Journal of Natural Gas Science and Engineering 51 (2018) 210–222

Contents lists available at ScienceDirect

Journal of Natural Gas Science and Engineering

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

Evaluation of structured coal evolution and distribution by geophysical logging methods in the Gujiao Block, northwest Qinshui basin, China

Yingjin Wang[a], Dameng Liu[a,*], Yidong Cai[a], Yanbin Yao[a], Yingfang Zhou[b]

[a] School of Energy Resources, China University of Geosciences, Beijing 100083, PR China
[b] School of Geosciences, King's College, University of Aberdeen, AB24 3UE, Aberdeen, UK

A R T I C L E I N F O

Keywords:
Coal structure
Novel methodology
Quantitative evaluation
Geophysical logging

A B S T R A C T

Structured coal is characterized by tectonically caused features (e.g. a cataclastic or mylonitic structure with small particle sizes), which is crucial for coal exploitation and coalbed methane (CBM) development. To quantitatively identify high-resolution coal structures, a destruction F-Index that determined through multiple geophysical logging with principal component analysis (PCA), was proposed to divide coal structure into five types: I-undeformed, II-transitional, III-cataclastic, IV-granulated and V-mylonitized coals. The undamaged coals (including types I and II) that dominate the target area are normally concentrated in low-angle and gentle strata, while the structured coals (including types III, IV and V) are only distributed along syncline axial parts and fault zones. Furthermore, a deformation D-Index, to quantify the coal deformation degree in single well, was set from 1 to 5, which indicates that the larger the number is, the higher the degree is. The results showed that a negative relation between parting (normally shales or mudstones) content and D-Index, which suggests that the parting provides the resistance for coal seam deformation. Furthermore, coal deformation degree increases with the burial depth and thickness of coal seam. From the Hercynian orogeny to Himalayan orogeny, coal seams of the research area have experienced three phases of deformation. Most structured coals that distribute along syncline axial parts and fault zones formed during this process, and the undamaged coals are distributed in the internals of extensional tectonic belts (e.g. graben and horst). In addition, for a local area, the regional tectonic styles may also determine the structured coal distribution.

1. Introduction

Coalbed methane (CBM), mostly stored in the coal matrix by adsorption, or free in the larger pores or micro-fractures (Alireza Gerami et al., 2016), is considered as a recent and welcoming change (Hamawand et al., 2013). Decline in conventional resources, along with the environmental benefits of utilizing natural gas has inclined the global interest to this alternative energy resource (Dabbous et al., 1974; Williams et al., 2012). Exploitation of CBM also contributes a lot to improving coal-mining safety and reducing greenhouse gas emission (Karacan et al., 2011; Moore, 2012). Many countries have recently put more science and technologies into CBM expansion (Thomson et al., 2003; Gentzis, 2006; Maricic et al., 2008; Palmer, 2010). In China, Qinshui Basin and Eastern Ordos Basin have already step into the stage of commercial CBM development (Meng et al., 2014). However, constrained by highly diversified and complicated geologic conditions of CBM reservoirs in China (Li et al., 2016; Jiang et al., 2010), most CBM wells belong to moderate-to low-yield levels (normally < $3000 m^3$/day) (Tao et al., 2014). The coal permeability is a key attribute in determining CBM production (Connell et al., 2010), and can be directly reflected by coal structure (Min et al., 2004; Rutqvist and Stephansson, 2003). Qinshui basin has experienced multistage tectonics including Hercynian, Indosinian, Yanshanian and Himalayan movements after coal formation (Li et al., 2011), which led to various coal structures (Li et al., 2016). Therefore, coal structure evaluation is important not only for prediction of coal permeability under in-situ stress but also for gas concentration (Ju and Li, 2009).

Structured coal is ever termed as deformed coal, tectonic coal or fractured coal, characterized by tectonically caused features, correspondingly a cataclastic or mylonitic structure due to the generation of small particles (Frodsham and Gayer, 1999). Currently, there are three methods to identify coal structure: core drilling, unaided eye identification from the working face of the coalmine, and well logging curve recognition. The former two are undoubtedly the most immediate methods to indentify coal structure. However, core drilling is difficult to get full core recovery due to the fragile and soft structured coal lithology and the work fatalness at the working face of structured coals. Therefore, exploring coal structures is significant for determining

* Corresponding author.
E-mail address: dmliu@cugb.edu.cn (D. Liu).

https://doi.org/10.1016/j.jngse.2018.01.022
Received 14 March 2017; Received in revised form 19 October 2017; Accepted 13 January 2018

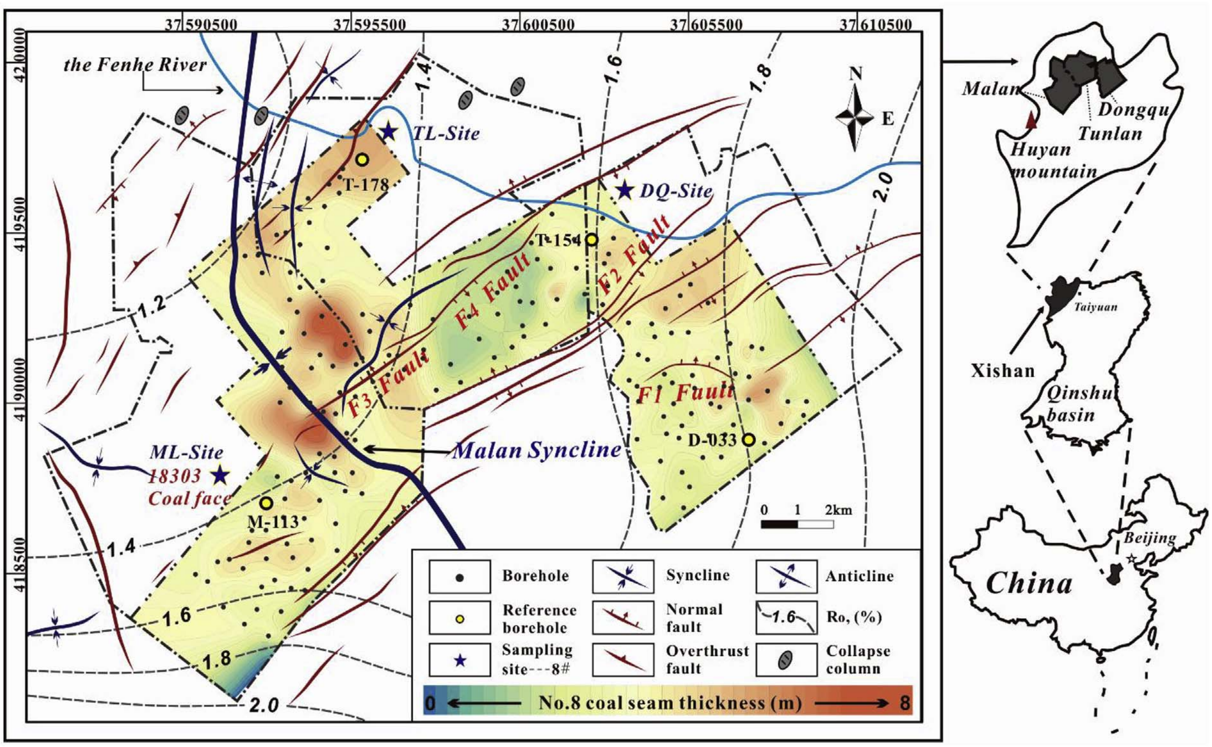

Fig. 1. Location and geological structure of the Gujiao Block in the northern Qinshui basin, North China (the structure outline was modified from Wang et al., 2015).

favorable CBM production areas and avoiding mining disaster. Previously, structured coal often shows various brittle and ductile deformations (Ju and Li, 2009). Obviously, coal structure types, with an increasing brittle deformation, can be classified as undeformed, cataclastic and granulated coals (Fu et al., 2009). Due to the differences in the pore structure or different degrees of consolidation between structured coal and undeformed coal (Yao et al., 2011a,b), the porous structure exponent can be used as an indicator to quantitatively recognize coal structures. After that, Teng et al. (2015) developed geophysical logging methods to evaluate the vertical and regional coal structures in the southern Qinshui basin, China. Recently, Xu et al. (2016) proposed and validated that coal macro-lithotypes can be revealed using geophysical logging data.

To date, identifying coal structure through well logging data is still feasible (Fu et al., 2009; Yao et al., 2011a,b; Teng et al., 2015). However, these methodologies are only suitable for individual blocks and faces, a practical challenge existed: lacking of universal evaluation method for quantitative identification of coal structure. Therefore, in this paper the principal component analysis (PCA) is selected to precisely and sequentially evaluate coal structures by using well log data including CAL, Rt, GR and DEN. Firstly, an F-Index as a quantitative index of coal structure is proposed to indentify the destruction of coal sub layers. Secondly, the D-Index is established to reflect the deformation of whole coal seam in a single well. Moreover, the above two indexes are universally and synthetically applied to assess the coal structure in the Gujiao block, northwestern Qinshui basin. Finally, the paper concludes with a discussion of the relationship of coal structures with related geologic variables.

2. Geological setting

2.1. Geological structure

The Gujiao block is located in the Xishan coalfield of northwestern Qinshui basin, which includes three coalmines, Malan, Tunlan and Dongqu from east to west. The area covers 29.5 km from east to west (longitude 112°16′22” to 111°58′08”) and 26.5 km from north to south (latitude 37°45′13” to 37°55′58”) (Fig. 1). Qinshui basin structures are mainly characterized by a series of broad and gentle folds with NNE and nearly NS directions (Sang et al., 2009) and a few internal secondary folds (Cai et al., 2011). The Gujiao block is surrounded by a rift depression basin on the east and south and is on the edge of a tectonically developed area, mainly controlled by the Malan syncline (Wang et al., 2015). Collapse columns are mainly developed in the area containing the river near the basin margin (Fig. 1). The coal-bearing strata in the study area experienced multiple orogenic events including Hercynian, Indosinian, Yanshanian and Himalayan movements (Liu et al., 2013). A shallow fault system primarily developed during the early Yanshanian movement, which includes normal faults, horst and graben, in the middle of the study area. Due to magmatic intrusion influences in the southwest research area, coal seams were promoted to middle-high rank coal through superimposed plutonic metamorphism and magmatic intrusion (Pang et al., 2015). That is, the current geological structures in the study area are products of the Yanshanian movement, and basement structures of coal-bearing strata are characterized by fold-thrust patterns with sub-folds that developed parallel to the Malan syncline.

2.2. Coal-bearing strata

The main coal-bearing strata consists of Upper Carboniferous Taiyuan formation (C2t) and Lower Permian Shanxi formation (P1s), which include Nos. 02, 03, 2, 3, 4, 6, 7, 8 and 9 coal seam (Fig. 2). The Taiyuan formation was deposited in a seashore-delta environment with variable lithology including sandstone, mudstone, siltstone, limestone and coal (Wang et al., 2015). No. 8 and 9 coal seams of the Taiyuan formation and No. 2 coal seam of the Shanxi Formation are the most continuous and stable, with thicknesses of 1–8 m, 1–4 m and 1–6 m, respectively. The targeted No.8 coal seam was deposited in a tidal flat, which formed in the late high-stand system tract and was located at the top of the sequence I high-stand system tract (Fig. 2). The coal rank (R_o %) of No.8 coal seam ranges from 1.2% to 2.0% (Fig. 1).