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Seismic stratigraphy of the Chalk Group in the Norwegian Central Graben, North Sea

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ABSTRACT

The Late Cretaceous to Early Palaeogene Chalk Group in the Norwegian Central Graben contains prolific hydrocarbon reservoirs that have been producing at high rate for more than forty years. Based on integration of regionally extensive 3D seismic data and numerous wells, this paper describes the seismic development of the Chalk Group with particular focus to the syndepositional geomorphological features produced by the activity of bottom currents and large-scale gravity flows. Using standard seismic stratigraphic interpretation techniques, eight seismic sequence boundaries are identified, which in turn define seven seismic stratigraphic sequences characterized by different seismic facies and well log signatures. The seismic sequences can be grouped into three sequence groups that reflect the general tectono-stratigraphic evolution of the chalk depositional system in the Norwegian Central Graben. During the Late Cretaceous, uplift of the Lindesnes Ridge and the Albuskjell Anticline due to inversion tectonic and halokinesis modified the physiography of the Norwegian Central Graben basin and affected the style of chalk sedimentation by influencing the location and importance of gravity flows. In addition, bottom currents, sea-level fluctuations and environment changes significantly influenced the chalk depositional system creating regional unconformities and influencing the input of terrigenous material in the chalk epeiric sea.

1. Introduction

The Chalk Group (Upper Cretaceous–Lower Paleocene) in the Norwegian Central Graben (Fig. 1) is of major importance as a hydrocarbon reservoir and has been the focus of research for more than 40 years (see Surlyk et al., 2003 for an overview). Chalk is a biogenic sediment primarily deposited from the slow settlement of coccoliths in marine settings, with secondary inputs of foraminifers and calcispheres (Hancock, 1975; Kennedy, 1987a; Surlyk et al., 2003). Gravity-driven resedimentation of previously deposited chalks occasionally occurred in areas that experienced syndepositional tectonic and halokinetic activity (Watts et al., 1980; Hatton, 1986; Kennedy, 1987a,b; Van der Molen et al., 2005). In the last decade, the classical paradigm of chalk as a monotonous and flat-lying deposit has been significantly revised and increasing evidence from seismic data has reveal the role that bottom currents have on chalk deposition. These currents sculpted the chalk seafloor relief creating important topographic features such as channels, drifts and valleys (Lykke-Andersen and Surlyk, 2004; Esmerode et al., 2007, 2008; Surlyk and Lykke-Andersen, 2007; Surlyk et al., 2008; Esmerode and Surlyk, 2009; Gennaro and Wonham, 2013).

In the Norwegian Central Graben, wells penetrating the Chalk Group are mainly located over intrabasinal highs or at graben margins limiting investigation of the successions in the depocentres. Moreover, cores in these wells are limited to the producing reservoir intervals of the Ekofisk and Tor Formation, with only a few wells coring the underlying formations in the Eldfisk and Valhall fields (Figs. 1 and 2). These circumstances have significantly limited the development of a regional understanding of the distribution and interaction of the sedimentary processes operating during the chalk deposition and the controls of depositional sequence development. The application of seismic stratigraphy principles and seismic facies analysis of 3D seismic data calibrated to the Norwegian Central Graben chalk successions core and wells allows the regional seismic stratigraphy of the chalk successions to be established (see Mitchum et al., 1977; Fontaine et al., 1987; Brown, 1991; Macurda, 1997). As a result, this study provides, for the first time, regional maps of seismic facies that document the spatial and

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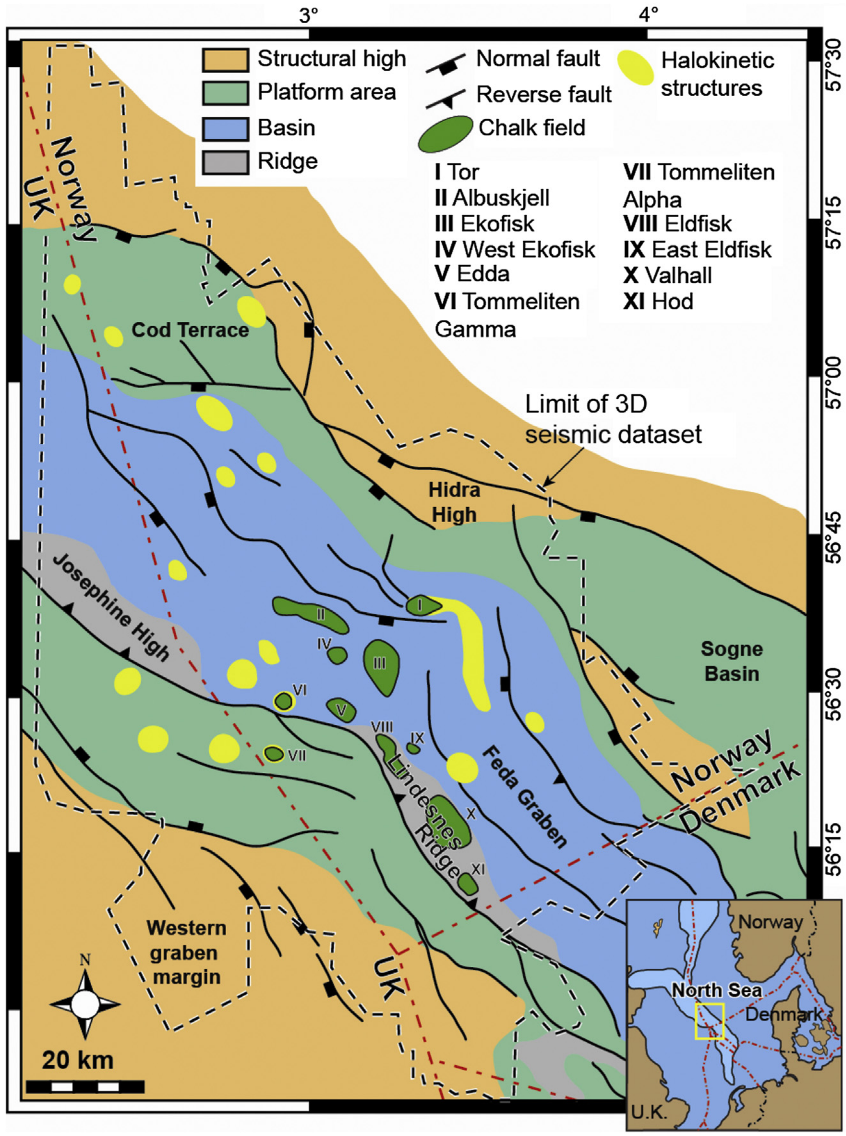

Figure 1. Structural map of the Norwegian Central Graben. The study area coincides with the limit of the 3D seismic dataset outlined by the black dashed line. The figure also illustrates the dominant structural and halokinetic features that were active during the Late Cretaceous and the relative position of the chalk fields (after Ziegler, 1990; Gowers et al., 1993; Knott et al., 1993; Bailey et al., 1999). Position of the study area relative to the North Sea is shown in the inset map in the bottom right corner.

temporal evolution of the chalk depositional system in both basinal and shelfal settings. In addition, seismic evidence of syndepositional geomorphological features produced by contour-parallel bottom currents, large-scale gravity flows and syndepositional tectonic activity confirm, together with other recent studies of chalk successions, that the chalk depositional system was highly dynamic and subject to both alongslope and downslope depositional processes.

2. Geological setting and stratigraphy

During the Late Cretaceous, one of the major sea-level rises of the Phanerozoic established a large epeiric sea over most of NW Europe that was characterized by oligotrophic waters and normal salinity (Håkansson et al., 1974; Hancock and Kauffman, 1979; Hancock and Rawson, 1992). These conditions permitted coccolithophores to flourish so that coccoliths, the calcareous tests of these algae, were deposited from suspension in the water column and resulted in accumulation of thick chalk successions (>1 km thick) over the region (Hancock, 1975; Surlyk et al., 2003).

The formal stratigraphic nomenclature for the Chalk Group in the study area was published by Deegan and Scull (1977). However, the present study follows the stratigraphic subdivisions of Bailey et al. (1999) and Bramwell et al. (1999), which are based on more recent seismic and well data (Fig. 2). These subdivisions are correlated to a series of tectonic phases identified by the present study in the Late Cretaceous successions of the study area.

In the Norwegian Central Graben, Late Cretaceous regional NNE–SSW-directed compression, coupled with movements of the Zechstein salt, inverted Late Jurassic normal faults generating inversion anticlines and intrabasinal highs such as the Lindesnes Ridge (Figs. 1 and 3) (Oakman and Partington, 1998; Cartwright, 1989; Bramwell et al., 1999; Farmer and Barkved, 1999; Vejbæk and Andersen, 2002). This ridge developed along the inverted Skrubbe Fault and is limited to the east by the Omega Subbasin and to the west by the Feda Graben (Fig. 3). The regions to the north, northeast and northwest of the Lindesnes Ridge are