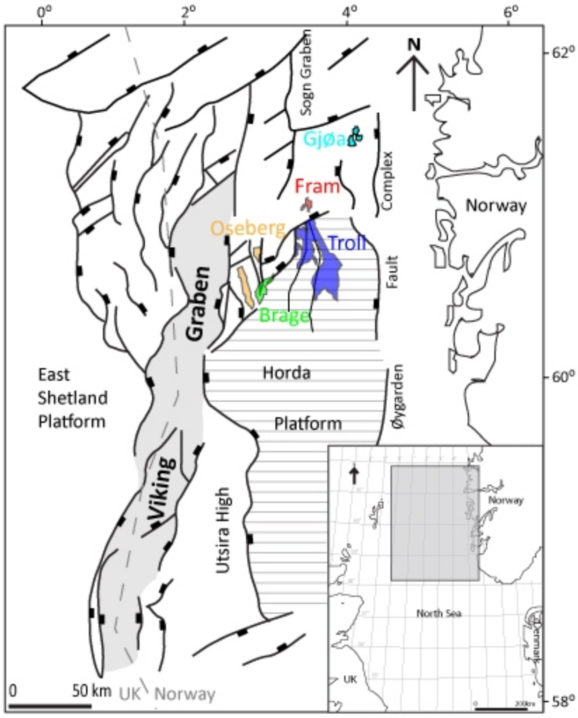
A comparative study of controls on shoreline trajectories in rift-margin and rift-interior shallow marine systems

N.E. Holgate, Dept. Earth Science and Engineering, Imperial College London.
Supervisors: C.A-L. Jackson and G.J. Hampson.

Overall project outline:



The sedimentological character, distribution and stratigraphic architecture of shallow marine deposits are strongly controlled by physical processes at and near the shoreline (e.g. wave- vs. tide- vs. fluvial-dominated). These aspects can be further complicated by the interplay of tectonics in rift basins through fault block rotation, uplift, and subsidence. An example comes from the Middle-to-Upper Jurassic Krossfjord and Fensfjord formations of offshore Norway. These shallow marine sandstone formations are situated below the Draupne Formation and above the Brent Group on the Horda Platform (eastern margin of the Viking Graben, northern North Sea) and overall they thin and pinch out into offshore shales of the Heather Formation towards the graben. Both formations may be classified as 'syn-rift' as they were deposited during the Middle-to-Late Jurassic rift event (Ravnås and Bondevik, 1997). They are poorly understood as they have not been the focus of previous work, but they form a prospective reservoir interval in the area around the existing Troll, Brage and Gjøa fields.

Working with data provided by Statoil ASA, 3D seismic data are being integrated with core, biostratigraphic and wire-line log data from the limited number of wells that penetrate the Krossfjord and Fensfjord formations in order to produce a consistent geological interpretation for the formations. Results from core logging and wireline-log analysis indicate that the Krossfjord and Fensfjord formations represent two prograding sandstone packages punctuated by transgressive marine shales of the Heather Formation. The Krossfjord Formation (~90 m thick) consists of three medium-to-coarse-grained, coarsening-upwards units (~20-30 m each). In contrast, the Fensfjord Formation (~140 m) is overall finer-grained (fine-to-medium-grained). The lower part of the formation consists of three coarsening-upwards units (~30 m), whereas in the upper part an overall fining upwards profile is identified. The facies associations identified in core represent wave- and tide-dominated deltaic, shoreline and shelf depositional environments.

Future work will focus on seismic interpretation away from the sparse well-data control. It is intended that these seismic interpretations will be calibrated by numerical modelling of the seismic expression of stratigraphic architectures observed in outcrop analogues. Once the 3D seismic data volume has been interpreted and calibrated with outcrop-based seismic models, shoreline trajectory analysis will be used to characterise the stratigraphic architecture of these shallow marine deposits and to constrain the volumes of sediment contained within particular stratigraphic packages. Seismic geomorphological analysis (e.g. Posamentier et al., 2007) will be used to interpret shoreline process regime (e.g. relative influence of waves, tides and river-mouth processes) in the context of shoreline trajectories and sediment volumes. Variability in stratigraphic architecture and sediment volumes will be evaluated in different parts of the evolving rift basin, in order to identify local and regional controls.

Overall, this project aims to improve prediction of the location and character of shoreline sandbodies. In applying a quantitative approach to characterising stratigraphic architecture, via 3D seismic imaging of the rock volume, this work will create a methodology which could be applied to other areas to better understand the distribution and character of potentially hydrocarbon-bearing shallow marine reservoir sandstones. The project will: (1) highlight the relationship between shallow-marine sedimentology, sequence stratigraphy and syn-depositional structure in rift basins, and (2) aid the prediction of the character, distribution and connectivity of shallow-marine reservoir sandbodies.

Funding Application:

Introduction This application is for funding to support fieldwork involved in seismic modelling of outcrop analogues, as described in detail below. Shoreline trajectory analysis can help define the gross stratigraphic architecture of the Krossfjord and Fensfjord reservoir sandstones using seismically imaged clinoforms to track the shoreline position through time. However, the limited availability and distribution of core and well-log data restricts the detail and confidence with which these seismically imaged architectures can be interpreted. For example, well data indicate many more lithological breaks with a clinoform set than are imaged in seismic data, which raises a number of questions: (1) what combination of lithological attributes generates a seismic reflection?, (2) how does clinoform spacing interact with seismic resolution to generate a seismically imaged stratigraphic architecture?, and (3) how sensitive are the seismic responses to subtle changes in the geometry and distribution of clinoform surfaces? Forward seismic modelling is a novel method by which petrophysical properties are integrated with an interpreted lithology distribution to describe seismic amplitudes. Seismic modelling of outcrop analogues can therefore bridge the critical gap in both resolution and scale between well data and 3D seismic data. Stratigraphic architectures and lithology distributions observed in outcrop can be combined with subsurface petrophysical properties for different lithologies (e.g. from core measurements, density and velocity logs) to model their seismic response under reservoir conditions. This approach can constrain lithology distributions and reservoir architectures that would otherwise be overlooked or misinterpreted in the subsurface.

Methodology The Krossfjord and Fensfjord formations represent wave- and tide-dominated deltaic, shoreline and shelf depositional environments. Seismic modelling of a range of outcrop analogues to these various shallow-marine depositional environments would allow the sensitivity of modelled seismic response to different lithology distributions and stratigraphic architectures to be evaluated. A wide range of shallow-marine sandbodies containing clinoforms is exposed in outcrops of the US Cretaceous Western Interior in Utah, Colorado and Wyoming: (1) the Ferron Sandstone, a fluvial-dominated delta with ascending regressive shoreline trajectory (Anderson et al., 2004); (2) the Panther Tongue, a fluvial-dominated delta with descending regressive shoreline trajectory (Enge and Howell, 2010); (3) the Chimney Rock Tongue, a mixed wave- and fluvial-dominated delta front with variable shoreline trajectory (Plink-Bjorklund, 2008); (4) the Hygiene Sandstone, a tide-dominated shelf sandstone (Kiteley and Field, 1984), and (5) the Loyd Sandstone, a bioturbated shelf sandstone (Boyles, 1983). Many of these analogues (1-4 above) have been documented in detail by previous workers, such that the supplemental field data needed to constrain the seismic models can be collected quickly and efficiently. The range of depositional environments reflects the uncertainty in the character of the subsurface sandstones and the sensitivity of the modelled seismic expression to various sedimentological and stratigraphic parameters.

Field work on the range of outcrop analogues listed above will quantify the geometry, distribution and lithological character of clinoform-bearing units in order to create a range of detailed Earth models. The data collected will be matched to the observed facies changes in core data from the Troll Field and petrophysical properties from those intervals will be extracted. These data will be imported into the Earth model to create a forward seismic model which will provide calibration of the seismic data from the Troll Field.

Wider Implications As well as addressing the specific issues of reservoir characterisation within the Krossfjord and Fensfjord formations, the methodology that will be developed and implemented in this study has wide applications. Firstly, the method is generic and can be applied to bridge the gap between seismic data and well data, and to enable more robust interpretation of subsurface stratigraphic architectures. The results of the outcrop-analogue seismic model will also be directly applicable to many other shallow marine reservoir sandstones, for which the outcrops described above are considered to be sedimentological analogues.

Funding Breakdown

Funding is sort for a 28 day field season in June 2011 to visit outcrop analogues in Utah, Colorado and Wyoming (USA). For each analogue I will collect the data essential for the modelling aspect of the study. This will include detailed lithological logs and photo montages of outcrops. Photo montages will define the geometries of the models through quantifying clinoform geometry and distribution. I will describe the large-scale stratigraphic architecture of the analogues visited through photo-mosaics, correlation of sedimentary logs and previously published work.

A field assistant will also be required and is shown in the detailed budget below.

Detailed budget:

	Number	**Cost per item(£)**	**Total cost (£)**
Return airfare to Salt Lake City	2 people	500	1000
Vehicle rental	28 days	50	1400
Vehicle fuel	28 days	12	336
Motel	Twin room 28 days	30	840
Food	2 People 28 days	30	840
Total Required			**4416**

My PhD project is self-funded and no money is provided by research councils, oil companies or academic institutions. I am applying for £500 from The Steve Farrell Memorial Fund. I have applied to other institutions which provide grants for field-work to cover the short-fall in funds. These include full grant applications to AAPG Grants-in-Aid for £1890 ($3000), The Geological Society of London for £1000 and The Society for Sedimentary Geology (SEPM) for $500. Any short-fall remaining will come out of my limited personal savings.

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