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Feldspar dissolution with implications for reservoir quality in tight gas sandstones: evidence from the Eocene Es4 interval, Dongying Depression, Bohai Bay Basin, China

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ABSTRACT

Feldspar dissolution is a pervasive water-rock interaction in siliciclastic sediments and has critical impact on reservoir quality. The purpose of this paper is to evaluate the influence of feldspar dissolution on reservoir quality in tight gas sandstones from the Eocene Es4 interval, Dongying Depression. Based on petrographic, mineralogical, and geochemical analysis, distribution patterns of authigenic minerals associated with feldspar dissolution are recognized. Dissolution of feldspar in Eocene Es4 interval is related to organic acids and CO_2 expelled from adjacent source rocks in deep burial environment. Diffusion is inferred to be the predominant transport mechanism for dissolved solids during feldspar dissolution and result in dissolution by-products (e.g. quartz, kaolinite, illite and albite cements) precipitated in-situ or in adjacent pores. Mass balance calculations also demonstrate most of silica derived from K-feldspar dissolution was precipitated as quartz cements within tight sandstone reservoirs. The net porosities created by feldspar dissolution were insignificant but reservoir permeability was reduced significantly by the precipitation of authigenic quartz, kaolinite, albite, and especially by conversion of kaolinite to hair-like illite at higher temperatures.

1. Introduction

As one of the major unconventional hydrocarbon resources, tight gas sandstone reservoirs are widely distributed in numerous rift basins in China including Bohai Bay, Tarim, Ordos and Sichuan Basins (Zhu et al., 2012; Ren et al., 2014; Lai et al., 2015). In general, tight gas reservoirs are deeply buried and normally characterized by low porosity and permeability (Higgs et al., 2007; Zhu et al., 2012). Moreover, these tight gas reservoirs show strong heterogeneities which are mainly attributed to the significant compaction and cementation (Zou et al., 2012; Lai et al., 2015). In previous studies, secondary porosity, which is defined as the pore space created by dissolution of detrital framework grains and/or authigenic cements, is typically considered as a significant proportion of the total porosity and as the sweet spot for tight gas reservoirs (e.g. Zou et al., 2012; Lai et al., 2015). The enhancement of total porosity during the formation of secondary porosity requires large-scale mass transfer of solids in solution (Bjørlykke, 2014). However, for these tight reservoirs, how does the large scale of mass transfer occur during mineral dissolution to increase the total porosity? Many workers have raised some key controversial issues about the timing of secondary porosity formation related to feldspar dissolution and whether it can enhance total porosity or not during the last 30 years (e.g. Stoessell, 1987; Giles and de Boer, 1990; Bjørlykke and Jahren, 2012). Some geologists have inferred that the majority of secondary porosity probably is created during shallow burial due to leaching by meteoric water (Giles, 1987; Bjørlykke, 2010). This process can make high flux of water available for large scale of mass transport and subsequently, generated an increase in overall porosity for sandstone reservoirs. In contrast, some other workers have ascribed creation of secondary porosity to deep burial environment based on petrographic evidence and geochemical data (e.g. Schmidt and Mcdonald, 1979; Surdam et al., 1989; Rahman and McCann, 2012). As the notable difficulty of transport large amounts of solutes out of sandstone system during deep burial environment, formation of secondary porosity was associated with other mineral reactions that caused precipitation of cements (Chuhan et al., 2001; Bjørlykke and Jahren, 2012). This process probably could not result in net increase in total porosity, but a redistribution of porosity (Giles and

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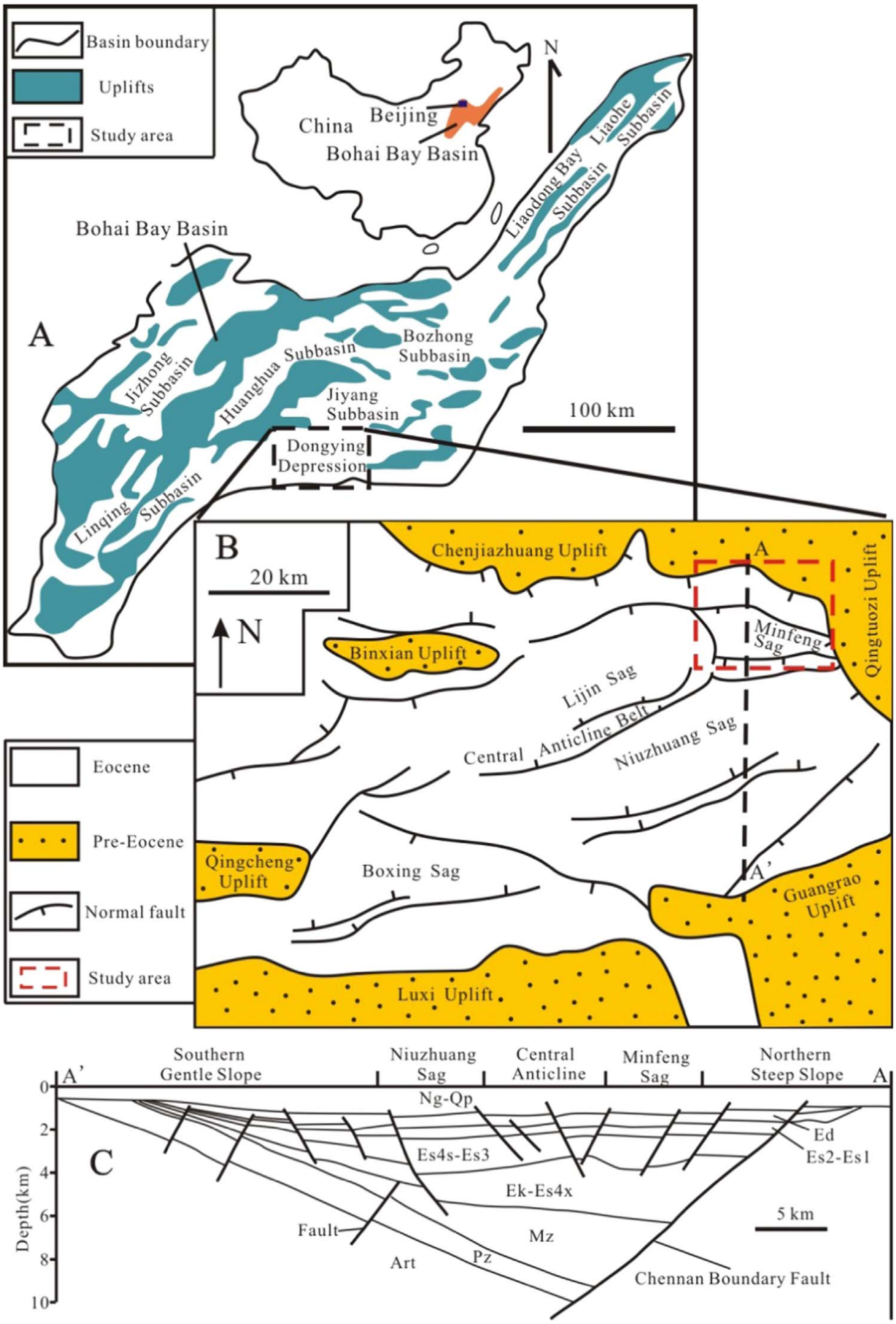

Fig. 1. A. Locality map of subbasins of the Bohai Bay Basin, eastern China (modified from Guo et al., 2010); B. Distribution of main sags and uplifts and major faults and location of section AA'; C. Cross section AA' showing major statigraphic units and major tectonic features within the Dongying Depression (modified from Guo et al., 2010).

de Boer, 1990). Therefore, understanding when the secondary porosity related to feldspar dissolution was formed and whether dissolution by-products were transported out of sandstone reservoirs or not has critical impact on prediction of reservoir quality for tight sandstones.

The Eocene Es4 interval in the Dongying Depression, Bohai Bay Basin in eastern China (Fig. 1) developed in a rift basin and is an important tight gas sandstone interval (Guo et al., 2010; Wang et al., 2014). The Es4 interval consists of sublacustrine-fan, coarse-grained conglomerates, pebbly sandstones, sandstones, and lacustrine mudstones. In addition, the lower unit (Es4x) contains local evaporites in the form of gypsum, anhydrite and halite. With a wide range of burial depths (2500–5000 m), formation temperatures (100–180 °C) and formation pressures (25–70 MPa), the Es4 interval in Dongying Depression is ideally suited to investigate the effects of feldspar dissolution on reservoir quality for tight gas sandstones. Thus, the objectives of this study are to: (1) document the characteristics of feldspar dissolution and other diagenetic minerals using thin section petrography in conjunction with a range of analytical techniques; (2) understand the timing of feldspar dissolution and associated authigenic minerals by utilizing fluid inclusion and burial history analysis; and (3) evaluate the effects of feldspar dissolution on reservoir quality for tight gas sandstones.