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Research paper

Prediction of diagenetic facies using well logs – A case study from the upper Triassic Yanchang Formation, Ordos Basin, China

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A R T I C L E I N F O

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A B S T R A C T

Understanding diagenetic heterogeneity in tight sandstone reservoirs is vital for hydrocarbon exploration. As a typical tight sandstone reservoir, the seventh unit of the Upper Triassic Yanchang Formation in the Ordos Basin (Chang 7 unit), central China, is an important oil-producing interval. Results of helium porosity and permeability and petrographic assessment from thin sections, X-ray diffraction, scanning electron microscopy and cathodoluminescence analysis demonstrate that the sandstones have encountered various diagenetic processes encompassing mechanical and chemical compaction, cementation by carbonate, quartz, clay minerals, and dissolution of feldspar and lithic fragments. The sandstones comprise silt-to medium-grained lithic arkoses to feldspathic litharenites and litharenites, which have low porosity (0.5%–13.6%, with an average of 6.8%) and low permeability (0.009×10^{-3} μm^2 to 1.818×10^{-3} μm^2, with an average of 0.106×10^{-3} μm^2).

This study suggests that diagenetic facies identified from petrographic observations can be up-scaled by correlation with wire-line log responses, which can facilitate prediction of reservoir quality at a field-scale. Four diagenetic facies are determined based on petrographic features including intensity of compaction, cement types and amounts, and degree of dissolution. Unstable and labile components of sandstones can be identified by low bulk density and low gamma ray log values, and those sandstones show the highest reservoir quality. Tightly compacted sandstones/siltstones, which tend to have high gamma ray readings and relatively high bulk density values, show the poorest reservoir quality. A model based on principal component analysis (PCA) is built and show better prediction of diagenetic facies than biplots of well logs. The model is validated by blind testing log-predicted diagenetic facies against petrographic features from core samples of the Upper Triassic Yanchang Formation in the Ordos Basin, which indicates it is a helpful predictive model.

1. Introduction

Porosity and permeability of sandstone reservoirs play an important role in hydrocarbon exploration, controlled by numerous factors such as sand composition and grain size, texture, pore-fluid chemistry, temperature and effective stress. These variables and others have been the focus of many recent studies (e.g. Nguyen et al., 2013; Salem et al., 2000; Stricker et al., 2016a; Taylor et al., 2010; Yuan et al., 2015). Variations in the above controlling factors result in reservoir heterogeneity at various extends and scales, ranging from micrometers to hundreds of meters (Morad et al., 2010). Thus, reservoir evaluation is achieved by dividing reservoirs into relatively homogeneous subgroups based on a set of criteria obtained from core analysis and petrophysical analysis, and subsequently evaluated in each subgroup. To that end, hydraulic units, lithofacies, petrofacies and electrofacies have been mentioned in several studies (Amaefule et al., 1993; Perez et al., 2005; Porras et al., 1999). Similarly, Rushing et al. (2008) proposed three rock types (i.e. depositional, petrographic and hydraulic) to estimate rock properties of tight gas sandstones. Meanwhile, diagenetic facies are used by Grigsby and Langford (1996) and Ozkan et al. (2011) to describe diagenetic heterogeneity in reservoirs. Diagenetic facies refer to intervals or units formed

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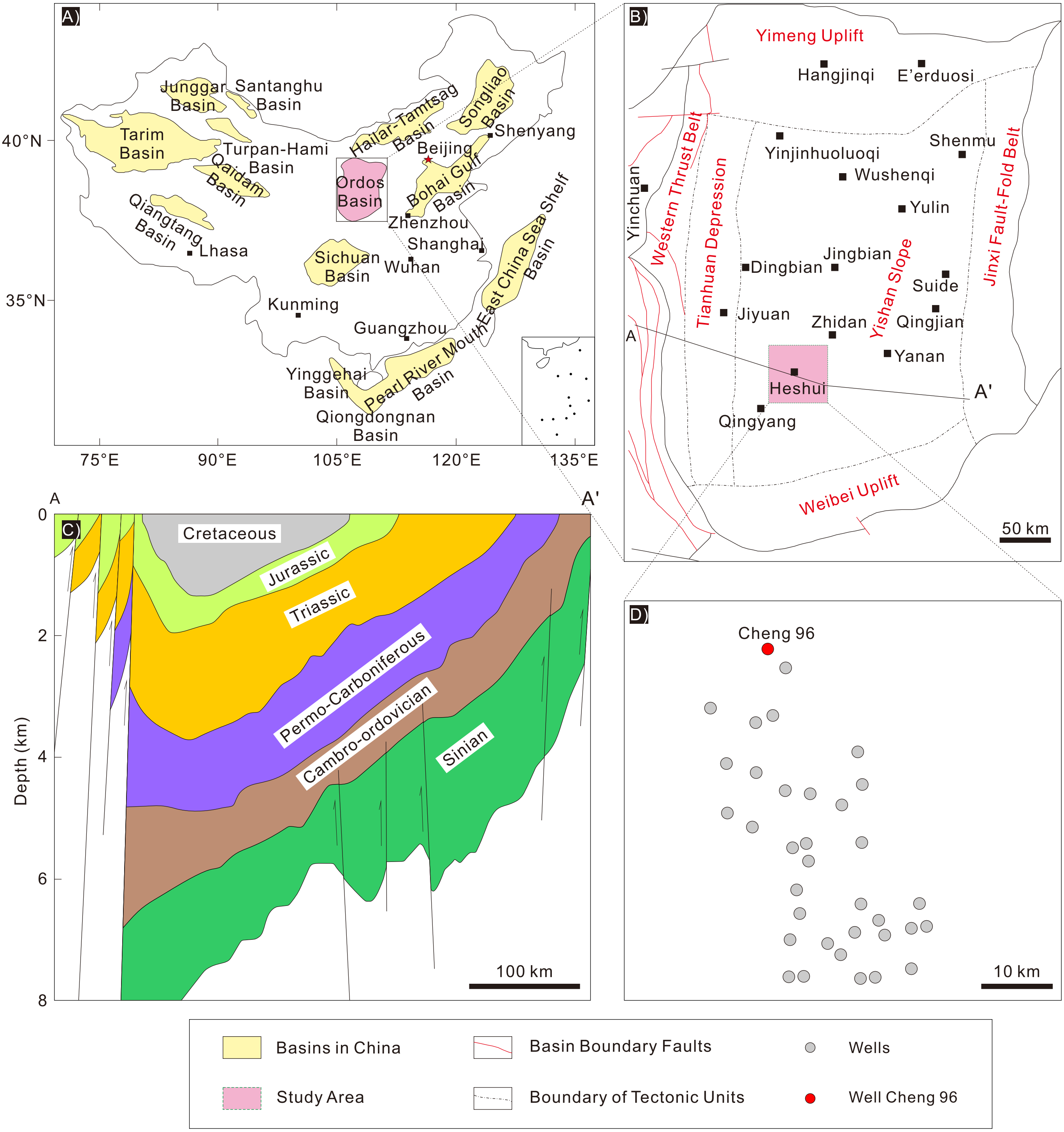

Fig. 1. Map showing locations of A) Ordos Basin in north central China, and B) Heshui Field; C) Geological cross section of line AA′ in B), modified from Zhao et al. (2015); D) wells in this study. The well with red colour is Cheng 96, which is used for validating the model in this article. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

from sediments interacting with diagenetic processes in certain tectonic settings. In other words, diagenetic facies involve effects on initial sediments exerted by compaction, cement types and textures, replacement and dissolution (Liu et al., 2015; Zou et al., 2008).

As the costs of coring are high and only limited intervals are cored, it is critical to upscale diagenetic features by correlation with well logs for subsequent field scale reservoirs quality evaluation. However, prediction of diagenetic features using well logs is relatively poorly explored in literatures. One of the few examples is that of Serra (1986) who listed the log characteristics of diagenetic minerals in sedimentary rocks, and provided plentiful evidence to indicate the viability for prediction of diagenetic alterations using well logs. Another example is that of Ozkan et al. (2011) and they