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Evolution and strike variability of early post-rift deep-marine depositional systems: Lower to Mid-Cretaceous, North Viking Graben, Norwegian North Sea

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ABSTRACT

The controls and development of early-post-rift, deep-water depositional systems are poorly understood due to their commonly deeply-buried nature. As a consequence, in the subsurface there is usually a lack of well penetrations and/or weak seismic imaging. At outcrop, early post-rift strata have commonly been deformed beyond reasonable recognition by later inversion tectonics. In contrast to these systems, the North Viking Graben shows a well-imaged Cretaceous early post-rift package with good well control and little effect from inversion. Therefore, this paper examines the early post-rift, deep-water depositional systems of the North Viking Graben to determine the controls on their stratigraphic position, geometry and evolution, and thus provide an analogue for comparable systems. Greater understanding of such systems will allow for the enhanced prediction of reservoir units in the subsurface and development of new play models since post-rift intervals are generally under-explored.

The basin configuration inherited by the Cretaceous early post-rift in the northern North Sea was set up by Permo-Triassic and Late Jurassic rifting. In the North Viking Graben this established considerable along-strike variability, resulting in a northern basin segment surrounded by steep slopes and faulted-bounded structural highs and a southern basin segment margined by slopes with noticeably gentler gradients. Associated with the Cretaceous post-rift is an overall transgressional trend, which drowned local source areas, resulting in prevalent carbonate and hemipelagic mudstone deposition in the basins. In the North Viking Graben, the uplifted Oseberg fault-block provided the sub-aerial clastic source area until it was submerged in the early Upper Cretaceous.

The early post-rift infill of the North Viking Graben was divided into four key seismic stratigraphic units (K1, K2, K3 and K4) using an integration of seismic and well data. Inside this stratigraphic framework, the depositional systems within each K-unit were resolved from characteristic seismic facies, amplitude anomalies, relationship with adjacent reflections, and geomorphologies. In the northern basin segment, the early post-rift stratigraphy contains basin-floor fans, a channel complex and a shoreline-like geometry, whereas the southern basin segment is solely characterised by hemipelagic and carbonate deposition. This spatial variability indicates that one of the dominant controls on the development of the early post-rift depositional systems in the North Viking Graben was the inherited syn-rift fault-controlled topography. The steep slopes bounding the northern basin segment aided the delivery of sediment from the sub-aerial Oseberg source area to the graben whereas the submerged, gentle slopes in the southern basin segment were relatively sediment-starved.

Long- and short-term changes in relative sea-level also heavily influenced the evolution of the early post-rift basin stratigraphy. Short-term relative sea-level fall allowed basin-floor fan emplacement whereas short-term relative sea-level stand-still favoured deposition of a channel complex. Deposition of the shoreface-like geometry is associated with a short-term relative sea-level rise. This temporal difference in the style and scale of the depositional systems is also interpreted to reflect the gradual denudation and drowning of the Oseberg source area. Regional short-term trangressive and anoxic events in the northern North Sea further influenced the early post-rift strata, resulting in the deposition of stratigraphic units that can be correlated across the North Sea.

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1. Introduction

Early post-rift, deep-marine depositional systems are poorly documented due to the common lack of well penetrations, deeply

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buried nature, and their deformation at outcrop resulting from post-depositional inversion. As a consequence, there is a significant lack of understanding with regard to the controls and development of such systems. In the North Viking Graben, northern North Sea, the Cretaceous post-rift basin only experienced very minor inversion in the Tertiary (Gabrielsen et al., 2001), shows a clearly-defined post-rift package on 3D seismic, and has reasonable well control. It is therefore an ideal candidate to study sedimentary and tectonic evolution in a post-rift basin.

The Cretaceous early post-rift deep-marine depositional systems of the northern North Sea inherited fault-bounded structural highs and deep basins from the Late Jurassic rifting events. In many places, the structural highs developed into local source areas and during periods of relative sea-level fall, clastic sediment was derived from the uplifted footwalls, such as the Oseberg footwall island and the proto-Scottish mainland in the UK sector and the Trøndelag Platform, Måløy Terrace and Halten Terrace in the Norwegian Sea (Fig. 1). Clastic sediments were delivered into the deep-marine basins by way of slumping and mass-flow processes, as commonly recognised on seismic profiles and in core samples (e.g. Shanmugam et al., 1995; Martinsen et al., 2005). Due to the high stand of sea-level that prevailed during the Cretaceous, limited shelfal, shallow marine and coastal systems are preserved in the North Sea (Brekke et al., 2001; Copestake et al., 2003).

Most studies of the North Sea Cretaceous post-rift system overlook the influence of local controls on the development of the deep-marine depositional systems (e.g. Shanmugam et al., 1995; Skibeli et al., 1995; Brekke et al., 1999; Argent et al., 2000; Garrett et al., 2000; Law et al., 2000; Brekke et al., 2001; Bugge et al., 2001; Copestake et al., 2003). Similarly, no detailed seismic stratigraphic analysis of early post-rift base-of-slope to basin-floor depositional systems exists for rift basins. In order to fill this knowledge gap, this paper investigates the evolution of, and documents the local versus regional controls on, early post-rift clastic depositional systems of the Cretaceous within the North Viking Graben. In particular, the seismic facies and seismic geomorphology of the depositional systems are analysed and compared with analogous systems to unravel the controls on their stratigraphic position, geometry and evolution. Since individual depositional systems have rarely been documented within early post-rift, deep-marine strata, this study aims to provide greater insight into a system that is poorly understood, and an excellent analogue for the documentation and interpretation of comparable systems.

2. Regional setting

The North Viking Graben is a major N–S trending, deep-water bathymetric feature in the northern North Sea, located to the northeast of the UK and to the west of the Norwegian coastline (Fig. 1). It is part of the failed trilete rift system that accompanied rifting in the Permo-Triassic and Middle to Upper Jurassic. Permo-Triassic rifting is responsible for the dominant N–S-trending Oseberg fault complex, Brage fault and southern basin segment faults in the study area, whereas the Jurassic events created the deep-water basins and intervening structural highs, including the North Viking Graben (Fig. 1). It has been established that rifting ceased in the northern North Sea during the Volgian (Johnson, 1975; Færseth et al., 1995; Færseth and Ravnås, 1998; Færseth and Lien, 2002; Zachariah et al., 2009). The basin then underwent post-rift thermal subsidence (Badley et al., 1984; Gabrielsen et al., 1990; Prosser, 1993; Nøttvedt et al., 1995; Gabrielsen et al., 2001) and was affected by relative changes in sea-level, in association with the far-reached effects of renewed North Atlantic rifting and the Austrian Orogeny during the Aptian (Skibeli et al., 1995; Brekke et al., 2001; Bugge et al., 2001; Kjennerud et al., 2001; Kyrkjebø et al., 2001; Copestake et al., 2003; Oakman 2005).

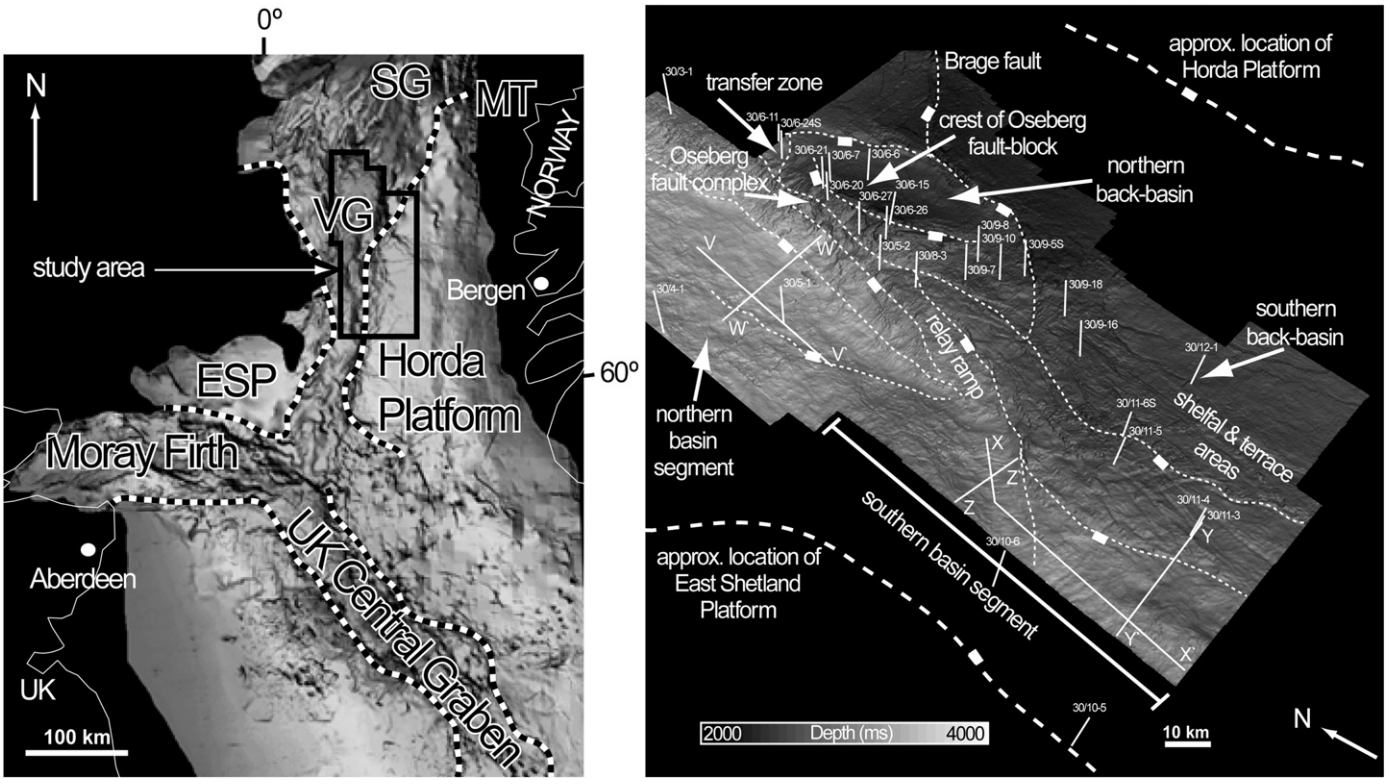

Fig. 1. The black box in the left inset outlines the North Viking Graben study area shown in the right inset. All maps represent the TWTT (ms) present-day Base Cretaceous (BCU) structure map (after Fraser et al., 2002). The thin dashed lines in the right inset represent the major structural trends at BCU level. The seismic sections shown in Figs. 4, 5 and 7 are shown by the solid white V–V', W–W', X–X', Y–Y' and Z–Z' lines. ESP, East Shetland Platform; MT, Måløy, Terrace: SG, Sogn Graben; VG, Viking Graben. All the features highlighted, except for the graben areas, UK and Scotland, represent areas of palaeoshelf during the Cretaceous.

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