Regressions, Geological Society of LondonSpecial Publication 172, p. 19-46.

Pracht, M., 1994, The geology of the Beara Peninsula, Ireland: Unpub. PhD (Unpublished)) thesis, National University of Ireland.

Prendergast, B. M., 1972, The Silurian and Devonian Inlier of KnockshigownaHill, County Tipperary, Ireland.: Sci. Procs. R. Dub. Soc., v. Series A, Volume 4.

Ramsay, J. G., 1961, The effects of folding upon the orientation of sedimentation structures: Journal of Structural Geology.

Reilly, T. A., and Graham, J. R., 1972, The historical and geological setting of the Glandore Mines: Bull. Geol. Surv. Irel., v. 1, p. 253-265.

Reilly, T. A. G., J. R., 1976, The stratigraphy of the Roaringwater Bay area of south-west County Cork.: *Geol. Surv. Ireland, Bull*, v. 2, p. 1-13.

Reineck, H., and Wunderlich, F., 1968, Classification and origin of flaser and lenticular bedding: Sedimentology, v. 11, p. 99-104.

Reineck, H. E., and Singh, I. B., 1972, Genesis of laminated sand and gravel rhythmites in storm-sand layers of shelf mud: Sedimentology, v. 18, p. 123-128.

Rossetti, D. d. F., Goes, A. M., Truckenbrodt, W., and Anaisse, J., 2000, Tsunami-indiced large-scale scour-and-fill structures in Late Albian to Cenomanian deposits of the Grajau Basin, northern Brazil.: Sedimentology, v. 47, p. 309-324.

Sadler, S. P., 1992, The late Palaeozoic clastic sequence of northeast Beara, SW Ireland; Sedimentology and Basin Analysis: Unpub. PhD (Unpubl) thesis, National University of Ireland.

Sadler, S. P., and Kelly, S. B., 1993, Fluvial processes and cyclicity in terminal fan deposits: an example from the Late Devonian of southwest Ireland: Sedimentary Geology, v. 85, p. 375-386.

Sanderson, D. J., 1984, Structural variations across the northern margin of the Variscides in N.W. Europe, *in* Hutton, D. H. W., and Sanderson, D. J., eds., Variscan Tectonics of the North Atlantic Region, Special Publication of the Geological Society of London, p. 149-165.

Sleeman, A. G., Johnston, I. S., Naylor, D., and Sevastopulo, G. D., 1974, The

stratigraphy of the Carboniferous rocks of Hook Head, Co Wexford.: Proc. Roy. Irish Acad., v. 74, p. 227-243.

Sleeman, A. G., 1978, Preliminary stratiraphy and palynology of five sections through the Old Head Sandstone and Kinsale Formations (Upper Devonian to Lower Carboniferous), on the west side of Cork Harbour.: Geological Survey of Ireland Bulletin, v. 2, p. 167-186.

Sleeman, A. G., Thornbury B & Sevastopulo G. D., 1987, The stratigraphy of the Courceyan (Carboniferous; Dinantian) rocks of the Cloyne Syncline,West of Cork Harbour.: *Irish Journal of Earth Sciences*, v. 8, p. 21-40.

Smith, D. G., Meyers, A. M., and Jol, H. M., 1999, Sedimentology of an upper-mesotidal (3.7m) Holocene barrier, Willapa Bay, SW Washington, USA: Journal of Sedimentary Research, v. 69, p. 1290-1296.

Snedden, J. W., and Swift, D. J. P., 1991, Is there evidence for geostrophic currents preserved in the sedimentary record of inner- to middle-shelf deposits?-Discusssion: Journal of Sedimentary Petrology, v. 61, p. 148-151.

Swift, D. J. P., 1976, Coastal sedimentation, *in* Stanley, D. J., and Swift, D. J. P., eds., Marine Sediment Transport and Environmental Management, New York, Wiley, p. 255-310.

Swift, D. J. P., Young, A. Y., Clarke, T. L., Vincent, E. V., and Niedoroda, A. L., B., 1981, Sediment transport in the Middle Atlantic Bight of North America: synopsis of recent observations, *in* Nio, S. D., Shuttenhelm, R. T. E., and van Weering , T. C. E., eds., Holocene Sedimentation in the North Sea Basin, International Association of Sedimentologists.

Swift, D. J. P., Figueiredo JR., A. G., Freeland, G. L., and Oertel, G. F., 1983, Hummocky cross-stratification and mega-ripples: A geological double standard?: Journal of Sedimentary Petrology, v. 53, p. 1295-1317.

Swift, D. J. P., and Nummedal, D., 1986, Hummocky cross stratification, tropical storms, and intense winter storms: Discussion.: Sedimentology, v. 34, p. 338-344.

Tanner, P. W. G., 1998, Interstratal dewatering origin for polygonal patterns of sand-filled cracks: a case study from late Proterozoic metasediments of Islay, Scotland.: *Sedimentology*, v. 45, p. 71-89.

Terwindt, J. H. J., 1981, Origin and sequences of sedimentary structures in inshore mesotidal deposits of the North Sea, *in* S. D. Nio, Shuttenhelm, R. T. E., and Weering, T. C. E. v., eds., Holocene marine sedimentation in the North Sea Basin., Special publication of the international Association of Sedimentologists, p. 4-26.

Trapp, E., Baumann, A., Menning, M., Mezger, K., Wachendorf, H., and Weyer, D., 2001, Kalibration des jungerenn Palaozoikums (Devon, Karbon) auf der grundlage von biostratigraphischen untersuchungen und isotopischen altersbestimmungen.: Evolution des systems erde wahrend des jungeren palaozoikums im spiegel der

sedimentgeochemie.

Tucker, R. D., Bradley, D. C., Ver Straeten, C. A., Harris, A. G., Ebert, J. R., and McCutcheon, S. R., 1998, New U-pb zircon ages and the duration and division of Devonian time: Earth and Planetary Science Letters, v. 158, p. 175-186.

Van der Zwan, C. J., and Walton, H. S., 1980, Aspects of Late Devonian and Early Carboniferous palynology of southern Ireland, Palynology of Devonian-Carboniferous transition sequences with special reference to the Bantry Bay area, County Cork Review of Palaeobotany and Palynology, p. 133-155.

Van Gelder, A., 1974, Sedimentation in the marine margin of the Old Red Continent, South of Cork, Ireland.: Unpub. Phd (unpubl.) thesis, University of Utrecht.

Van Gelder, A., and Clayton, G., 1978, New data on Early Dinantian (Early Carboniferous) stratigraphy and sedimentation in south Cork, Ireland: Geology Mijnbouw, v. 57, p. 25-32.

Veen, V., 1981, Aspects of late Devonian and ealy Carboniferous palynological assemblages at the Devonian Carboniferous Boundary: Rev. Palaeobot. Palynol., v. 34, p. 67-97.

Vermeulen, N. J., Shannon, P. M., Masson, F., and Landes, M., 2000, Wide-angle seismic control on the development of the Munster Basin, SW Ireland, *in* F., F. P., and Williams, B. P. J., eds., New perspectives on the Old Red Sandstone, Geological Society of London Special Publications, p. 223-238.

Viswanathiah, M. N., 1959, Geology and Mineralisation around Allihies-Castletownbere area, County Cork, Ireland.: Unpub. Phd (unpubl.) thesis, University College London.

Wagner, P., 2001 (in press), Palynology at the Devonian/Carboniferous Boundary: Discussion of the sedimentological environmnet at sampled sections in Portugal, Ireland, the USA and Canada: Zeutralblatt fur Geologie uud Palaontologie.

Walsh, P. T., 1968, The Old Red Sandstone west of Killarney, County Kerry, Ireland: Proceedings of the Royal Irish Academy, v. 66B, p. 9-26.

Weimer, R. J., Howard, J. D., and Lindsay, D. R., 1998, Tidal flats and associated tidal channels, *in* Scholle, P. A., and Spearing, D., eds., Sandstone depositional environments, American Association of Petroleum Geologists.

Wiegel, R. L., 1964, Oceanographic Engineering: Eaglewood Cliffs, N.J., Prentice Hall.

Williams, E. A., Bamford, M. L. F., Cooper, M. A., Edwards, H. E., Ford, M., Grant, G. G., MacCarthy, I. A. J., McAfee, A. M., and O'Suillivan, M. J., 1989, Tectonic controls and sedimentary response in the Devonian Carboniferous Munster Basin., *in* Arthurson R. S., G. P. N. S. C., ed., The role of tectonics in Devonian and Carboniferous sedimentation in the British Isles., The Yorkshire Geological Society.

Williams, E. A., Sergeev, S. A., Stossel, I., and Ford, M., 1997, An Eifelian U-Pb zircon date for the Enagh Tuff Bed from the Old Red Sandstone of the Munster Basin in NW Iveragh, SW Ireland.: Journal Geological Society London, v. 154, p. 189-193.

Williams, E. A., Sergeev, S. A., Strossel, I., Ford, M., and Higgs, K. T., 2000, U-Pb zircon geochronology of silicic tuffs and chronostratigraphy of the earliest Old Red Sandstone in the Munster Basin, SW Ireland, *in* F., F. P., and Williams, B. P. J., eds., New perspectives on the Old Red Sandstone, Geological Society of London Special Publications, p. 269-302.

Williams, E. A., 2000, Flexural cantilever models of extensional subsidence in the Munster Basin (SW Ireland) and Old Red Sandstone fluvial dispersal systems, *in* F., F. P., and Williams, B. P. J., eds., New perspectives on the Old Red Sandstone, Geological Society of London Special Publications, p. 239-268.

Wingfield, R. T. R., 1968, The geology of Kenmare and Killarney.: Unpub. Phd (Unpubl.) thesis, University of Dublin.

Winn, R. D., 1990, Storm deposition in marine sand sheets: Wall Creek Member, Frontier Formation, Powder River Basin, Wyoming.: Journal of Sedimentary Petrology, v. 61, p. 86-101.

Witzke, B. J., and Heckel, P. H., 1988, Paleoclimatic indicators and inferred Devonian paleolatitudes of Euramerica, *in* McMillan, N. J., Embry, A. F., and Glass, D. J., eds., Devonian of the world, Canadian Society of Petroleum Geologists., p. 49-63.