IRISH CENTRE FOR RESEARCH IN APPLIED GEOSCIENCES

Detailed characterisation of thin-beds in deep-water settings

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ABSTRACT

Thin-bedded deposits in deep-water settings are rarely investigated and relatively poorly understood, despite comprising a substantial volume of the deepwater sedimentary record, where they are important features of deep-water environments ranging from the basin floor (e.g. channel-lobe transition zone, lobe off-axis and lobe fringes) to the upper slope (e.g. frontal lobes, crevasse/avulsion splays, internal levees, external levees, and channel margins). Units of stacked thin beds are often used to subdivide lobes stratigraphically and to recognise hierarchical stacking arrangements in basin floor settings, whilst channel-related thin-beds record channel evolution from inception (frontal lobes), channel extension and growth (crevasse/avulsion splays, internal levees, terrace deposits, external levees and channel margins) to abandonment (abandonment drapes). Thin-bedded successions can also act important baffles and barriers within some hydrocarbon reservoirs, whilst in others they form the producing reservoir (e.g. Ram/Powell field, Gulf of Mexico). As such, it is likely that they form an important component of the prospective Cretaceous and younger deep-water systems offshore Ireland where channel systems are increasingly imaged in 3D seismic datasets.

The extensive outcrops of the Ross Sandstone and Gull Island Formations of the Clare Basin in combination with a series of behind outcrop boreholes forms a unique dataset with which to examine thin-bedded sediment gravity flows. This project is in its very early stages and aims to develop a core and log based suite of criteria upon which thin-bedded deposits can be characterised and more fully understood.

Sediment Gravity Flows: Processes and Products

Subaqueous sediment gravity flows occur on a spectrum from fully turbulent to fully laminar; this is reflected in their depositional products (Fig. 1). More mixed/composite deposits are termed hybrid event beds, and it has been shown in recent years that these form a significant component of the deep-water depositional system (Fig. 2). The interest here is in thin-bedded hybrid event beds, turbidites and mudstones, and what they can tell us about the environment in which they where deposited (Figs. 2 and 3).

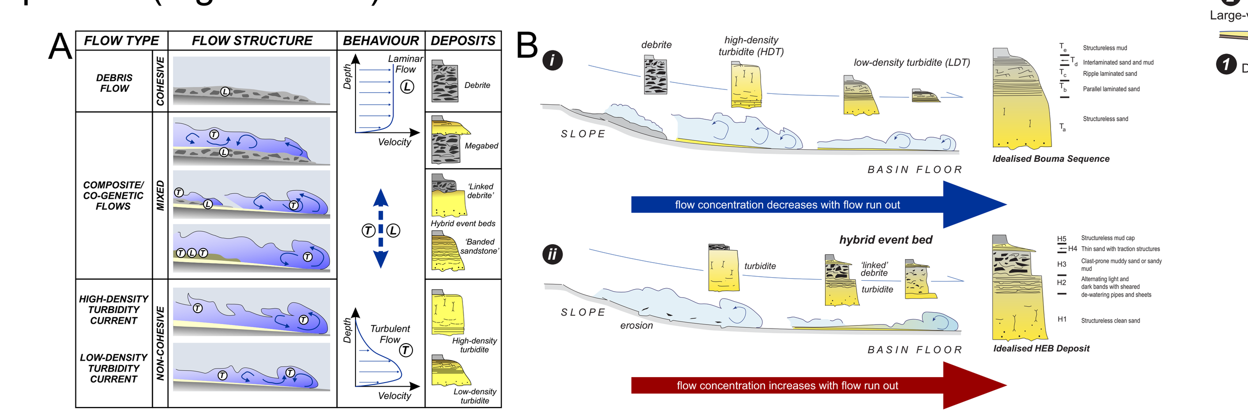


Figure 1. (A) Classification scheme for event beds deposited by subaqueous sediment gravity flows recognising that many of the deposits are composite or transitional in character lying between end-member turbulent and laminar flow states (from Haughton et al., 2009). (B) Schematic figure illustrating the downslope transformation from: (i) cohesive to turbulent flow with increasing flow dilution down-dip due to mixing and loss of sediment to the bed, with an idealised flow facies models showing the classic 'Bouma' sequence (Bouma, 1962) and (ii) down-slope evolution from turbulent via transitional flow to laminar flow as the flow decelerates and clays damp turbulence (modified from Haughton et al., (2009); Pierce et al., [in press]) with an idealised model of a hybrid event bed (HEB) after (Haughton et al., 2009).

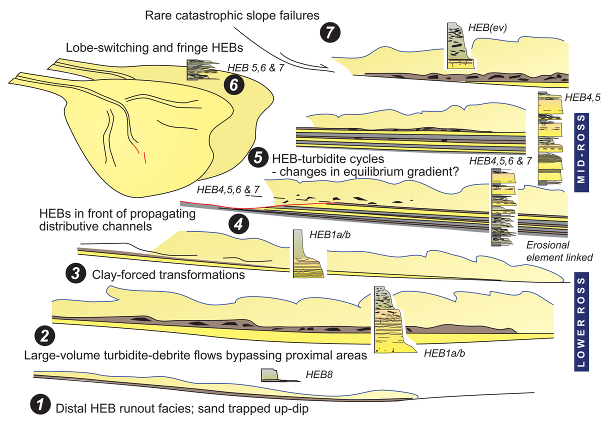


Figure 2. Schematic diagram illustrating seven hybrid event bed generation mechanisms that are inferred to have operated on the Ross Fan System (from Pierce et al., [in press]).

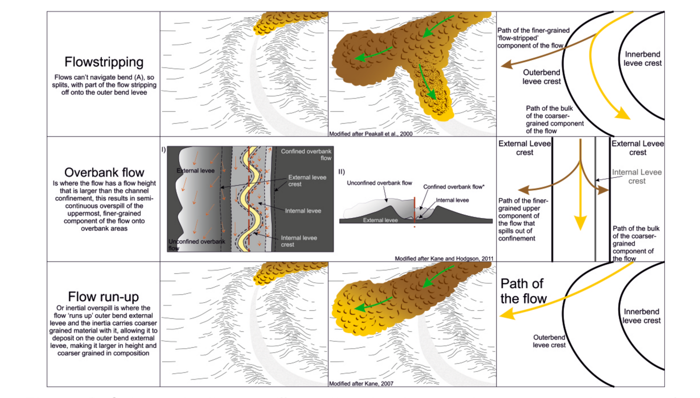


Figure 3. Schematic diagram illustrating the three main processes that control the bulk of deposition of flows onto overbank areas (modified from Peakall et al., 2000; Kane and Hodgson, 2011; Kane, 2007)

Deep-water thin-beds: character, depositional setting and significance

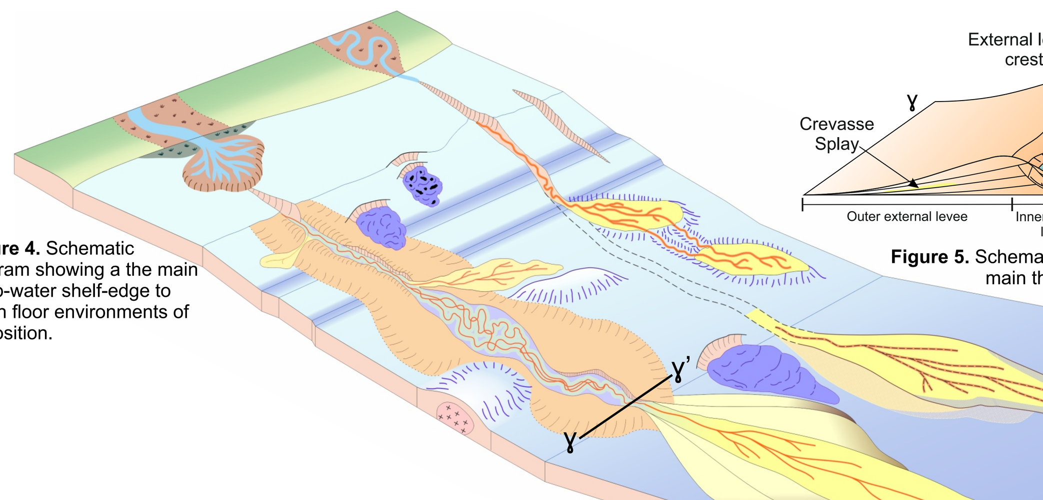


Figure 4. Schematic diagram showing a the main deep-water shelf-edge to basin floor environments of deposition.

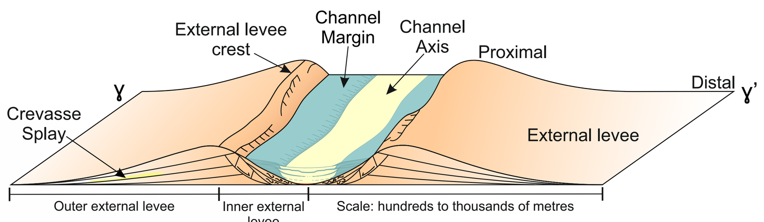


Figure 5. Schematic diagram of a channel-levee system with main thin-bedded sub-environments labelled.

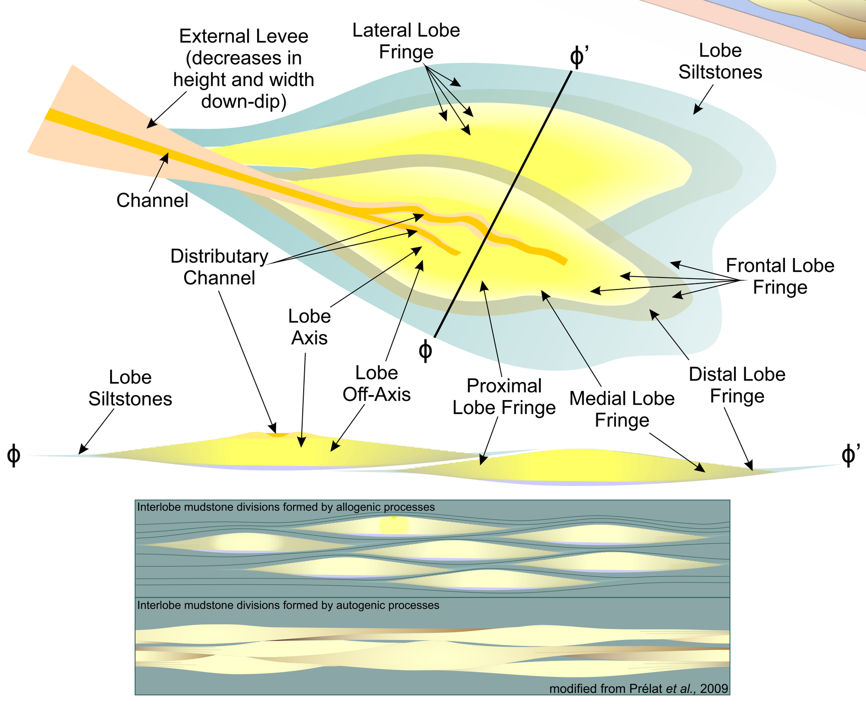


Figure 6. (A) Schematic diagram showing the sub-environments associated with basin-floor terminal lobe deposits in both map view and cross-sectional view. (B) Schematic figure illustrating the difference between mudstone divisions that have been deposited by allogenic versus autogenic processes.

Despite comprising a substantial volume of the deepwater sedimentary record, thin-bedded deposits in deep-water settings are rarely investigated and as such are relatively poorly understood beyond their ability to act as baffles and barriers to flow within turbidite reservoirs. They form important features on the basin floor within the channel-lobe transition zone, distributary channels and their levees, lobe off-axis, frontal and lateral lobe fringes, and distal lobe fringes (Figs. 4, 5 and 6). On the submarine slope, thin-beds form a significant proportion of frontal lobes/splays, crevasse/avulsion splays, internal levees, external levees, terrace deposits and channel margins (Figs. 4 and 5).

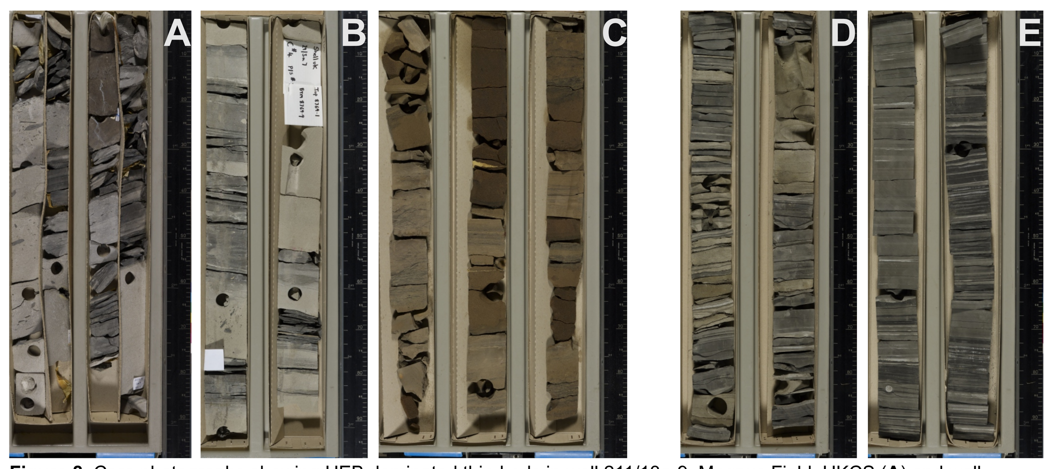
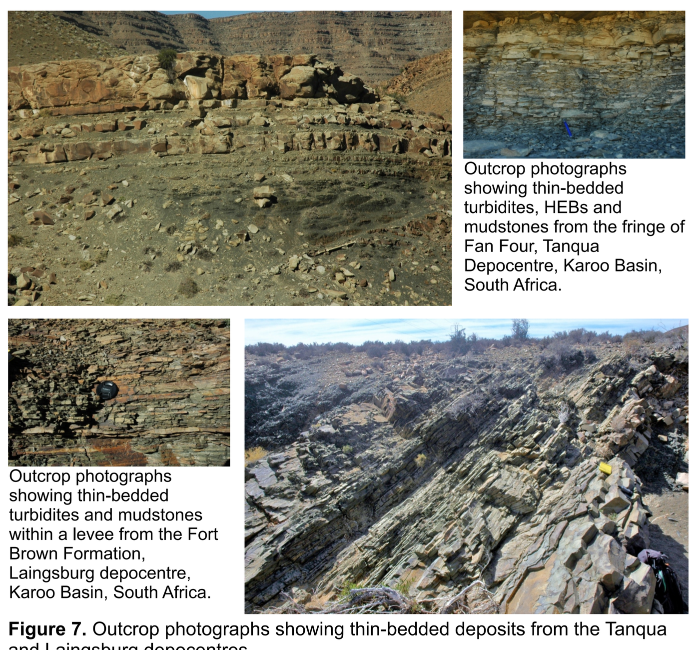


Figure 8. Core photographs showing HEB dominated thin-beds in well 211/13a-9, Magnus Field, UKCS (A) and well 29/03a-7, Forties Field, UKCS (B). The core photos in image (C) are from well 204/25a-2, Schiehallion Field, UKCS, although thicker bedded, the hybrid beds here clearly illustrate the impact that the debrite prone component of the bed has on porosity and permeability as the heavy oil staining prevalent in the clean sandstone does not extend into the debrite component. Core photographs (D) and (E) show thin-beds that are relatively more mud-prone and dominated by LDT, these photographs are from well 20/06a-B11, Buzzard Field, UKCS. Contains British Geological Survey materials ©NERC 2017.

Units of stacked thin beds are often used to subdivide lobes stratigraphically and to recognise hierarchical stacking arrangements in basin floor settings (Fig. 6), as such it is necessary to determine whether or not these deposits represent true stratigraphic divides that can be correlated basin-wide (governed by allogenic processes such as eustasy, tectonic setting and climate change), or if they represent local changes in sediment supply (governed by autogenic intrabasinal processes such as channel migration, avulsion and depositional topography) in which case they represent the distal fringes of laterally offset lobes.



Outcrop photographs showing thin-bedded turbidites, HEBs and mudstones from the fringe of Fan Four, Tanqua Depocentre, Karoo Basin, South Africa.

Outcrop photographs showing thin-bedded turbidites and mudstones within a levee from the Fort Brown Formation, Laingsburg depocentre, Karoo Basin, South Africa.

Figure 7. Outcrop photographs showing thin-bedded deposits from the Tanqua and Laingsburg depocentres.

Deep-water thin-bedded deposits have been observed at outcrop (e.g. Karoo Basin (Fig. 7), Clare Basin), turbidite reservoirs in the North Sea UKCS (e.g. Magnus, Forties, Schiehallion, Buzzard, (Fig. 8)). They are also associated with the Miocene-aged channel-levee systems of the Taranaki Basin, New Zealand (Fig. 9), and are highly likely to form an important component of the palaeogene-aged channel-systems observed within 3D-seismic datasets in the Porcupine Basin (Fig. 10).

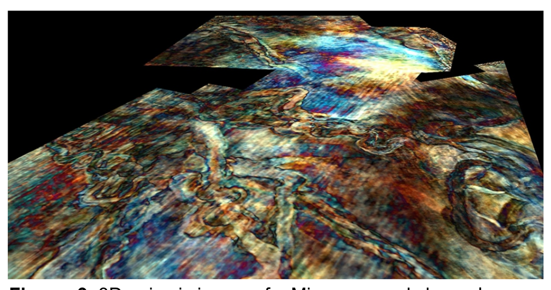


Figure. 9. 3D-seismic image of a Miocene-aged channel system from the Taranaki Basin, New Zealand. Image from the Taranaki MegaSurvey (partnered project between PGS and GNS Science). https://www.pgs.com/campaign/2017/mc-asia-pacific/taranaki-2016webinar-megasurvey/

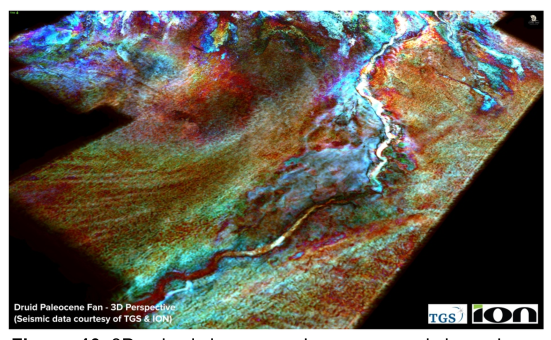


Figure. 10. 3D-seismic image a palaeogene-aged channel system from the Porcupine basin http://www.providenceresources.com/drombeg-and-druid-images

Clare Basin thin-beds: character and depositional setting

Recent work has demonstrated the occurrence of significant thin-bedded and finer-grained successions within the Ross Sandstone and Gull Island Formations of the Clare Basin, a world-renowned Carboniferous (Pennsylvanian)-aged basin floor and slope succession respectively.

Locally, these finer-grained facies subdivide lobe sandbodies or lobe complexes forming either condensed sections or distinctive alternating stacks of thin-bedded hybrid event beds or low-density turbidites that persist laterally for several kilometres. The origin of this distinctive partitioning of bed types is still poorly understood.

Figure 11. Summary geological map of the Loop Head Peninsula area showing the UCD-Statoil behind-outcrop borehole locations

A series of behind outcrop boreholes have been drilled through the Ross Sandstone and Gull Island Formations (see stratigraphy and borehole locations shown on map in fig. 11). These boreholes have been fully cored and logged with a suite of wireline and borehole image logs as part of a research drilling campaign between Statoil and University College Dublin between 2009-2012.

This core and log dataset, in combination with the outcrop exposures (Figs. 12 and 13) on the west coast of County Clare, form a unique dataset with which to examine the thin-bedded sediment gravity flows of the Ross Formation to develop a core and log based suite of criteria upon which thin-bedded deposits can be characterised and more fully understood.

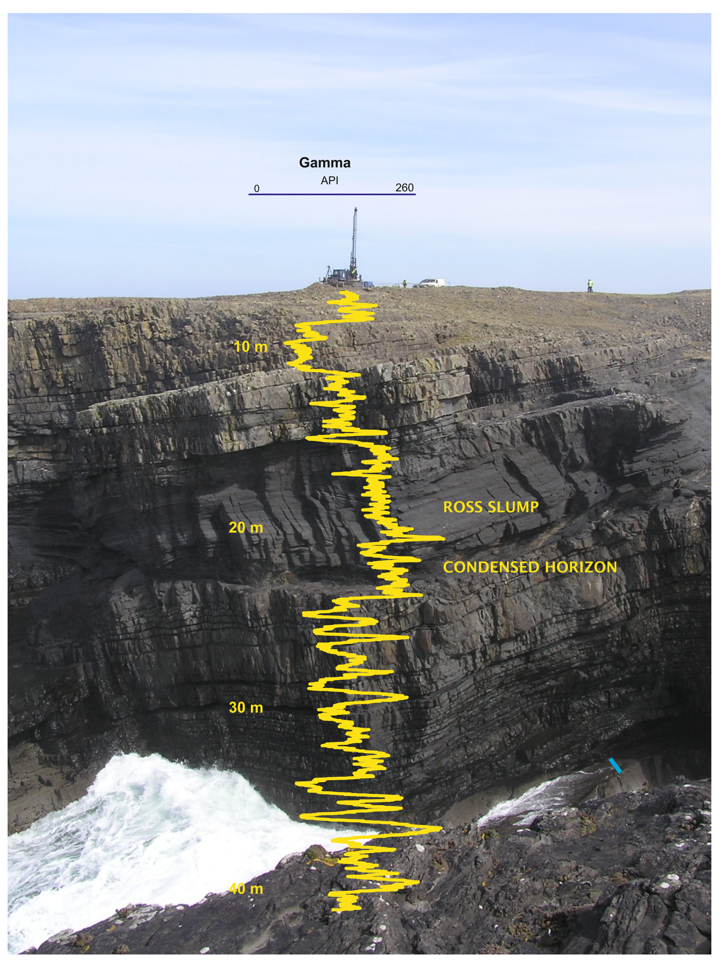


Figure 12. Photograph showing the outcrop expression of the 09-UCD-CE-01 well with the Gamma Ray wireline log superimposed. This borehole location captures the succession outcropping at the Bridges of Ross, Loop Head. This location and borehole captures a variety of different bed types (both turbidites and hybrid event beds), a channel complex and a basal erosion surface, the Ross Slump and a series of sheet sandstones (lobe sandbodies).

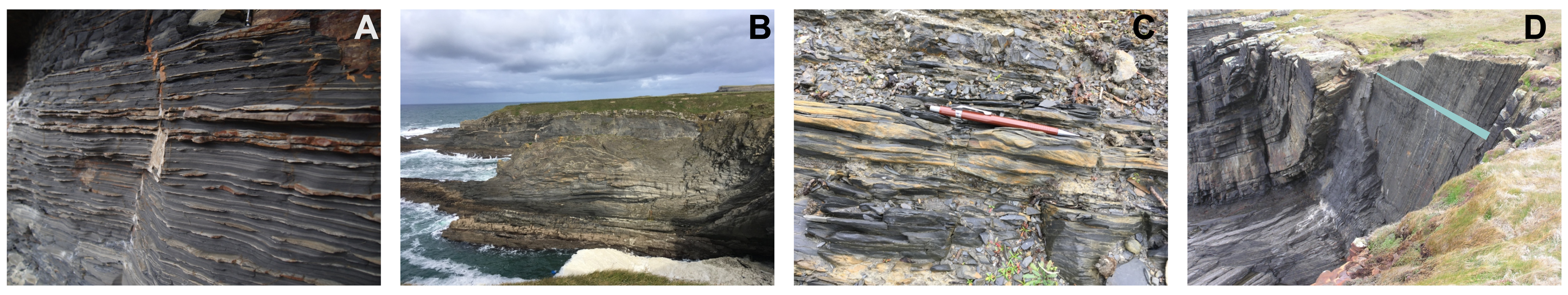
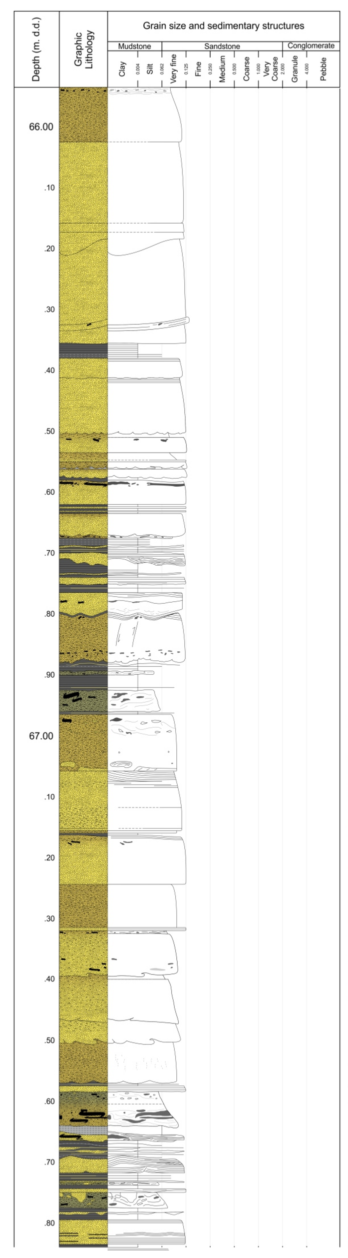


Figure 13. (A) Thin-bedded succession composed of interbedded mudstone and low density turbidites in the Ross Sandstone Formation, Co. Clare; (B) Thin-bedded wedge-shaped package overlying a succession of laterally stepping, dipping sandstones interpreted as laterally migrating channel margins. The channel-margin association suggests that the thin-bedded package could be a levee/overbank succession, in the Gull Island Formation, Co. Clare; (C) Thin-bedded mudstones and ripple sandstone beds within the Gull Island Formation, Co. Clare; and (D) Thin-bed package that displays an overall thinning and fining upwards motif. It can be correlated laterally for ~10km until it pinches out.



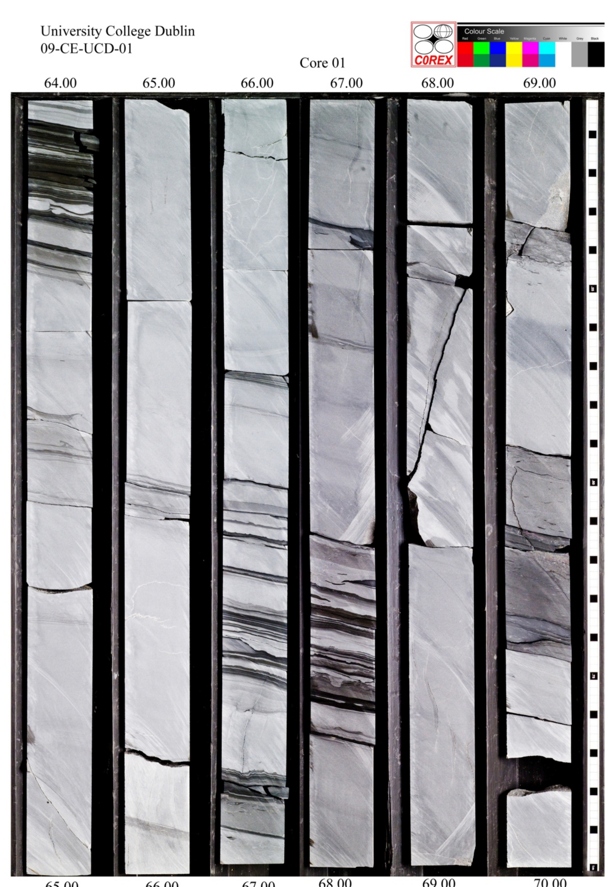


Figure 14. Core log and core photograph of a heterogeneous interval composed of alternating (relatively) thick-bedded sandstone and HEB-dominated thin-beds thought to represent intercalated off-axis lobe and lobe fringe deposits.

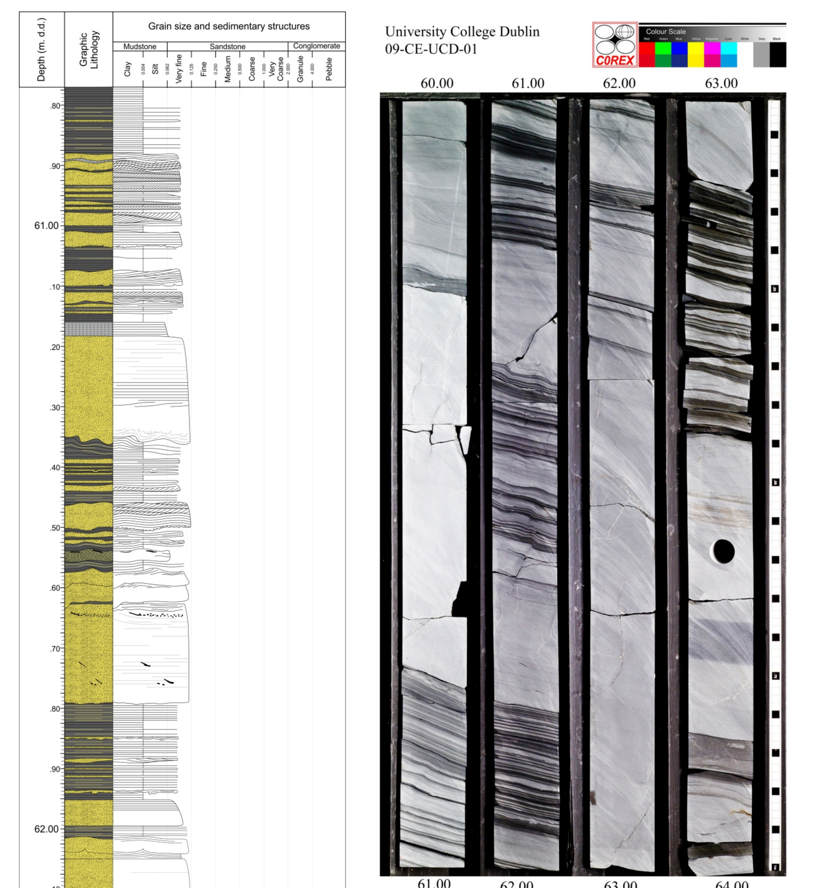


Figure 15. Core logs and core photographs of a heterogeneous interval of intercalated (relatively) thick-bedded sandstone and LDT-dominated, highly structured thin-beds potentially representative of over-spilling flows.

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