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Chemostratigraphy of upper Jurassic reservoir sandstones, Danish Central Graben, North Sea

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ABSTRACT

A chemostratigraphic study of Upper Jurassic sandstones in the northern Danish Central Graben has been undertaken within the framework of a well-defined stratigraphic/sedimentological model based particularly on cored well sections. Two reservoir sandstone units are recognised, the transgressive marginal marine to shoreface sandstone of the Gert Member and the regressive to transgressive shoreface sandstone of the Ravn Member. Both members belong to the Heno Formation, which is equivalent to the Fulmar Formation (UK) and the Ula Formation (Norway).

Multivariate analysis of geochemical data from 264 core samples from 8 wells reveals the distinction between the two reservoir sandstones (Gert and Ravn members) and the two offshore claystones (Farsund and Lola formations). Specific elements have proven to be important for this separation and these elements demonstrate differences even in 2-dimensional cross plots. The Farsund Formation is characterised by higher V, U and P_2O_5, and lower MgO and K_2O when compared with the Lola Formation. The Gert Member typically has higher maximum amounts of Cr and TiO_2 than the Ravn Member. The high Cr and TiO_2 content (probably from chrome spinel and Ti-minerals) might be related to a source of exposed Carboniferous sediments in the Gert Ridge area. The Ravn Member is characterised by higher Na_2O, P_2O_5 and Th contents than the Gert Member, which may reflect a higher content of plagioclase (Na_2O) and a changed heavy mineral assemblage. The Mid North Sea High is a likely source for the heavy mineral suite that characterises the Ravn Member. The Rita-1 well, situated closest to the Mid North Sea High, seems to have been more influenced by this source than the other wells. In the Hejre area, a volcanic source supplying K-feldspar may be responsible for the relatively high K_2O/Al_2O_3 observed in both the Gert and Ravn members. Hence in addition to differentiation between the two reservoir sands and between the two offshore claystones, this study also illustrates the use of geochemical data for evaluation of source characteristics and dominance of different sediment source areas.

1. Introduction

Chemostratigraphy is increasingly utilised as a substitute for biostratigraphy in barren sequences or as a supplementary technique to improve stratigraphic resolution (Ehrenberg and Siring, 1992; Pearce et al., 1999; Preston et al., 1998; Ratcliffe et al., 2004). The main purpose of chemostratigraphy is typically to facilitate correlation between members and formations, in addition to subdivision of units. Of equal importance, however, is the contribution that geochemical data can make to the understanding of the sediment source areas supplying the sedimentary basin of interest. The relation between bulk-rock geochemistry and specific minerals in a well-defined sediment source area is one way to investigate the provenance. Heavy minerals, in particular, are sensitive indicators of sediment provenance, sediment-transport history and post-depositional alteration (Morton and Hallsworth, 1999). The original provenance signature may be overprinted, for example due to sorting, controlled by the nature of the transport media and hydrodynamics, together with weathering during temporary deposition and after final deposition and diagenesis (Morton and Hallsworth, 1999). Hence elements associated with stable heavy minerals and immobile elements are preferably used in investigating reservoir-scale inter-well correlation and for sediment source evaluation (see Preston et al., 1998; Friis et al., 2007).

Identification of source areas contributes to an improved understanding of the depositional history of the sedimentary basin; knowledge of transport routes may result in identification of unrecognised depocentres and thus may eventually lead to discovery of new reservoir sandstones.

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Despite detailed investigations of the Danish Jurassic sediments (e.g. Damtoft et al., 1992; Michelsen et al., 1992; Johannessen and Andsbjerg, 1993; Rasmussen, 1995; Johannessen et al., 1996; Andsbjerg, 2003; Andsbjerg and Dybkjær, 2003; Johannessen, 2003; Michelsen et al., 2003; Surlyk and Ineson, 2003) chemostratigraphic studies have not previously been published on these strata. As the deeply buried marginal to shallow marine reservoir sandstones are characterised by a very low content of identifiable stratigraphically useful microfossils, the potential of non-biostratigraphical methods is clear. In most cases, samples from the Gert and Ravn members of the Heno Formation, cannot be distinguished biostratigraphically.

In this chemostratigraphic study, an independent non-biostratigraphic method is used in a known area with an existing well-defined sedimentological and stratigraphical model. It is shown that the two reservoir sandstone members of the Heno Formation, the Gert and Ravn members, can be geochemically distinguished from each other. This is of particular importance in areas with poor biostratigraphical resolution. In addition, the two offshore claystone units, the Lola and Farsund formations, are geochemically significantly different from each other. This could be of major importance when tracing the boundary between the claystones in an attempt to find levels of possible turbidite sands. Furthermore, the data set shows some distinct relationships between geochemical composition and local sediment source areas.

2. Geological setting

2.1. Structural elements

The Danish Central Graben is bounded to the east by the Ringkøbing–Fyn High and to the west by the Mid North Sea High (Fig. 1). During the Early and most of the Late Kimmeridgian, the Mid North Sea High extended eastwards as far as the eastern margins of the Inge and Mads highs (Johannessen, 2003). During the late Late Kimmeridgian and the Volgian, the westernmost part of the Danish Central Graben subsided, resulting in the creation of the Ål and Outer Rough basins whilst the Inge and Mads highs and the Gert Ridge area became intra-basinal highs. The Mandal High in the northeastern part of the Danish Central Graben was an intra-basinal high during the Early and most of the Late Kimmeridgian.

The Heno Plateau lies between the Inge and Mads highs and the Tail End Graben. The Gertrud Plateau is situated between the Heno Plateau and the Mandal High. During the late Late Kimmeridgian and the Volgian, the Gertrud Plateau began to subside and became the Gertrud Graben. The Feda Graben lies between the Inge High,

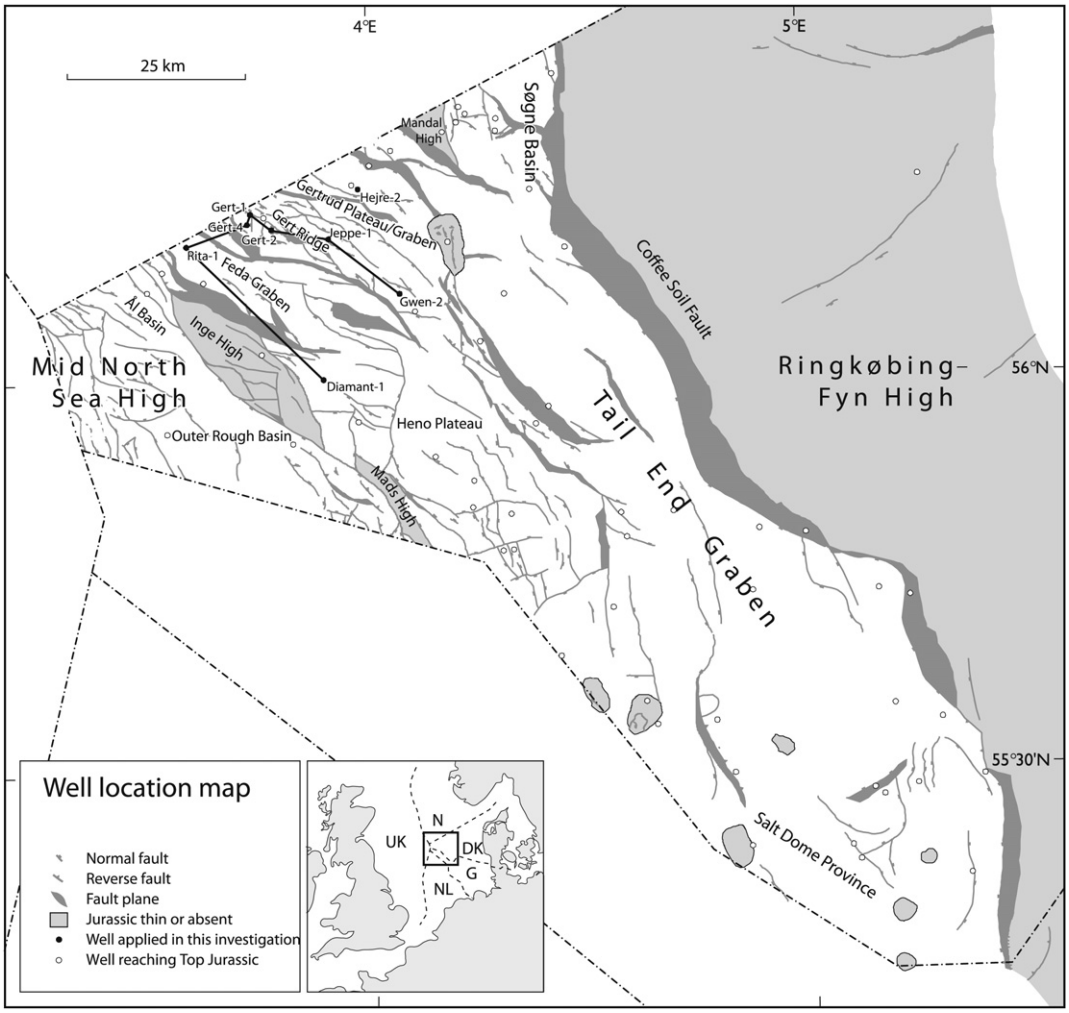

Fig. 1. Structural map of the Danish Central Graben area. Wells reaching the Jurassic in the Danish sector of the North Sea are indicated with open circles. Wells used for this investigation are marked with filled circles and names. Location of the log panel shown in Fig. 4 is indicated. Modified after Japsen et al. (2003).