Proceedings of the Geologists' Association xxx (2018) xxx–xxx

Contents lists available at ScienceDirect

Proceedings of the Geologists' Association

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

Porosity preservation due to grain coating illite/smectite: Evidence from Buchan Formation (Upper Devonian) of the Ardmore Field, UK North Sea

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ARTICLE INFO

Article history:
Received 21 August 2017
Received in revised form 6 March 2018
Accepted 12 March 2018
Available online xxx

Keywords:
Grain coating illite/smectite
Upper Devonian
Clay infiltration
Porosity preservation
Central North Sea Basin

ABSTRACT

The Buchan Formation sandstone reservoirs from the Ardmore Field in the UK Central North Sea are fluvial-aeolian deposits and provide examples of porosity preservation in deeply-buried reservoirs (2.7–3.2 km) caused by grain-coating illite/smectite (I/S). Here, high reservoir quality commonly correlates with the occurrence of grain-coating I/S and consequent inhibition of quartz cementation in the aeolian dune and interdune sandstones. Porosity is lower in fluvial sandstones lacking grain coating I/S but with intense quartz overgrowths. We propose that the presence of I/S reflects concentration of the smectitic-rich clay bearing water which would have been the deposits of the interdune and/or distal sector of fluvial distributary system, and were introduced into aeolian deposits by mechanical infiltration. Petrographic relationships indicate that these coatings grew mainly before the mechanical compaction as the clays occur at grain contacts. The use of empirical model suggested that about 6–7% porosity have been preserved. The burial-thermal history of the Ardmore area contributed to the high quality reservoir because throughout much of the time since deposition, the Devonian sandstones have been little buried. Only from the Palaeogene the reservoir temperatures exceeded about 70 °C and rapidly buried to today's maximum depth, which have minimized the negative effect generally ascribed to smectitic clays on reservoir quality. The circumstances of porosity preservation shown in this study may be unusual, but nonetheless have profound consequences for exploration. It is possible to identify new Buchan Formation prospects in areas hitherto dismissed because they were generally assumed to be poor reservoir.

1. Introduction

Quartz cement is one of the dominant porosity reducing agents in many reservoir sandstones, but other factors such as grain size, sorting, clay content, mechanical compaction, pore fluid pressure, early cementation and authigenic clay minerals also play a critical role (Worden and Morad, 2000). Different types of grain coatings have been identified to inhibit or reduce quartz cementation. The basic mechanism of inhibiting quartz overgrowth is that the grain coatings covered the nucleation site on the host grains and the authigenic quartz could not nucleate on or through the coatings (Pittman, 1972). The most effective grain coating mineral is said to be micro-quartz (Aase et al., 1996) and for the grain coating clays, authigenic chlorite is commonly reported as a preserver (e.g. Pittman and Lumsden, 1968; Ehrenberg, 1993; Berger et al., 2009; Stricker and Jones, 2016). Illite is less frequently reported as grain coatings that preserve porosity (Storvoll et al., 2002) but frequently cited as the cause of permeability destruction (Robinson et al., 1993). Smectitic clay is commonly regarded as having negative effects on reservoir quality due to its water-sensitive swelling property (Gray and Rex, 1965), and it commonly transforms to fibrous/hairy illite in a potassium-rich pore fluids. Precipitation of illite usually causes significant permeability reduction (Almon and Davies, 1981; Le Gallo et al., 1998; Wilson et al., 2014).

The oil reservoirs in the Ardmore Field, UK Block 30/24, Central North Sea, are hosted in Permian Zechstein carbonates, Permian Rotliegend sandstones and Upper Devonian Buchan Formation sandstones (Gluyas et al., 2005). The two Permian units have been studied in a number of publications (e.g. Nagtegal, 1979; Glennie and Provan, 1990; Purvis, 1992; Howell and Mountney, 1997; Leveille et al., 1997; Sweet, 1999); however, the deeper and older Buchan Formation sandstones (2.7–3.2 km TVDSS) are poorly understood but have also been proven to be an important

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https://doi.org/10.1016/j.pgeola.2018.03.001
0016-7878/© 2018 Published by Elsevier Ltd on behalf of The Geologists' Association.

hydrocarbon reservoir in the Central North Sea (e.g. Edwards, 1991; Knight et al., 1993; Gambaro and Currie, 2003; Gluyas et al., 2005).

In this study, we discovered that the aeolian-associated sandstones with grain coating illite/smectite (I/S) usually have anomalously high porosity and permeability, while quartz overgrowth is almost absent in this sandstone type. Conversely, the fluvial facies without thick and continuous I/S coatings are usually cemented by extensive quartz overgrowth, and commonly show poor, or at best, moderate reservoir quality. Therefore, this study focused on the following points and questions: 1) why is the grain coating I/S only presented in aeolian sandstones and how did it form? and 2) is it possible to quantitatively evaluate the porosity preserving effect of I/S grain coatings? The positive effect of grain coating I/S can be expected to occur only under particular circumstances, but in such cases it can have profound consequences for exploration. This study has broad implications for future exploration, appraisal and production of Devonian reservoirs within this area.

2. Geological setting

2.1. Tectonic setting

The Ardmore Field is located on the Argyll Ridge, a large SW-NE trending Palaeozoic age tilted fault block on the south-western flank of the Central Graben in Block 30/24, UK North Sea Basin, about 350 km south-east from Aberdeen. The field is located in a horst feature with the crest in the north and fault closure to the north-east. It measures 2.5 km wide and 6 km long (Fig. 1a). A combination of dip and faulting defines the limits of the field on the north-west and south-east flanks, while dip closure defines the southern limits of the field. The major fault trends are in two main directions, WNW–ESE cut by NE-SW faults (Fig. 1b). The top seal is provided by Triassic shale in the far west, Jurassic shale in the mid-part of the field and impermeable Chalk at the north-eastern crest (Gluyas et al., 2005). The trap relies heavily on the major NE-SW trending graben edge faults to the northeast and southwest of the field while dip closure occurs to the northwest and west.

2.2. Stratigraphy

The Devonian sequence in the Ardmore Field comprises a succession of the Middle Devonian Kyle limestone and Upper Devonian Buchan Formation. The succession dips to the south-west, and is separated from the Permian by a palaeo-topographic unconformity, in which successively younger stratigraphic units in the Devonian sub crop towards the south-west. Although the pre-Permian surface has topography it also dips to the SW, this has the effect of making the oldest part of the Buchan Formation subcrop the unconformity in the NE of the field and thus the youngest Devonian in the SW slightly deeper (Fig. 1b).

The Upper Devonian Buchan Formation comprises a thick, generally upward-coarsening succession of shales of mixed shallow marine and sabkha environment at the base, passing upwards into mainly fluvial and aeolian sandy sediments (Fig. 2).

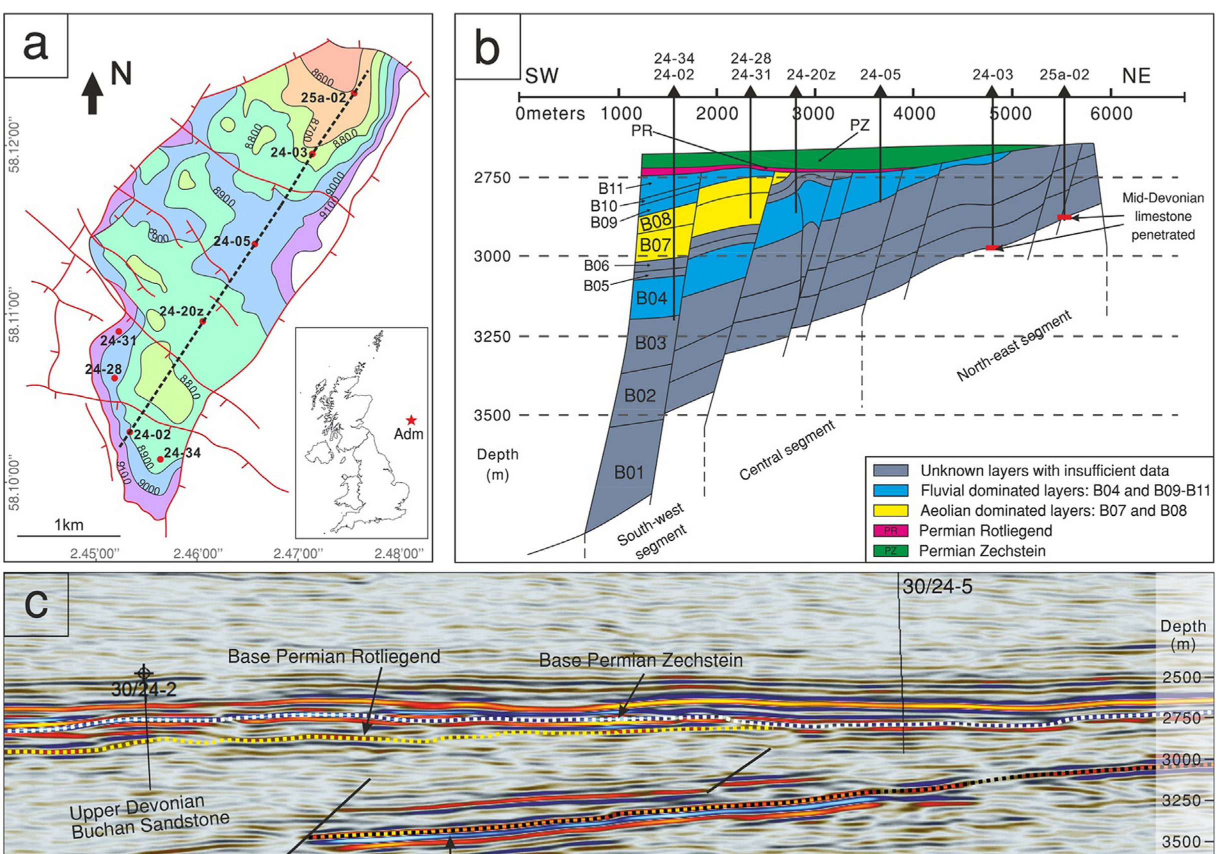

Fig. 1. Geological maps showing: (a) Location and main structure elements of Ardmore (Adm) Field; (b) Vertical section of an SW-NE profile (dashed line in 1a); (c) Seismic section of an SW-NE profile (part of dashed line in 1a).

Please cite this article in press as: L. Tang, et al., Porosity preservation due to grain coating illite/smectite: Evidence from Buchan Formation (Upper Devonian) of the Ardmore Field, UK North Sea, Proc. Geol. Assoc. (2018), https://doi.org/10.1016/j.pgeola.2018.03.001