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Research paper

# The role played by carbonate cementation in controlling reservoir quality of the Triassic Skagerrak Formation, Norway

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ABSTRACT

Anomalously high porosities up to 30% at burial depth of >3000 m along with varying amounts and types of carbonate cements occur in the fluvial channel sandstone facies of the Triassic Skagerrak Formation, Central Graben, Norway. However, porosities of the Skagerrak Formation are lower in the Norwegian sector than in the UK sector. In this study, petrographic analysis, core examination, scanning electron microscopy, elemental mapping, carbon and oxygen isotope, fluid inclusion and microgeometry analysis are performed to determine the diagenesis and direct influence on reservoir quality, with particular focus on the role played by carbonate cementation. The sandstones are mainly fine-grained lithic-arkosic to sub-arkosic arenites and display a wide range of intergranular volumes (2.3%–43.7% with an average of 23.6%). Porosity loss is mainly due to compaction (av. 26.6%) with minor contribution from cementation (av. 12.1%). The carbonate cements are patchy in distribution (from trace to 20.7%) and appear as various types e.g. calcretes (i.e. calcareous concreted gravels), poikilitic sparite and sparry ferroan dolomite, and euhedral or/and aggregated ankerite/ferroan dolomite crystals. This study highlights the association of carbonate precipitation with the remobilisation of carbonate from intra-Skagerrak calcretes during early burial stage i.e. <500 m. During deeper burial, compaction is inhibited by carbonate cements, resulting high intergranular volume of up to 32% and 29% for fine- and medium-grained sandstones, respectively. Carbonate cement dissolution probably results from both meteoric water flow with $CO_2$ during shallow burial, and organic $CO_2$ and carboxylic acid during deep burial. The maximum intergranular volume enhanced by dissolution of early carbonate cements is calculated to 8% and 5% for fine- and medium-grained sandstones, respectively. Compaction continues to exert influence after dissolution of carbonate cements, which results in a loss of ~6% intergranular volume for fine- and medium-grained sandstones. Reservoir quality of the Norwegian sector is poorer than that of the UK sector due to a lower coverage of clay mineral coats e.g. chlorite, later and deeper onset of pore fluid overpressure, lower solubility of carbonate compared to halite, and a higher matrix content.



## 1. Introduction

Carbonate cements are a common authigenic mineral in many sandstones, and thus an understanding of the role played by carbonate is vital for reservoir evaluation. They have been the subject of research for decades mainly focusing on formation mechanisms (e.g. Asquith, 1979; Chowdhury and Noble, 1996; Dutton and Flanders, 2004; Irwin et al., 1977; Purvis and Wright, 1991; Salomons et al., 1978) and more recently effects on reservoir quality (e.g. Cui et al., 2017; Dutton, 2008; Taylor, 1990; Wang et al., 2016; Xiong et al., 2016). Early-precipitation of pore-filling carbonates could increase the pressure-resistance of reservoir sandstones and provide a chance for subsequent dissolution (Chi et al., 2003; Morad et al., 2010), whereas late-precipitation of carbonate cements filling residual pores could reduce the final porosity. Therefore, the timing of precipitation, dissolution and distribution of carbonate cements exert significant effect on reservoir quality.

Carbonate cements occur with various types and a wide range of content in the Skagerrak Formation in the Central Graben (UK and

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Norwegian sectors) along with exceptional porosities up to 30% at burial depth of >3000 m. It merits attention that porosities are significantly higher in the UK sector than in the Norwegian sector. Previous studies attribute the exceptional reservoir porosities to chlorite coats (Stricker et al., 2016a, 2016b; Taylor et al., 2015), overpressure (Grant et al., 2014; Nguyen et al., 2013; Stricker et al., 2016a, 2016b), halite dissolution (Nguyen et al., 2013) and limiting time for quartz cement due to rapid burial (Maast, 2016). However, the occurrence of various carbonate cements within fluvial channel facies has been neglected.

This paper aims to highlight the role that carbonate cements play in reservoir quality of the Triassic Skagerrak Formation in the Norwegian sector. A multidisciplinary approach has been undertaken to identify why anomalously high porosities occur in the Norwegian sector but they are still lower than porosities from the same fluvial sandstone reservoirs in the UK sector.

## 2. Geological setting

The Central Graben of the North Sea is approximately 550 km long with a width of 70–130 km. The Central Graben is the southern arm in an incipient ridge-ridge triple junction in the North Sea, with the Viking Graben as the northern arm and the Moray Firth Basin as the western arm. The Central Graben is divided into the East and West Central Graben by Josephine High and Forties-Montrose High and separates the Norway continental shelf from United Kingdom continental shelf (Fig. 1). At least two major rifting phases in the complex rift system, one in the Permian-Triassic (290-210 Ma) and a second in the Late Jurassic (155-140 Ma), have influenced the evolution of Central Graben (Glennie, 2009; Gowers and Sæbøe, 1985). The geological history of Central Graben has been commonly divided into prerifting, synrifting, and postrifting phases (Clark et al., 1999). Synrifting sediments are dominated by siliciclastic Triassic and Jurassic sediments up to 2000 m in thickness. The postrifting sediments from the Cretaceous to the Holocene are mainly siliciclastic rocks of approximately 4500 m in thickness. The siliciclastic postrifting sediments are dominated by shale, sandstone, silty sandstone, and a thick chalk succession (Goldsmith et al., 2003). This study focuses on the East Central Graben on the Norway continental shelf, including samples from the Cod field (well 7/11-7R), Ula field (well 7/12-6), Gaupe field (well 6/3-1) as well as other 8 further wells (Fig. 1). The sandstones of the Skagerrak Formation in the Norwegian East Central Graben commonly have a patchy distribution of carbonate cements and provide a good opportunity to study the role of carbonate cements in reservoir quality.

### 2.1. Skagerrak stratigraphy

The Triassic strata of the Central North Sea area were deposited in a closed or internally draining basin with no marine influence (Goldsmith et al., 2003). The stratigraphy of the Triassic in the area

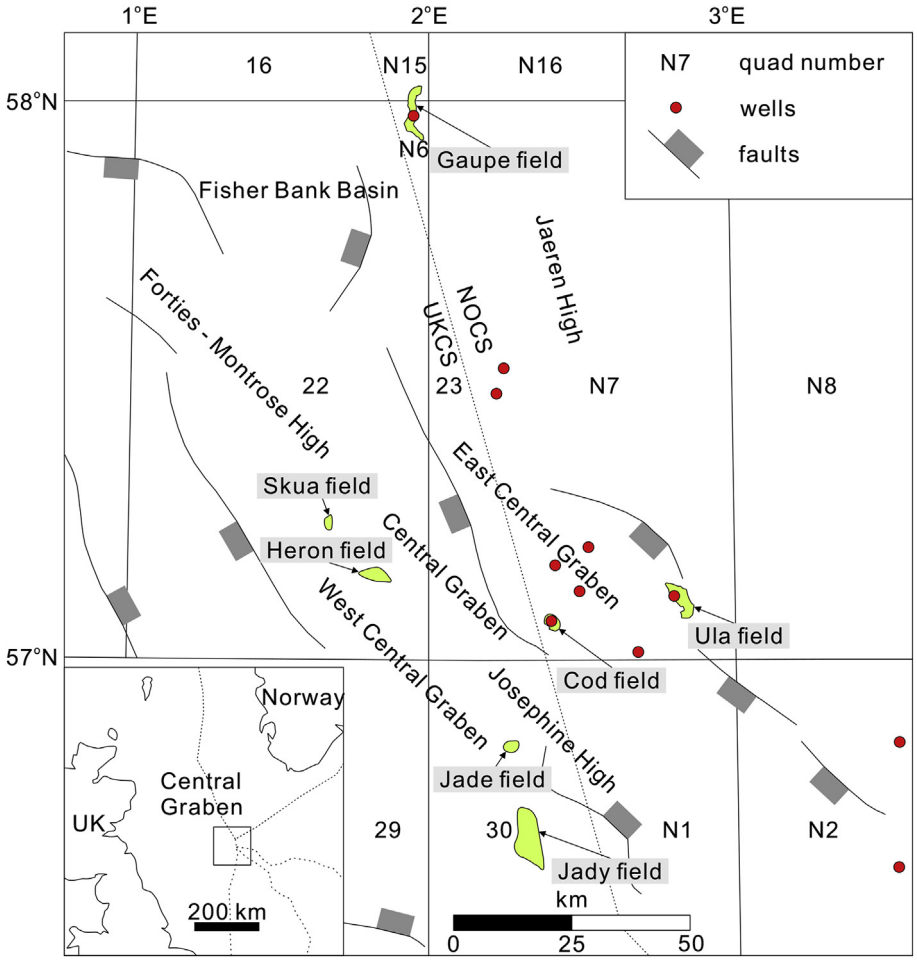


**Fig. 1.** Location map of the central North Sea showing wells and fields referred in this study. The UK continental shelf (UKCS) and the Norway continental shelf (NOCS) boundaries are shown for reference.