Along-Strike Prediction of Syn-Rift Fan Delta Architecture
with Field, Subsurface and Numerical Modeling Investigations*

B.J. Barrett¹, D.M. Hodgson¹, R.E.L. Collier¹, R.L. Gawthorpe², R.L. Dorrell³, and T.M. Cullen¹

Abstract

Syn-rift successions are attractive plays in many mature and frontier basins, but the interaction of normal faulting, and along-strike variation in shallow water processes and supply results in complicated depositional architectures that make the subsurface distribution of reservoirs and seals difficult to predict. Here, we integrate field, numerical, and subsurface approaches to address: 1) the along-strike variability and interplay of accommodation and sediment supply, and 2) the quantification of sequence stratigraphic interpretations in syn-rift settings. Field data and UAV photogrammetry-based 3D outcrop models are analysed from two adjacent and contemporaneous, Early-Middle Pleistocene, syn-rift fan-deltas, onshore the Gulf of Corinth, Greece. The deltas are situated 6 km apart in the hangingwall of a single normal fault, with one positioned near the fault centre (Kerinitis) and one near the fault tip (Selinous). By comparing the two systems, we quantify estimates of lake level, subsidence and sedimentation rates. Field data is input into the 3D sequence stratigraphic forward model ‘Syn-Strat’ to assess the impact of along-strike, down-dip and temporal (3D) variation of controls on the nature of stacking and formation of stratal surfaces. Varying the relative magnitude of subsidence to eustasy and different subsidence and sedimentation regimes through time provides the first quantitative insight into how the diachroneity of stratigraphic surfaces changes around a fault block. ‘Syn-Strat’ and a unit thickness extrapolation technique are also used to dissociate base level change from tectonic subsidence in the preserved stratigraphic record and reduce uncertainties in interpretation. Interfan areas, away from sediment sources, are occupied by reworking of marginal deposits and preserve a markedly different depositional architecture to fan axes. The evolution of the Kerinitis-Selinous interfan area reveals stratigraphic response to net subsidence followed by net uplift regimes, because of northward migration of fault activity and death of the normal fault controlling the two deltas. Our quantitative approach to the prediction of syn-rift stacking patterns and time transgressive surfaces is applicable to other rift basins to help reduce uncertainty during reservoir appraisal. Implications for stratigraphic pinchout assessment, connectivity analysis and cross-hole correlations are demonstrated with 3D reflection seismic and well data (North Sea).
1. Rationale

Rift basins are the subject of physical and intellectual exploration, as they host 30% of the largest hydrocarbon accumulations greater than 500x10^12 BBL in the world. The impact of rift-related movement on sedimentary architecture is difficult to distinguish from the influence of other alloogenic controls, such as eustasy and sediment supply. Characterisation of multiple, along-strike spatially-distributed deltas is required, because of marked along-strike changes in depositional architecture. Models that aim to capture alloogenic control interactions recorded in fan delta successions have not considered the stratigraphic archive that forms in interfan areas, yet interfan stratigraphy can provide a complementary record to fan delta axes. Better differentiation of stratigraphic controls would enable quantification and facilitate prediction, which remains challenges in basin analysis to ameliorate.

2. Research questions

- How does the role of along-strike variation in stratigraphic architecture contribute towards deconvolving alloogenic controls in the depositional record?
- What is the value of a quantitative approach to basin analysis?

3. Terminology

Rift basin = sedimentary basins that have formed as a result of lithospheric extension

Sequence stratigraphy = method used for description, interpretation and prediction of strata that relates stratigraphic units, facies and depositional elements in time

Accommodation = space available for deposition; i.e. the measurable space available at any given time for subsequent deposition that results from the combined influence of the preceding base level, tectonic displacement and sedimentation rates during the lifetime of the deltas.

Allogenic controls = 'external' controls acting on the basin including: base level (eustasy), tectonics and sedimentation

...
Along-Strike Prediction of Syn-Rift Fan Delta Architecture with Field, Subsurface and Numerical Modelling Investigations


School of Earth and Environment, University of Leeds, Leeds, LS2 9JT, UK
Department of Earth Sciences, University of Exeter, Exeter, EX4 4PS, UK

Seismic and Environmental Institute, University of Huddersfield, Huddersfield, HD1 3DH, UK
Correspondence: dbhodgson@ex.ac.uk

SEISMIC ANALYSIS

FIELD ANALYSIS
8.1. Quantification of controls

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Seleinus</th>
<th>Keninitis</th>
<th>Uncertainty (1-5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of units</td>
<td>15</td>
<td>11</td>
<td>1</td>
</tr>
<tr>
<td>Thickness of units</td>
<td>25m</td>
<td>60m</td>
<td>1</td>
</tr>
<tr>
<td>Total sedimentary thickness</td>
<td>~400m</td>
<td>~800m</td>
<td>1</td>
</tr>
<tr>
<td>Total subsidence</td>
<td>~400m</td>
<td>~800m</td>
<td>1</td>
</tr>
<tr>
<td>Eustatic base level change</td>
<td>~4kyrs</td>
<td>~4kyrs</td>
<td>1</td>
</tr>
<tr>
<td>Delta build time</td>
<td>~615kyrs</td>
<td>~451kyrs</td>
<td>2</td>
</tr>
<tr>
<td>Subsidence rate</td>
<td>0.65/mkyrs</td>
<td>1.77/mkyrs</td>
<td>2</td>
</tr>
<tr>
<td>Subsidence decay rate along fault</td>
<td>0.19/km</td>
<td>0.19/km</td>
<td>2</td>
</tr>
<tr>
<td>Mag. of base level change each cycle</td>
<td>&lt;25m</td>
<td>10-15m*</td>
<td>2**</td>
</tr>
<tr>
<td>Average sedimentation rate</td>
<td>0.65/mkyrs</td>
<td>1.77/mkyrs</td>
<td>2</td>
</tr>
<tr>
<td>Sedimentation model through time</td>
<td>Increasing</td>
<td>Increasing</td>
<td>4</td>
</tr>
</tbody>
</table>

8.2. Key surfaces in the field

8.2.1. Uncertainty values from 1(low) to 5 (high) assigned to control parameters in Syn-Strat to test the least certain parameters (base level change amplitude).

8.2.2. Independent unit thickness extrapolation technique to validate numerical modelling outputs.

8.3. Numerical modelling inputs

A) Relative base level curve + subsidence + lake level

B) Accumulation curve + lake level - sedimentation

8.4. Numerical modelling results

8.5. Unit thickness extrapolation approach

9.1. Papers contributing to this presentation


9.2. References


9.3. Conclusions

We undertook a quantitative analysis, integrating field, numerical, and subsurface methodologies and used a multi-system, along-strike distributed approach to understand the architecture of the system and test different control scenarios.

We found that a multi-system, along-strike distributed approach is an effective way to quantify allogenic basin controls.

The position of fixed drainage systems on the faulted crest that supply haphazardly fans are critical for the development and distribution of haphazardly fans.

Using field data and UAV photogrammetry-based 3D outcrop models from two adjacent contemporaneous, syn-rift fan deltas (Seleinus, Greece), we demonstrated the first time-true comparison of stratigraphic architecture between along-strike systems in the haphazardly fans, and to include inferential analysis.

Modern structural and stratigraphic analysis of stratigraphic architecture of stratigraphic sequences from three units, and, where possible, the entire sequence, can provide insight into the evolution of the fault system and the basin evolution.

By comparing the two fan deltas with facies and thickness analysis, we quantified the smaller-scale variability of lake-level changes and included accommodation data (Seleinus: ~50%/Kerinitis: ~45%/Kerinitis: ~45%/Kerinitis: ~45%)

The base level change algorithm was validated using an independent unit thickness extrapolation technique.

Thus, with the use of quantitative data, techniques and outcomes, we have reduced uncertainty, improved interpretations and fluidal predictions.