Marine and Petroleum Geology 78 (2016) 516–535

Contents lists available at ScienceDirect

Marine and Petroleum Geology

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

Research paper

Provenance of Triassic sandstones on the southwest Barents Shelf and the implication for sediment dispersal patterns in northwest Pangaea

Edward J. Fleming [a, *], Michael J. Flowerdew [a], Helen R. Smyth [a, 1], Robert A. Scott [a, 2], Andrew C. Morton [a, b], Jenny E. Omma [c], Dirk Frei [d], Martin J. Whitehouse [e]

[a] CASP, 181A Huntingdon Road, Cambridge, CB3 0DH, UK
[b] HM Research Associates, St Ishmaels, Haverfordwest SA62 3TG, UK
[c] Rocktype Limited, Oxford, OX4 1LN, UK
[d] Stellenbosch University, Victoria Street, Stellenbosch, South Africa
[e] Swedish Museum of Natural History, Frescativägen 40, 114 18, Stockholm, Sweden

ARTICLE INFO

Article history:
Received 21 June 2016
Received in revised form
24 August 2016
Accepted 3 October 2016
Available online 5 October 2016

Keywords:
Barents sea
Triassic
Palaeogeography
Provenance
U-Pb zircon geochronology
Reservoir quality
Sediment composition
Petroleum basin analysis

ABSTRACT

Thick Triassic siliciclastic units form major reservoir targets for hydrocarbon exploration on the Barents Shelf; however, poor reservoir quality, possibly associated with variation in provenance, remains a key risk factor in the area. In this study, sandstone dispersal patterns on the southwest Barents Shelf are investigated through petrographic and heavy mineral analysis, garnet and rutile geochemistry and zircon U-Pb geochronology. The results show that until the Early Norian Maximum Flooding Surface, two contrasting sand types were present: (i) a Caledonian Sand Type, characterised by a high compositional maturity, a heavy mineral assemblage dominated by garnet and low chrome-spinel:zircon (CZi) values, predominantly metapelitic rutiles and mostly Proterozoic and Archaean detrital zircon ages, interpreted to be sourced from the Caledonides, and (ii) a Uralian Sand Type, characterised by a low compositional maturity, high CZi values, predominantly metamafic rutiles and Carboniferous zircon ages, sourced from the Uralian Orogeny. In addition, disparity in detrital zircon ages of the Uralian Sand Type with contiguous strata on the northern Barents Shelf reveals the presence of a Northern Uraloid Sand Type, interpreted to have been sourced from Taimyr and Severnaya Zemlya. As such, a coincidental system is inferred which delivered sand to the Northern Barents Shelf in the late Carnian/early Norian. Following the Early Norian Maximum Flooding Surface, a significant provenance change occurs. In response to Late Triassic/Early Jurassic hinterland rejuvenation, supply from the Uralian Orogen ceased and the northern Scandinavian (Caledonian) source became dominant, extending northwards out on to the southwest Barents Shelf. The data reveal a link between reservoir quality and sand type and illustrate how provenance played an important role in the development of clastic reservoirs within the Triassic of the Barents Shelf.

1. Introduction

The Triassic succession on the Barents Shelf is currently of considerable importance for hydrocarbon exploration (Henriksen et al., 2011; Lundschien et al., 2014). During the Triassic, the area formed part of a large epicontinental seaway in the northwestern corner of the supercontinent Pangaea (Worsley, 2008). This seaway was progressively infilled by prograding delta complexes which deposited up to 7 km of siliciclastic sediment in a series of transgressive-regressive sequences (Glørstad-Clark et al., 2011; Klausen et al., 2015; Riis et al., 2008). The deposition of thin organic-rich shales in front of these prograding systems, followed by extensive paralic sandstones of the delta front and top have led authors to postulate prolific hydrocarbon play potential (e.g. Lundschien et al., 2014). These ideas were reinforced by the discovery of the Goliat field (174 MMbbl estimated) in 2000, which found good reservoir quality in mid-late Triassic sandstones in the southern Hammerfest Basin. The considerable thickness of Triassic

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* Corresponding author.
E-mail address: edward.fleming@casp.cam.ac.uk (E.J. Fleming).

[1] Present address: Neftex Exploration Insights, Halliburton, Abingdon OX14 4RW United Kingdom.

[2] Deceased.

http://dx.doi.org/10.1016/j.marpetgeo.2016.10.005

strata further north, combined with extensive play development has prompted a significant drilling campaign in recent years. However, outside the southern Hammerfest Basin, exploration results within the Triassic have been less successful, with only small accumulations and/or residual hydrocarbons being encountered (Henriksen et al., 2011).

The reservoir quality of Triassic sandstones on the Barents Shelf can be variable (Henriksen et al., 2011) which is a key risk factor for exploration in the area. The cause of this variability is likely to be complex, but differences in the original sandstone composition likely play a significant role. One of the fundamental controls of sandstone composition is provenance (Johnsson, 1993). Previous research has shown this to be inconsistent on the Barents Shelf in the Triassic (Mørk, 1999). Northern Scandinavia is thought to have been an important sediment source throughout the Mesozoic, particularly during the Jurassic. However, in the Triassic, seismic analysis has revealed that major deltaic complexes migrated from the southeast across the shelf (Glørstad-Clark et al., 2010; Klausen et al., 2015; Riis et al., 2008) in response to the developing Uralian Orogeny. Additional sources have been inferred from Greenland (Mørk, 1999; Pózer Bue and Andresen, 2014) and local topographic highs (e.g. Glørstad-Clark et al., 2010). The delineation and possible interaction between these systems on the southwest Barents Shelf is largely unknown.

This paper presents provenance data from Triassic core materials that form part of the CASP Barents Shelf provenance dataset. The selection includes 39 petrographic analyses, 72 heavy mineral analyses, 10 rutile geochemical analyses, 8 garnet geochemical analyses and 8 U-Pb zircon age analyses. Using an integrated approach, the aims of this study are to (i) characterise the provenance signatures of Triassic sandstones on the southwest Barents Shelf; (ii) map the distribution of sand types to reconstruct the drainage distribution; and finally (iii) compare the provenance data with published data from the greater Barents Shelf in order to provide insight into the wider tectonic evolution and location of sedimentary source regions. The outcomes of this work enable more precise constraints on the location and composition of Triassic sandstones on the Barents Shelf, which may be used to reduce uncertainty in reservoir prediction.

2. Geological background

The Barents Shelf is subdivided into numerous basins, platforms and highs (Fig. 1a; Gabrielsen et al., 1990). To the east, the regional structure is dominated by a major basin, located west of Novaya Zemlya, called the East Barents Basin. Westwards, there is a significant change in structural style, and a series of relatively narrow, predominantly northeast-southwest trending, elongate extensional basins are present (Gernigon et al., 2014). Deposition was initiated due to Late Palaeozoic collapse of the Caledonian mountain belt. This was followed by rift-related subsidence and the development of the North Atlantic rift system (Doré, 1992). Rapid subsidence occurred in the North and South Barents basins to the east during the Late Permian and continued through the Triassic resulting in the creation of a large epicontinental seaway (Smelror et al., 2009).

On the southwest Barents Shelf, a total thickness in excess of 2.5 km was deposited in the Triassic, which has been divided into 5 lithostratigraphic formations (Havert, Klappmyss, Kobbe, Snadd and Fruholmen formations; Fig. 1b). Each of these can be related to a transgressive-regressive cycle, bounded by a maximum flooding surface (MFS) (Glørstad-Clark et al., 2010; Henriksen et al., 2011; Klausen et al., 2015). Significant seaward shifts of the shoreline can be recognised seismically (Glørstad-Clark et al. 2010, 2011; Klausen et al., 2015). These reflect regression and the progradation of major delta complexes which gradually infilled the remnant end-Permian palaeotopography (Glørstad-Clark et al., 2010; Lundschien et al., 2014). These are separated by periods of transgression where offshore marine deposits onlap against deltaic facies. Of particular note is the Early Norian MFS (Klausen et al., 2015) which separates the Snadd and Fruholmen formations. Whilst being poorly defined seismically (Glørstad-Clark et al., 2010), the surface coincides with a profound change in mineralogy and depositional environments (e.g. Bergan and Knarud, 1993; Mørk, 1999; Ryseth, 2014).

Traditionally, northern Scandinavia was thought to have been the major source area for Palaeozoic and Mesozoic successions on the southwest Barents Shelf (Rønnevik et al., 1982). In the Triassic, Mørk et al. (1999) identified quartzofeldspathic sandstones in the Hammerfest Basin, interpreted to be derived from the Caledonides of Northern Scandinavia and the Baltic margin. However, since the early days of hydrocarbon exploration, the recognition of northwesterly prograding clinoforms and an increasing thickness of the sediment pile to the east (Jacobsen and Veen, 1984; Nøttvedt et al., 1993; van Veen et al., 1993) implied the existence of a major source area to the southeast of the Barents Shelf. This was supported by the work of Mørk (1999), who also identified distinct epidote-bearing, lithic-rich sandstones which were interpreted to be sourced from the developing Uralian Orogeny. Today, the seismic evidence for delta progradation to the northwest is well documented (Glørstad-Clark et al., 2010; Høy and Lundschien, 2011; Lundschien et al., 2014; Riis et al., 2008) and the shoreline is interpreted to have reached Svalbard in the late Carnian (Pózer Bue and Andresen, 2014). A source from Greenland has been suggested for some parts of the Triassic on Svalbard (Mørk, 1999) which may also have provided sediment to the southwest Barents Shelf (Glørstad-Clark et al., 2010).

Shelfal environments, such as those that characterise the Triassic on the Barents Shelf, can have a complex source-to-sink system as they are capable as acting both as sediment sources (e.g. wave ravinement), transporters (e.g. longshore drift) and sinks (Sømme et al., 2009). These processes have the ability to cause local provenance variation and are therefore an important consideration during analysis. However, the majority of the samples in this study were collected from deltaic facies formed during the rapid progradation of the clinoform belts (Klausen et al., 2015). As such, significant mixing and erosion of different source areas either by tides, waves or through long shore drift was probably minor at the scale examined.

3. Methods

Point counting of thin sections, stained for porosity and K-feldspar, and conventional heavy mineral analysis followed the methods outlined by Folk (1980) and Mange and Wright (2007), respectively. The provenance-sensitive heavy mineral ratios ATi (apatite:tourmaline index), GZi (garnet:zircon index), RuZi (rutile:zircon index), MZi (monazite:zircon index) and CZi (chrome-spinel:zircon index) were determined following Morton and Hallsworth (1994). Garnet geochemical analyses were performed using a Link Systems AN 10/55S energy-dispersive x-ray analyser attached to a Cambridge Instruments Microscan V electron microprobe housed at the University of Aberdeen. Garnet assemblages have been compared by determining the relative abundances of garnet types A (low-Ca, high-Mg), B (low-Mg, variable-Ca) and C (high-Mg, high-Ca), as defined by Mange and Morton (2007). Rutile chemical analyses were carried out at the School of Earth, Ocean and Planetary Sciences at Cardiff University, using a Thermo Elemental X(7) series inductively coupled mass spectrometer (ICP-MS) coupled to a New Wave Research UP213 Nd:YAG