International Journal of Coal Geology 165 (2016) 265–277

Contents lists available at ScienceDirect

International Journal of Coal Geology

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

Evaluation of coal macrolithotypes distribution by geophysical logging data in the Hancheng Block, Eastern Margin, Ordos Basin, China

Hao Xu [a,b,*], Dazhen Tang [a,b], Jonathan P. Mathews [c], Junlong Zhao [a,b], Bingyang Li [a,b], Shu Tao [a,b], Song Li [a,b]

[a] School of Energy Resources, China University of Geosciences (Beijing), Beijing 100083, PR China
[b] Coal Reservoir Laboratory of National Engineering Research Center of Coalbed Methane Development & Utilization, Beijing 100083, PR China
[c] Department of Energy and Mineral Engineering, The EMS Energy Institute, G3 Center, Pennsylvania State University, University Park, PA 16802, USA

A R T I C L E I N F O

Article history:
Received 3 June 2016
Received in revised form 31 August 2016
Accepted 1 September 2016
Available online 2 September 2016

Keywords:
Coal macrolithotype
Distribution
Coal seam
Well logging
Hancheng Block

A B S T R A C T

Macrolithotypes control the porosity and permeability heterogeneity in coal reservoirs, influencing coalbed methane (CBM) production. The traditional method of macrolithotype determination relies on coal cores, but these are expensive and often have limited availability. Geophysical logging data is far more common but few studies have evaluated coal macrolithotypes using these data. Here 57 macrolithotype samples from 16 wells (coal cores) informed the relationship between coal macrolithotypes and select logging parameters. The ash yield and density of coal increased while the vitrinite content, pores and fractures reduced from bright coal to dull coal, correspondingly the density (DEN) and natural gamma (GR) logging value gradually increased, while the acoustic time difference (AC) and deep lateral resistivity (LLD) logging value gradually reduced. Most of the macrolithotype identification could be achieved with regional or block specific density cut-off values however, to distinguish between semi-bright and semi-dull a combination of GR and AC values were utilized. The logging evaluation method for coal macrolithotype identification was used to determine their distribution from 67 drilled wells in the Hancheng Block. From that data it was possible to distinguish the macrolithotype vertical distribution and block macrolithotype thickness contour maps for three seams. There was considerable variability in coal thickness and macrolithotype distribution. The greater contribution was typically from the combination of dull, semi-dull, and semi-bright macrolithotypes. The dull coal macrolithotypes often had contributions adjacent to the top and bottom of the seam mudstones. For all of the seams the bright coal contribution was low, and when present occurred in elongated lenses. From the regional contour maps, the semi-bright, semi-dull, and dull coals were well distributed. The macrolithotypes variation reflects the inputs and depositional environment transformations. Here the contribution is mainly from dry peat marsh and the living water peat marsh facies. Incorporation of macrolithotype heterogeneity will aid in reservoir characterization and CBM development.

1. Introduction

Coalbed methane (CBM) is an important contributor to unconventional natural gas internationally (Moore, 2012; Xu et al., 2012). However, the structure of the seam is impacted by the organic inputs and depositional environment. The resulting heterogeneous reservoirs impact CBM formation and extraction (Clarkson and Bustin, 1996; Xu et al., 2005). This diversity manifests as obvious layers or macrolithotypes includes bright coal, semi-bright, semi-dull and dull coal (O'Keefe et al., 2013; Zhao et al., 2016).

These macrolithotypes not only differ in appearance but also in fracture propensity, porosity, and permeability (Gamson et al., 1993; Bustin, 1997; Karacan and Mitchell, 2003; Zhang et al., 2009). They also affect the adsorption capability (Harris and Yust, 1976; Mastalerz et al., 2008), gas content (Lamberson and Bustin, 1993; Scott et al., 2007), desorption rate (Crosdale et al., 1998), coal matrix shrinkage (Harpalani and Chen, 1993; Levine, 1996; Xu et al., 2014), mechanical properties, as well as the gas and water output (Xu et al., 2015; Zhao et al., 2015). Thus, incorporating the macrolithotypes distribution will provide an improved coal reservoir description. Unfortunately, obtaining coal cores for macrolithotype evaluation is expensive and in places challenging due to the extraction and evaluation of non-consolidated cores.

Geologic logging data however is more common. Compared with a standard sandstone reservoir, the well logging of coal reservoirs has low density (DEN), low gamma (GR), high neutron porosity (CNL), high acoustic time difference (AC), and high electric resistivity (RT) (Hou, 2000; Rai et al., 2004; Fu et al., 2009a, 2009b). Because it is rapid, efficient, and inexpensive, well logging is common for CBM exploration and development (Roslin and Esterle, 2015; Mavor et al., 1994). It has been used to determine the physical properties of the coal reservoir

* Corresponding author at: School of Energy Resources, China University of Geosciences (Beijing), Beijing 100083, PR China.
E-mail address: xuhao600@163.com (H. Xu).

http://dx.doi.org/10.1016/j.coal.2016.09.002
0166-5162/

(Olszewski et al., 1993; Karacan, 2009a; Li et al., 2011; Zhou and Yao, 2014; Fu et al., 2009a; Shao et al., 2013), the gas content (Hawkins et al., 1992; Fu et al., 2009b), coal seam structure (Mullen, 1989; Scholes, 1993; Fu et al., 2009a; Teng et al., 2015), and mechanical properties (Karacan, 2009b; Oyler et al., 2010).

However, coal macrolithotypes evaluation by the geophysical logging data is infrequent. Thus a logging evaluation method (such as the cut-off method) to identify the distribution of the macrolithotypes may provide an improved seam description for CBM development. Here, based on the compositions and physical properties differences of coal macrolithotypes from the Hancheng Block, the relationship between coal macrolithotypes and parameters of logging responses was determined. The macrolithotype vertical distribution and regional variation was produced for three seams in the Hancheng block and related to their transformations in depositional environments.

2. Geologic setting

The Hancheng Mining Area is in Shanxi province, on the southeastern margin of the Ordos Basin in China, with an area of 1120 km^2 (Xue et al., 2012). As a result of the regional tectonics, inside the west-dipping monocline, there are numerous small-scale high-angle faults and most cut through to the surface. The Hancheng Mining Area contains an estimated 1.7×10^{12} m^3 of total CBM reserves, and >88% of the reserves are <1000 m deep (Ma and Yin, 2002). The Hancheng Block, located in the southern section of this mining area, is a productive CBM field in China (Fig. 1).

The main coal-bearing sequences are the Permian Shanxi and Carboniferous Taiyuan Formations in the mining area (Fig. 2). The Shanxi Formation is approximately 35 to 115 m thick and was deposited mainly in a shallow water delta. The main mineable coal is the No. 3 seam, which has a general thickness of 1 to 2 m and a depth of 300 to 1200 m. The Taiyuan Formation is approximately 26 to 87 m thick, and was predominantly deposited in a coastal plain. The No. 5 and No. 11 are the main mineable coal seams. Among them, the No. 5 coal seam has a general thickness of 1 to 6 m and a common depth of 600 to 1100 m. The No. 11 seam is 2 to 6 m thick, at a depth of 600 to 1100 m (Zhao et al., 2015).

3. Methodology

Coal parameters for the macrolithotypes (ash yield and maceral composition) were obtained from four sets of fresh bulk coal (~$15 \times 15 \times 15$ cm^3) for Nos. 3, 5, and 11 coal seams. Sampling occurred at the Xiangshan underground mine within the Hancheng Mining Area. The macrolithotypes of these coal seams were also described at the mining coal face by: the overall relative luster and estimated percentage of bright components (vitrain and clarain), were bright (>80%), semi-bright (50–80%), semi-dull (20–50%), and dull (<20%) (Fig.2) (Zhao et al., 2016). The random vitrinite reflectance and maceral analyses (500 points) were performed on polished section of the crushed coal samples using a Leitz MPV-3 photometer microscope, according to ISO 7404.3-1994 (1994) and ISO 7404.5 (1994), respectively. A 5E-MAC III infrared fast coal analyzer was used to determine the moisture, volatile matter,

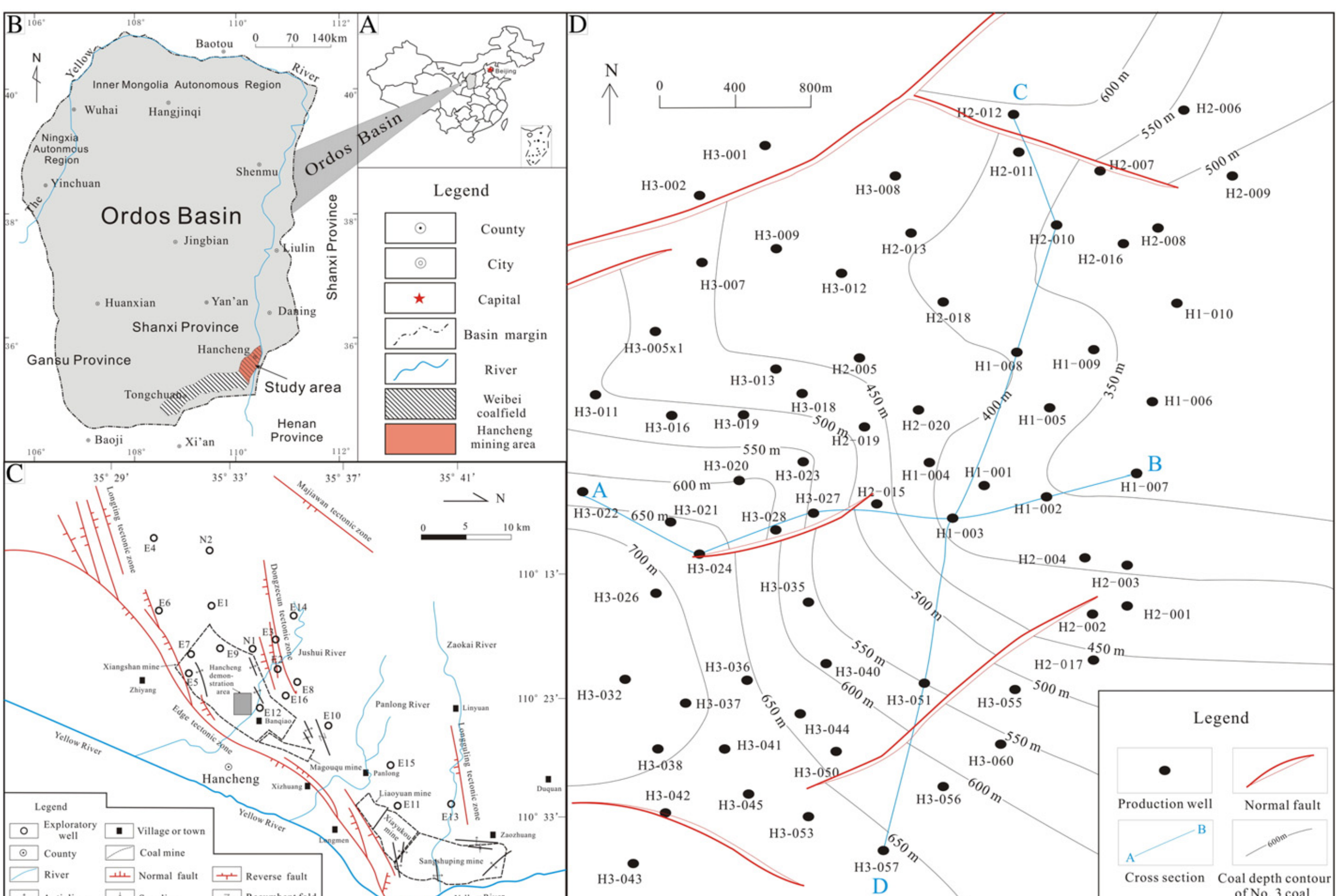

Fig. 1. Maps of the Ordos Basin, Hancheng mining area, and Hancheng Block showing the CBM exploratory and production wells (The wells considered in the east-west (A–B) and north-south (C–D) cross-sections are shown as blue lines.).