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In-situ stress distribution and its implication on coalbed methane development in Liulin area, eastern Ordos basin, China

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ABSTRACT

Based on well test parameters independently measured within depth from 400 to 1100 m in Liulin area, eastern Ordos Basin, China, the distribution of in-situ stress was analyzed systematically. Maximum horizontal principal stress (σ_{Hmax}), minimum horizontal principal stress (σ_{Hmin}), vertical stress (σ_v) and lateral pressure ratio variations with depth were obtained by regression analysis. Results show that the growth rate of horizontal stresses is higher than that of vertical ones. Three types of stress fields were found and calculated: the type of $\sigma_v \approx \sigma_{Hmax} \approx \sigma_{Hmin}$ mainly distribute in relatively shallow coal seams from 400 to 700 m; the $\sigma_{Hmax} > \sigma_v > \sigma_{Hmin}$ type ranges from 700 to 850 m; and, the $\sigma_v > \sigma_{Hmax} > \sigma_{Hmin}$ type is dominant in depth from 850 to 1100 m. Coal permeabilities obtained during injection/falloff tests showed that the permeability was damaged under a depth of 700–850 m for the relatively high σ_{Hmax} and σ_{Hmin}. The correlation between strata temperature and depth was also illustrated, which showed three linear relationships in depth of 400–700, 700–850, and 850–1100 m, separately. The gas content and gas/water production data were also plotted, showing that the strata shallower than 700 m is of better gas resources and recovery rate than the deeper strata.

1. Introduction

Estimation of in-situ stress for coal bearing strata has been applied widely in underground mines, as well as in coalbed methane (CBM) exploration in many coal basins of USA, China, Australia and Canada (Bell and Bachu, 2003; Meng et al., 2007; Gentzis, 2009; Meng et al., 2010). In-situ horizontal stress is a key factor for roof stability in underground coal mines and it also facilitates permeability predicting and fluid flow in CBM reservoirs (Tyler et al., 1997; Bell and Bachu, 2003; Shi and Durucan, 2005; Bell, 2006). The vertical stress (generally overburden load data) is significant in the numerical simulation of faulted zones, rock stiffness, and rock falls (Hoek and Brown, 1980; Wu et al., 2004; Karacan et al., 2008). The estimation of coal properties, such as cleat volume, cleat spacing, porosity and permeability, along with the in-situ stress, controls coal mining operation and coal mine gas drainage pattern.

In-situ stress is deeply affected by gravitational and tectonic forces, and is particularly associated with horizontal tectonic movements. A gravitational stress field is relatively simple, which is mainly influenced by the overlying rock mass, while the causes for a tectonic stress field are much more complicated. The tectonic stress is extremely irregular and almost impossible to be described by precise analytical solutions, for it is constant changing as with time (Kang et al., 2010).

Accurate prediction of in-situ stress distributions plays a principal role in estimating the production potential for CBM reservoirs, which is closely bound up with the permeable fracture aperture and direction. Permeability is one of the most important factors in determination of CBM productivity. During CBM production or enhanced CBM recovery, the pore pressure and gas content are placed in a variation state with a constant and almost simultaneous influence on permeability. To date, it has been generally accepted that coal permeability exponentially declines with an increase in effective stress, and this decline is potentially offset by the permeability enhancement because of matrix shrinkage (White et al., 2005; Bustin et al., 2008; Kumar et al., 2010). Commonly, matrix swelling/shrinkage is accompanied by a volumetric strain in coals, which further impacts the permeability of the coal (Wang et al., 2011). Moreover, coal permeability may decrease with increased moisture content for all the gases (including He, CH_4 and CO_2) (Kumar et al., 2012).

The particularities of coal properties in deep coal seams have also been proposed, such as vertical belting in gas adsorption capability, gas content and the presence of pores and fractures, and all those may be affected by the in-situ stress distribution.

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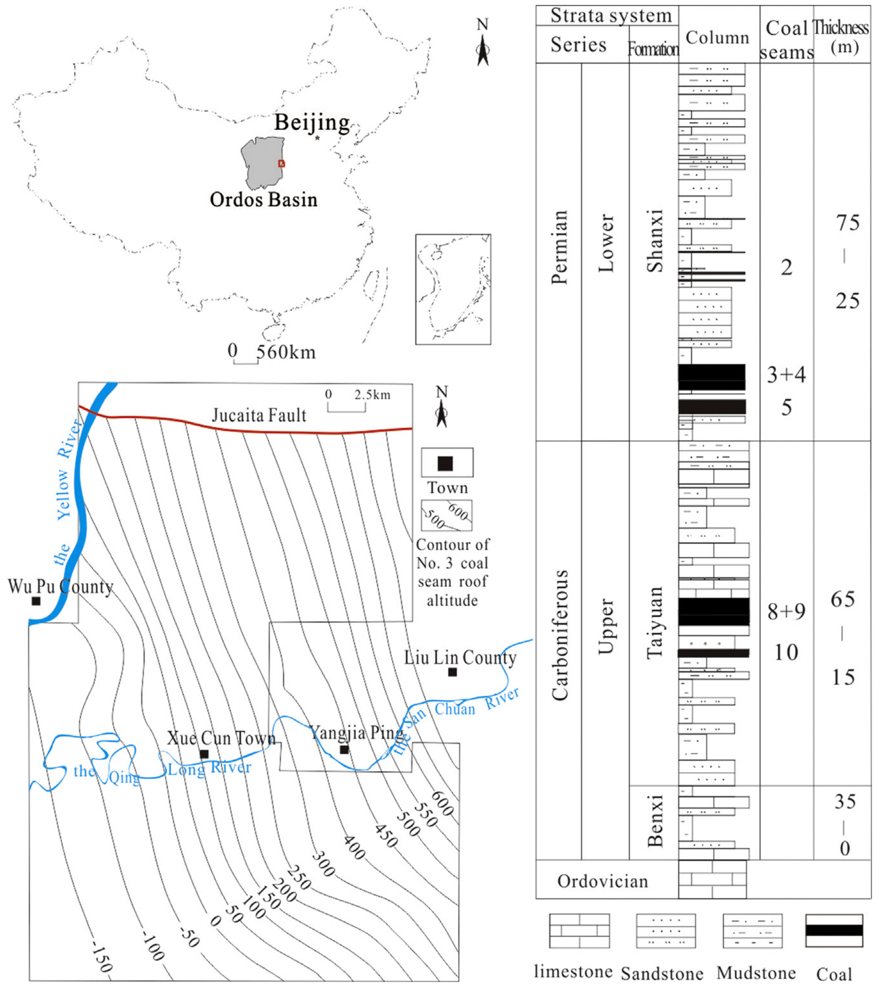

Fig. 1. Location of Liulin area, showing the contour of No. 3 coal seam roof altitude and the stratigraphic column of coal bearing strata.

The deep coal permeability is influenced by the transition of in-situ stress magnitude and direction, and the variation of adsorptive capacity is tightly associated with geo-temperature field (Qin, 2012; Liu et al., 2014). Focused on CBM development and its relationship with in-situ stress field under different coal burial depth, this study shall generate valuable data for various uses, (a) a combination of injection/falloff and in-situ tests parameters together showing the stress-permeability properties of coal strata, (b) to study the variation of in-situ stresses relative to the depth of coal seams, (c) to generate stress distribution characteristic graphs related to depth, showing the stress field types, (d) correlating in-situ stress and coal permeability, and (e) illustrate the effect of in-situ stress on geothermal field, CBM accumulation and production.

2. Geological and tectonic background

Liulin area locates in the middle of the eastern Ordos Basin, which is a key CBM development area since 1990s. The stratigraphy was eroded from Silurian to Early Carboniferous, then subsided and deposited from the Late Carboniferous period to Triassic time. The stratum is composed of marine carbonate of the Cambrian – Ordovician period and marine terrigenousfacies carbonate, with clastic sediment and coal seams of the Carboniferous – Permian period, with conformable or disconformable contact between adjacent stratigraphic units. The main strata containing coal seams are Taiyuan Formation and Shanxi Formation (Chen et al., 1989; Su et al., 2003). The stratigraphy strikes nearly north–south, and dips westward at 3–8°. The tectonic structure is relatively stable in the study area, with the Jucaita Fault appearing in the north edge of the study area (Fig. 1).

The Taiyuan formation was deposited in a lagoon, tidal flat, and sandbar environment under the influence of an Epicontinental Sea, and the coal seams were formed in a tidal flat environment after marine regression. However, when the Shanxi formation was deposited, the environment evolved to a prograded delta, and coal seams were formed on the floodplain of the delta interdistributary area. Nowadays, coal seams both in the Taiyuan and Shanxi Formation are target formations for CBM development. Some wells produce gas from coal seams of No. 3+4 and 5, and some from No. 8+9 coal seams.

3. Methodology

Injection/falloff method was used for the well test and data acquisition, and the wells were tested after completion and before production. To conduct a full cycle of injection/falloff test, water was injected at a constant rate for a period of time, causing a higher pressure distribution near the well bore, and then shut in the well. During both the injection and shut-in periods, the bottom-hole pressure is measured using a down-hole pressure gauge. Through processing pressure-data from both the injection period and the falloff period independently the permeability is estimated. The detailed test procedure has been discussed by Zuber et al. (1990) and Hopkins et al. (1998).