Journal of Petroleum Science and Engineering 157 (2017) 1130–1142

Contents lists available at ScienceDirect

Journal of Petroleum Science and Engineering

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

Distribution of radioactive elements (U, Th) in the upper Paleozoic coal-bearing strata of the eastern Ordos basin

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ARTICLE INFO

Keywords:
High radioactivity of natural gamma ray
Radioactive elements
Coal-bearing strata
Eastern Ordos basin

ABSTRACT

The presence of radioactive elements are detected by more 50 well loggings and plotted spatially and vertically to image their distribution, in the eastern Ordos basin. The radioactive element is investigated through quantitative methods, such as inductively coupled plasma mass spectrometry and X-ray diffraction. Results show the presence of three significantly high radioactivity of natural gamma-ray (GR) layers: (1) K_f with GR content ranging from 120.5 to 738.1 API, 2.93–39.97 ppm of U, and 8.4–97.93 ppm of Th, (2) K_d with GR content ranging from 121.2 to 475 API, 3.17–40.03 ppm of U, and 4.26–42.63 ppm of Th, and (3) K_b with GR content ranging from 117.4 to 453.4 API, 1.26–47.47 ppm of U, and 2.37–84.11 ppm of Th. The high concentrations of U and Th in coal-bearing deposits are spatially related to the rock blocks in the vicinity of the folded margins, which are rich in elements and are related to syndepositional volcanism before coal formation. The layers with significantly high radioactive content of U and Th might play a role in promoting and catalysing the hydrocarbon generation of coal-bearing hydrocarbon source rocks, which are also the reliable precise chronostratigraphic markers in continental strata for lacking of reliable marine markers.

1. Introduction

Explosive volcanic eruptions can produce large amounts of fine-grained pyroclastic materials, which may be spread laterally across large areas by wind drift. Volcanic ash is preserved when deposited in marine and non-marine sedimentary basins and is subsequently transformed into clay minerals by diagenetic processes (Huff et al., 1998). As generally accepted, volcanic ash in coal swamp environments is transformed into tonsteins, which leads to the formation of kaolinite (Spears, 2012). Tonsteins occur in coal-bearing sequences worldwide (Arbuzov et al., 2011, 2015). They are recognized and proven to be valuable mineral resources and commercial deposits in correlating coal seams and coal-bearing strata (Vine, 1955; Hower et al., 1999; Dai et al., 2003, 2010, 2014, 2016; Seredin, 2004; Arbuzov and Ershov, 2007; Seredin and Finkelman, 2008; Seredin and Dai, 2012). The natural gamma-ray (GR) data of Nb-Zr-REE ore beds and alkali tonsteins show a significant positive anomaly in well logging, which may be considered a geophysical indicator in ore prospecting (Dai et al., 2010, 2012, 2016).

At least six layers with significantly high radioactivity have been found in the Upper Paleozoic. As commonly known, considerable quantities of U, sometimes including high contents of natural radioactive elements (e.g., U, Th, and their decay products), are found concentrated in the coals, mudstones, and even sandstone in the Ordos basin. At the beginning, U-bearing coals were used as a source of U. However, with the discovery of higher-quality raw sources, the interest in U-bearing coals has diminished, and now they are considered to be a potentially dangerous cause of the radioactive contamination of the environment (Bauman and Horvat, 1981; Bride and Moore, 1978; Eisenbud and Petrow, 1964; Maurichéva and Kiselev, 2004).

Radio-geochemical and radioecological studies have been conducted on a very limited number of exploited coal basins and deposits, generally in the EU, USA, Russia (Arbuzov et al., 2011), and South China (Dai et al., 2008). In the present study, we conduct systematical investigations of the Carboniferous to Permian coal-bearing strata in the Ordos basin to fill this gap in the current research and to determine the main regularities of layers with the significantly high radioactivity using different radio-geochemical characteristics. These issues are considered in relation to the Triassic source rocks and sandstone reservoirs in the Ordos basin (Zhang, 2005; Zhao et al., 2006; Tan et al., 2007; Qiu et al., 2014). The Carboniferous to Permian coal-bearing strata are studied to a lesser

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http://dx.doi.org/10.1016/j.petrol.2017.08.032
Received 20 February 2017; Received in revised form 20 June 2017; Accepted 12 August 2017
Available online 14 August 2017

degree. These issues have been considered worldwide in the form of monographs (Arbuzov et al., 2000, 2003, 2008, 2011; Arbuzov and Ershov, 2007) and a number of articles. The present work represents an effort to generalize the extensive knowledge on the radio-geochemistry of the coal-bearing strata of the region. The high concentrations of U and Th in the coal-bearing deposits in this region have not been noticed. Their concentrations are significantly higher than the estimated average content of U (3.3 ppm) and Th (7.6 ppm) in the coals of northern China (Dai et al., 2006).

The Late Paleozoic is currently being explored for oil and gas production, especially for natural gas. It is also one of the most active periods for volcanoes during the depositional period. A large amount of syn-volcanism deposits, such as tuff (Zhong et al., 1995, 1996; Peng and Zhong, 1995; Yang et al., 2007), kaolinite depositional hydrolysis from volcanic ash (Feng, 1989), volcanic alteration clay rock (Liang et al., 1995), and so on, were deposited in the Late Paleozoic in the Ordos Basin. These rocks are richer in U and Th than in other source rocks. Uranium plays an active role in the hydrocarbon generation process of hydrocarbon source rocks (Lu et al., 2008; Mao et al., 2014). Especially for the type III, source rock can significantly promote the organic matter pyrolysis hydrocarbon process, increasing the yield of gaseous hydrocarbons (Mao et al., 2014). The layers with significantly high radioactive content of U and Th might play a role in promoting and catalysing the hydrocarbon generation of coal-bearing hydrocarbon source rocks. In this paper, we summarize the radioactive elements distribution spatially and vertically, in the eastern Ordos basin, with the aim of discussing the genesis of the high radioactivity, and providing the reliable precise chronostratigraphic markers in continental strata correlation for lacking reliable marine markers.

2. Geological background

The study area is located in the middle-eastern margin of the Ordos basin, which is situated on the western margin of the Sino-Korean paraplatform, the oldest craton in China (Dai et al., 2003, 2006; Yang et al., 2008; Zhu et al., 2008; Liu et al., 2008; Zhao et al., 2008; Jiang et al., 2011). It covers the Shannbei slope and the western Shanxi flexural fold belt of the present tectonic framework (Fig. 1). The sedimentary system and its combination style are diversified as a result of the influence of tectonic subsidence, sea level changes, and sediment supply. Our research shows that the Upper Paleozoic formed in passive continental margins. The study area consists of coal-bearing clastic rocks and limestones, and the area below the delta consists of lagoon tidal flat and restricted subtidal facies. The small rises or falls in the relative sea level may result in widespread transgression and regression processes. Against the background of a gentle ancient slope with a low deposition rate, the abovementioned characteristics result in a thin marine marker bed and coal seams deposited with a wide planar distribution. This marker bed has a favorable isochronism and provides a good foundation for regional stratigraphic correlation. Table 1 shows the major marker horizons for the stratigraphic correlation of the study area.

An evaluation of the core sample lithology and well logging data from more than 50 drillings indicate that the significantly high radioactivity of the GR layers are widely distributed in the Upper Paleozoic from the eastern Ordos basin (Fig. 2). Six layers with significantly high radioactivity have been identified, with the GR content decreasing from bottom to top. (1) K_f lies at the bottom of the upper Paleozoic and represents the boundary of the lower to upper Paleozoic, with a thickness of 1–15 m and mostly 3–5 m. (2) K_e is located above the Jinci sandstone, with a

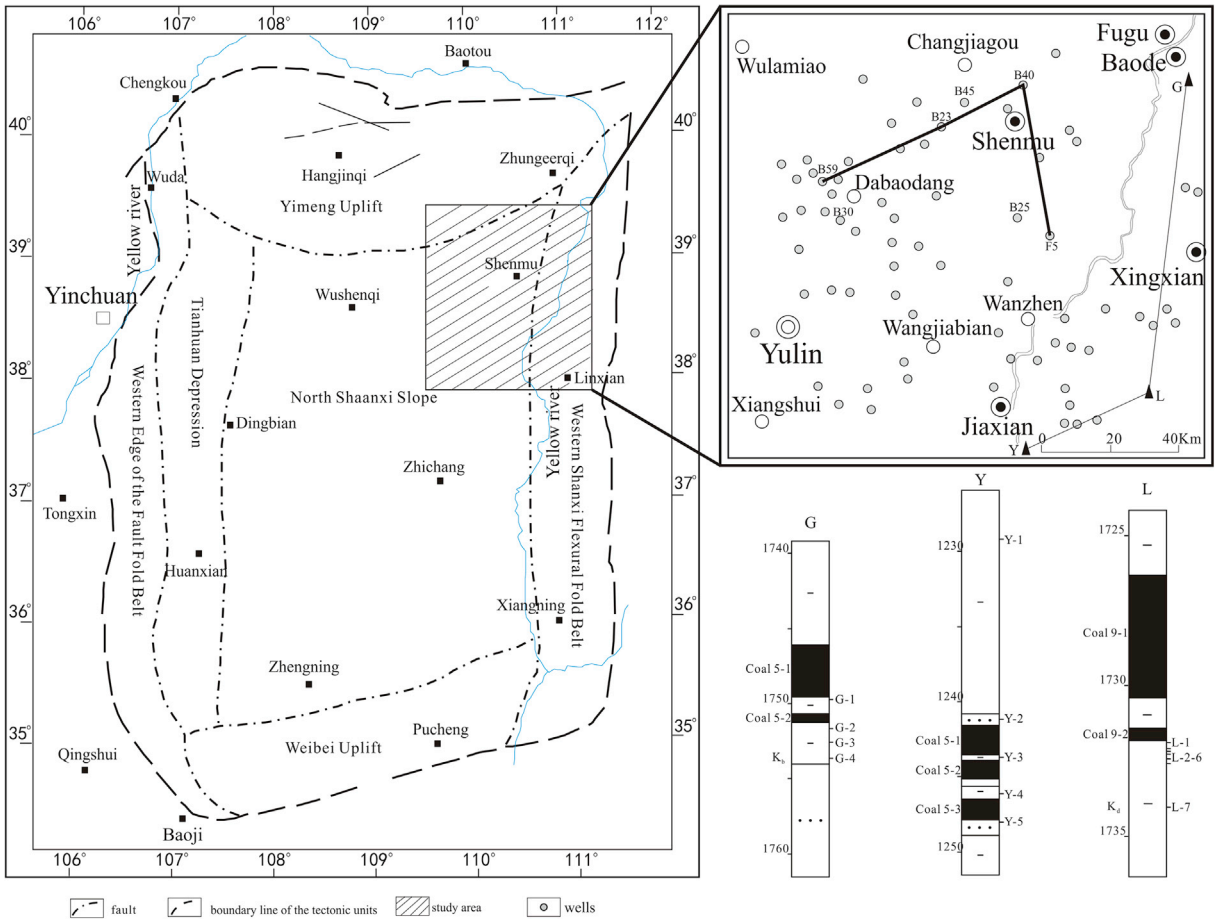

Fig. 1. Location map showing locations of the sections and well sites covered in this study. Study area indicated on map, located along eastern margin of the Ordos Basin.