Marine and Petroleum Geology 98 (2018) 335–355

Contents lists available at ScienceDirect

Marine and Petroleum Geology

journal homepage: www.elsevier.com/locate/marpetgeo

Research paper

A diagenetic study of intrabasaltic siliciclastics sandstones from the Rosebank field

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ARTICLE INFO

Keywords:
Rosebank field
Intrabasaltic reservoir
Diagenesis

ABSTRACT

The Rosebank field contains producible hydrocarbons from Paleocene-Eocene intrabasaltic fluvial and shallow marine siliciclastic sandstone reservoirs. Despite close proximity to volcanic lithologies the siliciclastic sandstones display very good reservoirs properties with permeability in the Darcy range and porosity values ranging from 19 to 23%. Preservation of high quality reservoir properties is the result of low quantities of volcanic minerals in the siliciclastic sandstones and limited element diffusion (e.g. Fe and Mg) from adjacent basalts into siliciclastic reservoir sandstones. The low content of volcanic derived detritus is most likely a result of the main sediment source being situated outside the volcanic terrain. The effect is that formation of clay minerals (smectites and or chlorites) reducing permeability and porosity is low. In contrast to the siliciclastic sandstones, the pore space of the volcaniclastics is occupied by authigenic clays (chlorite/smectite) and carbonates (calcite and Mg-calcite) resulting in poor reservoir quality. This paper demonstrates that high quality reservoirs can be found in intrabasaltic siliciclastic reservoirs.

In-depth analyses of core samples show that authigenic phases formed during progressive burial with temperatures up to ~120 °C. The suite of diagenetic phases in siliciclastic sandstones between wells and the different Colsay units vary and are interpreted to result from differences in pore water chemistry and/or detrital mineralogy. Laumontite was formed as a late stage authigenic mineral restricted to cored Colsay 1 and 3 units in well 213/26-1z and has not been observed in the neighbouring 213/27-2 core, which may be explained by differences in pore water pH or CO_2 partial pressure. The occurrence of laumontite is often associated with poor reservoir quality, but due to the patchy distribution of this mineral in the Rosebank reservoir sands it appears not to have affected reservoir quality.

1. Introduction

The Rosebank field is located on the Corona Ridge in the Faroe-Shetland Basin (FSB) approximately 130 km from the Shetland Islands (Fig. 1) at water depths of roughly 1110 m. As of 2018 the Rosebank field is operated by Chevron North Sea Limited (40%) with Suncor Energy (30%), Siccar Point Energy (20%) and INEOS (10%) as coventures.

The successful drilling of the Rosebank prospect in 2004 (Duncan et al., 2009) proved a new play concept in the region with producible hydrocarbons from intra basaltic siliciclastic reservoirs in the Colsay Member of the Flett Fm. (Figs. 1 and 2). Understanding the impact of volcanics on reservoir properties is an important consideration. In areas such as the Mangala field (Rajasthan India) (Compton, 2009), increased content of volcanic detritus has been associated with reduced reservoir quality. Similar effects have been observed in Rosebank analogue studies of the Kangerlussuaq Basin in the southern East Greenland (Larsen et al., 2016). The reduced reservoir quality is due to the unstable nature of volcanic material providing a source for elements necessary for diagenetic formation of secondary clay minerals. This in turn effectively reduces permeability and porosity (Ólavsdóttir et al., 2015; Larsen et al., 2016).

This study builds upon the work done by Clark (2014), with an in-depth analysis of the diagenesis of the siliciclastic reservoir sandstones on Rosebank. The purpose of the present paper is to study the diagenetic system in the intra basaltic siliciclastic reservoirs of the Colsay 1 and 3 units of the Rosebank field, with the aim of improving the understanding of siliciclastic diagenetic systems in close proximity with

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https://doi.org/10.1016/j.marpetgeo.2018.08.026
Received 15 June 2018; Received in revised form 16 August 2018; Accepted 21 August 2018
Available online 27 August 2018
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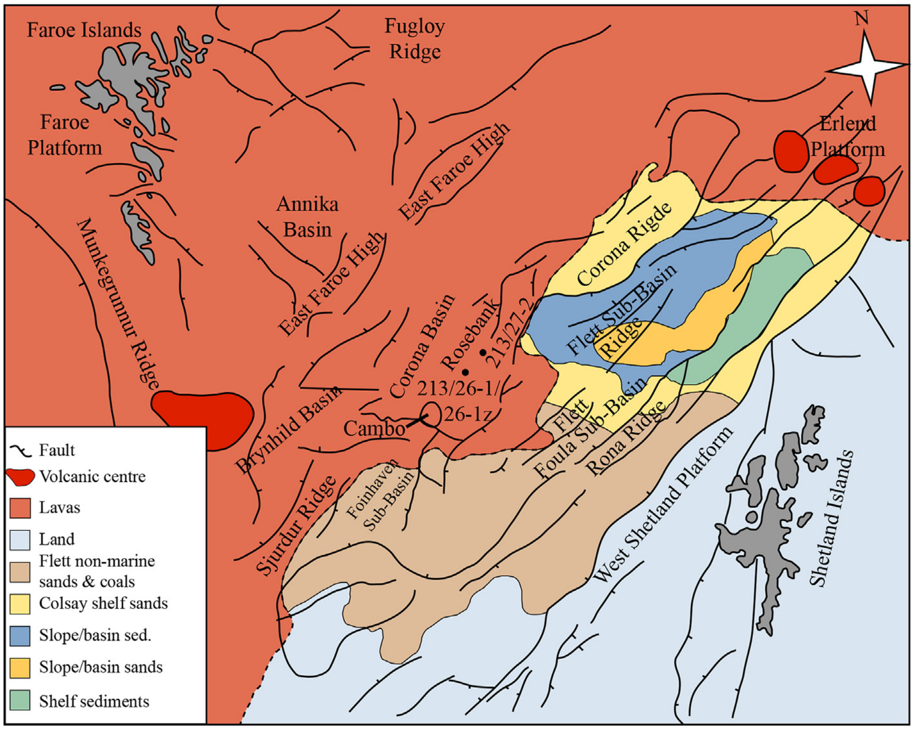

Fig. 1. Palaeogeography at Late Paleocene-Early Eocene of the Faraeo-Shetland basin with approximately well locations (213/27-2, 213/26-1, 213/26-1z), modified after (Schofield and Jolley, 2013; Poppitt et al., 2016).

basalts and volcaniclastics. This study also evaluates the effect these lithologies have on the diagenetic system and subsequently reservoir quality. This was achieved by studying well samples using optical microscope, scanning electron microscope, energy dispersive X-ray spectroscopy, X-ray fluorescence and fluid inclusion homogenization temperatures.

2. Geological setting

The Faroe-Shetland Basin (FSB) is a collective term for a series of NE-SW-trending sub basins along the NW Atlantic Margin between the Faroe Islands and the Shetland Isles. These sub basins are separated by Paleozoic basement highs, with Rosebank located on the southwestern part of Corona ridge (Fig. 1) (Dean et al., 1999; Sørensen, 2003; Hardman et al., 2018).

The FSB developed through a complex tectonic history with several rifting episodes from the Permo-Triassic, through the Palaeocene, culminating with opening of the North Atlantic in Eocene (Sørensen, 2003; Smallwood et al., 2004). During Oligocene-Miocene the FSB experienced compressional events resulting in regional uplift (Boldreel and Andersen, 1993; Davies et al., 2004). Other studies (e.g. Parnell et al., 1999) have recognized Cenozoic heating by migrating hot fluids in the region which complicates exhumation estimates. Tassone et al. (2014) overcame this using sonic transit times and showed that Cenozoic exhumation magnitudes varies in the Faroe-Shetland Region east of Rosebank. Based on vitrinite reflection profiles from the Rosebank discovery well ~800 m of uplift has been estimated for the Oligocene-Miocene (Oil and Gas Authority, 2017).

During Middle-Late Jurassic extension the organic rich Kimmeridge Clay Formation was deposited, the source rock for the FSB region (Scotchman et al., 1998; Loizou, 2014). Further extension in the Late Cretaceous to Early Paleocene led to development of SW-NE sub basins (Doré et al., 1999; Holmes et al., 1999; Schofield and Jolley, 2013; Hardman et al., 2018). Deposition of the Rosebank siliciclastic reservoirs occurred during the Paleocene and Eocene concurrently with the opening of the North Atlantic at 55 Ma (Naylor et al., 1999; Mudge, 2015). These siliciclastic fluvio-deltaic sands were likely sourced by a SW-NE drainage system adjacent to the Corona Ridge that filled in topographic lows which developed as a result of lava morphological control on where the drainage system established (Schofield and Jolley, 2013; Hardman et al., 2018) (Fig. 1). The drainage system has been observed extending at least to the Cambo region with a possible main drainage direction towards the NE (Schofield and Jolley, 2013; Hardman et al., 2018). Moreover, the sedimentary system competed for accommodation space with locally sourced flood basalts (Hardman et al., 2018). This magmatic activity was related to the proto-Icelandic plume (Saunders et al., 1997). Both the siliciclastic system and the volcanics exploited the same topographic lows, during periods of high volcanic activity the sedimentary system was diverted away from areas active volcanism (Schofield and Jolley, 2013; Hardman et al., 2018). At the end of Colsay 1 times the topographic lows had been filled by volcanics and sedimentary successions (Hardman et al., 2018). The source area for the siliciclastic sandstones where probably outside the volcanic terrains due to the "clean sand appearance" of the reservoirs (Hardman et al., 2018). This has resulted in the alternating volcanic and siliciclastic sequences observed at Rosebank. In addition to the siliciclastic and basaltic rocks, volcaniclastic rocks are also observed on Rosebank. These were produced locally by weathering of basalts in a warm and humid climate (Ellis et al., 2002).

The Colsay Member at Rosebank comprises four siliciclastic reservoir units, Colsay 1, 2, 3 and 4 which are separated by distinct volcanic intervals informally referred to as the Rosebank, Upper, Middle and Lower Volcanics (RUV, RMV and RLV) (Fig. 2). The uppermost unit, Colsay 1, consists of fluvial sandstones and mud overbank deposits. Below this are the fluvial and deltaic sediments of the Colsay 2 and 3 units. The Colsay 3 unit may have a possible estuarine influence (Schofield and Jolley, 2013). Gross thickness of each Colsay unit varies: Colsay 1 average thickness is relatively uniform (55 m), and Colsay 3 increases from southwest (5.5 m) to northeast (55 m) (Clark, 2014).

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