Introduction

Deepwater and deltaic sedimentary systems deposited in syn-rift settings form complicated successions that are difficult to predict in the subsurface. Nevertheless, they present significant hydrocarbon discoveries and existing exploration opportunities. A key uncertainty in exploration and development of such systems is the stratigraphic architecture. For example, 83.8% of exploration well failures in UKCS Upper Jurassic late syn-rift turbidite plays were attributed to misunderstood stratigraphic architecture (e.g. reservoir presence, top, bottom and lateral seal presence) rather than source rock maturity or reservoir quality (Mathieu, 2015). Structural variability of syn-rift basins makes predicting stratigraphic architecture particularly challenging (e.g. Gawthorpe et al., 1994, Gawthorpe & Leeder, 2000), which is seldom captured in conceptual depositional models (e.g. Prosser et al., 1993). Exhumed analogue systems can provide supporting information, but deepwater syn-rift studies are rarely well-preserved at outcrop. Here, we integrate conventional and digital outcrop studies with a fully cored research borehole from the Mid-Pleistocene deepwater syn-rift exposures in the Gulf of Corinth, Greece. A multi-scale and multi-disciplinary approach addresses stratigraphic heterogeneity and uncertainties in interpreting sedimentological core in deepwater syn-rift stratigraphy.

The West Xylokastro Fault Block, on the southern margin of the Gulf of Corinth, Greece, is filled by a 0.6-1 km succession of deepwater (~400-600 m) syn-rift stratigraphy fed by Gilbert type deltas (Evrostini/Ilias) positioned at the fault-tip (Rohais et al., 2008, Gobo et al., 2015, Gawthorpe et al., 2017, Rubi et al., 2018; Zhong et al., 2018), and a fault scarp apron system in the hangingwall of the West Xylokastro fault **(figure 1)**.

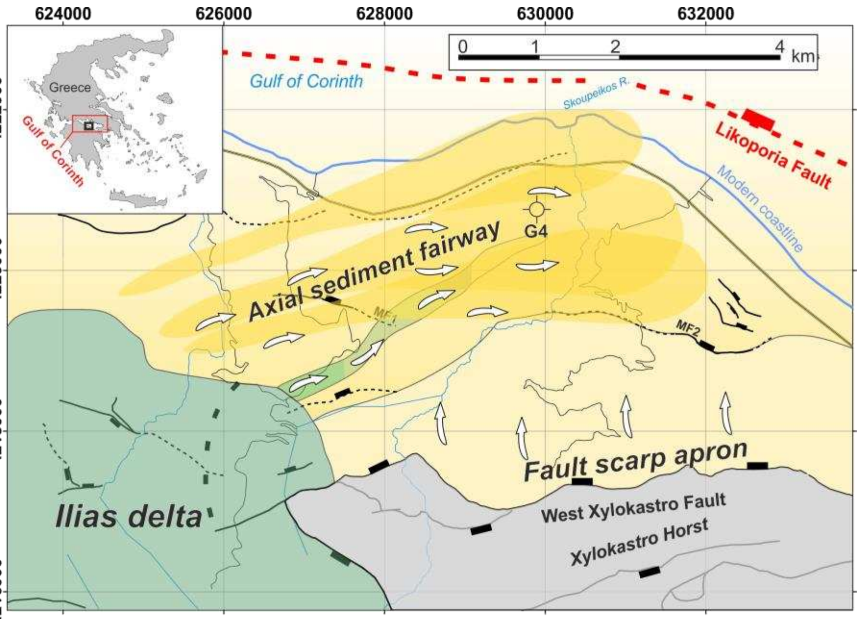

***Figure 1** Summary location map and palaeogeographic cartoon of the study area showing the location of the G4 borehole with relation to the principal structural elements and sediment fairways. Present-day active faults are shown in red. Thin black lines are roads.*

Extensive (200-500m long) cliff exposures highlight the temporal and spatial variability of depositional processes and stratigraphic architecture, which is complicated by the influence of structural evolution, base-level changes and climatic fluctuations. The G4 research borehole **(Figure 1)** retrieved 172 m of continuous core in a relatively distal part of the system (~8 km from the fault-tip Gilbert delta). The borehole intersected a range of gravity current deposits, mass transport complexes and hemipelagic intervals. Integration of UAV (unmanned aerial vehicle) generated digital outcrop models to the cored stratigraphy permits examination of outcrop architectures of channel-fills, sand-rich lobes, mass-transport complexes, and laterally extensive finer-grained intervals, which can be accessed and studied in the field and compared to their core expression. A suite of palynological and palaeomagnetic analysis of the core allows the age and palaeoclimate setting for this syn-rift stratigraphy to be established. This, coupled with correlation to stratigraphy outboard of the borehole, permits investigation into key stratigraphic elements such as finer-grained intervals, and the nature and distribution of coarse grained fairways.

G4 Stratigraphy

The basal part of G4 intersects ~35 m of marly mudstone facies. Core investigation highlights that these comprise thin (1-5cm) beds with basal very fine sands which are often diffuse on account of bioturbation. They are typically poorly sorted, but can show very slight fining or sorting up structures **(Figure 2a)**. We interpret that much of the finer-grained stratigraphy, previously thought to represent largely steady, hemi-pelagic deposition, in fact comprises thin (1-5 cm) turbidites interpreted as lobe fringe deposits. This is overlain by an abrupt transition into pebble and cobble grade conglomeratic stratigraphy (**Figure 2b**). Such conglomerate facies are typically interbedded with decametric thick structureless sands, separated by centimetric heterolithic sand-siltstone couplets (**Figure 2c).** These conglomeratic deposits are highly chaotic in their core expression (often showing poor recovery on account of their loose, coarse grained sandy matrix) and can be tied to laterally extensive conglomeratic sheets interpreted as debrites. These coarse grained sections tend to form ~ 20 – 30 m thick, disorganised "packages" separated by ~10 m thick fine grained successions of facies similar to that intersected in the lower part of the borehole, which are interbedded with thin (< 1m) mud-rich chaotic sections showing significant dip variation, floating clasts, and fluidisation structures interpreted as slumps and debrites. These facies associations form the axial and proximal part of conglomerate rich lobes. Toward the upper part of the borehole, thick (5-20 m), poorly sorted conglomerate sections are interbedded with packages of interbedded fining sands and siltstones occasionally with mud-intraclasts interpreted as a package of sand-rich turbidites and hybrid beds in off axis parts of the aforementioned lobes. These two main facies associations are punctuated by a ~10m thick chaotic deposit showing significant deformation, floating boulder clasts and highly variable lithofacies. Interpreted broadly as a slump deposit **(Figure 3)**, sourced from the fault scarp apron to the south, the expression of this can be highly variable in core and outcrop. Such slumps are frequently interdigitated with those of the axial system.

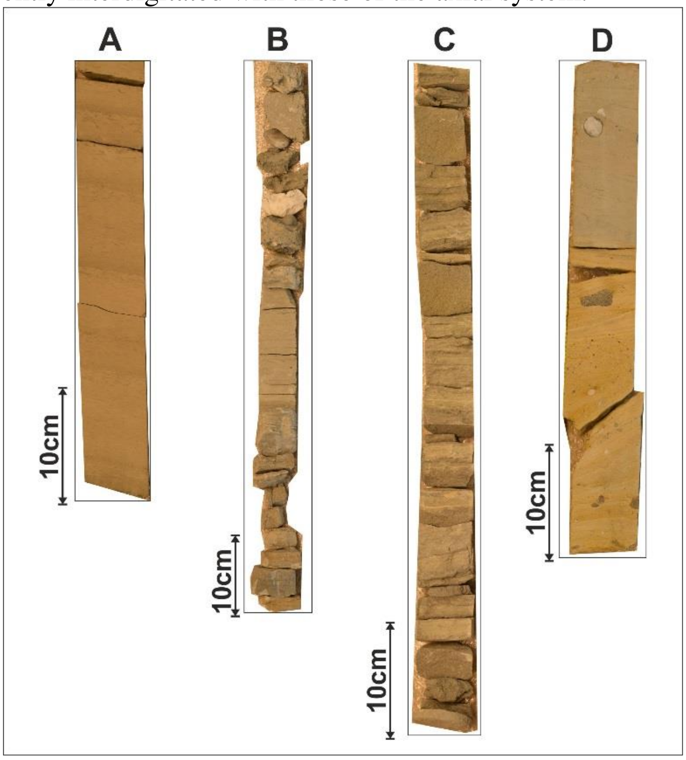

Figure 2 *Example sections of G4 core; a) fine grained "marlstones" comprising mud-rich turbidites, b) conglomeratic and sand-rich facies, poorly preserved on account of loose, sand-rich matrix, c) heterolithic stratigraphy of sand-silt couplets and sand-rich turbidites, d) slumps and debrites.*

Core to outcrop integration

A digital outcrop model for the exposures in a ~4 km^2 area around the well permits the tying of core sections to stratigraphy in cliff exposures (**Figure 3**). The outcrop block contains a broad spectrum of deepwater syn-rift architectures of conglomeratic, sand-rich and heterolithic lobe deposits, extensive slumps/debrites and conglomeratic channel-fills.

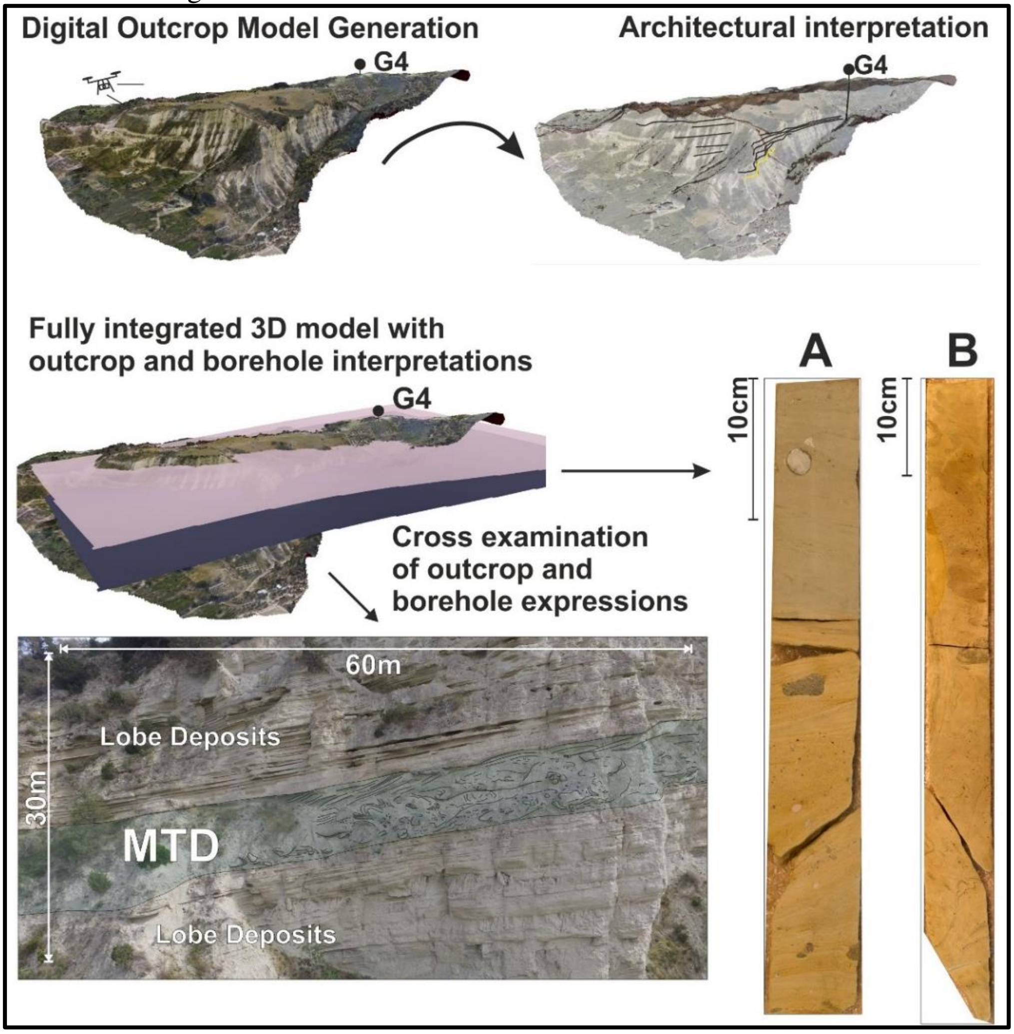

Figure 3 *An integrated 3D model with core, architectural surfaces and geobodies mapped in 3D permitting the outcrop architecture to be tied to the wellbore. A 10 m thick and laterally extensive MTD (mostly comprising slumps) has various expressions in core from gravel and pebbly sand-rich deposits (A) to highly fluidised and deformed mud-rich deposits (B).*

Similar facies in core can tie to remarkably different architectural elements. Conglomerates in the lower section of the G4 stratigraphy correlate to laterally extensive (~ 500 m), conglomerate rich bodies thought to represent the axial and proximal part of coarse grained lobe deposits. These bodies are typically intercalated by sand-rich or heterolithic facies associations and as such represent potentially significant coarse grained accumulations. Conversely, similar conglomerates intersected in upper G4 tie to a spatially restricted set of conglomeratic channel-fills that are interpreted to have been focused into palaeotopographic lows. These channel-fills are interpreted as part of a late-stage regression when the West Xylokastro fault block changed from an area of net-subsidence to net-uplift in the transition from rift-margin to fault-terrace with the growth of a basinward fault (the Likoporia fault, **figure 1**).

Observations in core have greatly enhanced the understanding of finer-grained portions of stratigraphy in the West Xylokastro fault block. Core investigation highlights that these successions are representative of continued sediment delivery (rather than full hiatus) to the basin. Correlation with outcrops show fine grained intervals can be fairly localised (~250 - 500 m^2) or extensive over the entire study area/system (>25 km^2). This continued influx of oxygenated sediment into the deeper basin is interpreted to provide circulation and nutritional replenishment to these areas, as is evidenced by the abundant, although low diversity, bioturbation in the core that presumably prevented the accumulation of significant organic rich deposits. Palynological analysis of the borehole highlights climatic variation, which can be tentatively tied to changes in sediment supply and lacustrine to marine fluctuations.

Conclusions

The West Xylokastro fault block provides a rare example of exposed, deep-water syn-rift stratigraphy on a multi-input fault-terrace. Integration of the G4 research borehole with the exposures provides, for the first time, an age model for the evolution of the West Xylokastro fault block. This allows stratigraphic changes to be placed in the context of allogenic forcing controls (base-level change, climate fluctuations, and structural evolution). The integrated core and outcrop data highlight the short length (and time) scale of stratigraphic variability, which generate new, conceptual models for syn-rift deepwater stratigraphy. The study highlights the need for robust, multi-disciplinary integration of different datasets for reliable interpretation of stratigraphy in such settings. Where these data may be absent, outcrop analogues can aid both qualitative conceptual models, and with the aid of data derived from digital outcrop models, quantitative facies proportions and distributions.

Acknowledgments

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