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Evolution and geochemical characteristics of gas phase fluid and its response to inter-well interference during multi-well drainage of coalbed methane

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ABSTRACT

The Fanzhuang block from the southern Qinshui basin was used as a monitoring area to determine the components, the methane carbon isotopes ($\delta^{13}C_1$) and the methane hydrogen isotopes (δD) of the recovered coalbed methane (CBM) during the different production times. The spatial evolution characteristics of the CBM components, $\delta^{13}C_1$ and δD and their response to inter-well interference during multi-well drainage in CBM production areas were analyzed visually. The results show that CBM components, $\delta^{13}C_1$ and δD all fluctuated; the spatial distribution direction of CBM components, $\delta^{13}C_1$ and δD also changed twice or more during sampling in the studied area. The fractionation of δD lags behind the fractionation of $\delta^{13}C_1$. The spatial distribution of the CBM components is affected by the CBM components obtained from partial CBM wells; the spatial distribution of $\delta^{13}C_1$ and δD of coalbed methane is affected by the fractionation of $\delta^{13}C_1$ and δD from the produced CBM. The decrease in the CBM components and the $\delta^{13}C_1$ and δD ratios reveals the effects of inter-well interference on the multi-well patterns. The variability in the spatial distribution direction of CBM components, $\delta^{13}C_1$ and δD shows that inter-well interference may still be in an early stage or the degree of inter-well interference may be relatively weak. The incomplete consistency of the spatial evolution of CBM components, $\delta^{13}C_1$ and δD is mainly related to the fractionation of CBM components and methane isotopes during drainage and the change in the CBM supply caused by the unstable fluid field under unbalanced inter-well interference. It was shown that inter-well interference during multi-well drainage increases and then begins to stabilize. The established geochemical response model and evaluation program of inter-well interference provide a method to determine the stage and the degree of inter-well interference in CBM production areas, not only in the southern Qinshui basin but also in other CBM basins with low permeability.

1. Introduction

Analysis of reservoir pressure and numerical simulation of the pressure drop funnel under multi-well drainage applied to inter-well interference of coalbed methane (CBM) wells is the primary method to study inter-well interference in CBM production areas worldwide (Fan et al., 2005; Harrison et al., 2006; Kang et al., 2007; Lai et al., 2013; Liang and Chen, 2012; Liu et al., 2005, 2014; Nenna and Aydin, 2011; Yang et al., 2009; Zhang et al., 2010). Not only the fluid pressure but also other properties of the fluid in a coal reservoir change under multi-well drainage in CBM production areas. This means that the geochemical properties of the formation water and coalbed methane will change, especially the distribution and the fractionation of CBM components and methane isotopes, all of which are related to the source of CBM (Liu et al., 2013a). Studies on the distribution and the fractionation characteristics of CBM components and the stable carbon isotopes of methane were applied to CBM exploration and exploitation (Duan et al., 2010; Gao et al., 2002; Ju et al., 2014; Qin et al., 2006; Qing et al., 1998; Zhang and Tao, 2000). The fractionation effect of CBM components and the mechanism of the rich light carbon isotope and the rich heavy carbon isotope are very well understood. However, the understanding of the effect of inter-well interference of the overlap area on the spatial distribution and

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the fractionation characteristics of the produced CBM during multi-well drainage are not as well understood. A study focused on the changes in the drainage fluid during CBM production in China was performed (Zhang et al., 2011), but the relationship between the change in the drainage fluid, especially the characteristics of CBM and the mechanism of inter-well interference, is not understood and requires further examination. Therefore, CBM production areas, including 15 CBM wells from the Fanzhuang block of the southern Qinshui basin of China, were chosen for monitoring CBM production areas. The CBM was systematically sampled; the CBM components and carbon and hydrogen isotopes of methane were tested. The spatial variations of CBM components and methane carbon and hydrogen isotopes during multi-well drainage in CBM production areas were analyzed by mapping. The correlation between the spatial evolution of CBM components, methane carbon and hydrogen isotopes and inter-well interference will be discussed. The evolution characteristics and their response to inter-well interference in a gas phase fluid field of CBM under multi-well drainage will be revealed based on the test data.

2. Geological setting

The Fanzhuang block in the southern Qinshui basin, Shanxin Province, is the most active region for CBM exploration and development in China (Liu et al., 2012; Lv et al., 2012; Su et al., 2005; Tao et al., 2014). The study area and the primary geological information such as faults and locations of sampling in CBM production areas are illustrated in Fig. 1. The coal-bearing strata in the area experienced multiple organic events, including the Variscan, Indosinian, Yanshanian and Himalayan orogenies (Song et al., 2005). Multiple structural evolutions controlled the main tectonic pattern, which formed a series of folds striking NNE and joints striking NW or EW, and extensional tectonics such as normal faults (Liu et al., 2013b, 2014).

The coal-bearing strata of the studied area consists of, from bottom to top, the Benxi, Taiyuan, Shanxi, Shangshihezi and Shiqianfeng formations of the Permo-Carboniferous; coal seams No. 3 and No. 15 in the studied area are developed in the Tanyuan and Shanxi formations. The Shanxi formation comprises mudstone, sandstone, sandy mudstone and coal deposited in the deltaic environments (Liu et al., 2014). The target coal seam No. 3 develops stably in the whole area with an average coal thickness of 6 m. The main aquifer is sandstone from the indirect roof among different coal seams, the mudstone and sandy mudstone in the Shanxi formation are the relative aquiclude, and there is no hydraulic relation between the Shanxi and Taiyuan formations. The equipotential surfaces of hydrodynamic force in the studied area decrease from north to south; an obvious stagnant area is formed in the Fanzhuang block (Su et al., 2005; Wang et al., 2001).

3. Methodology

3.1. Sampling

The Fanzhuang block has been a mature production block for CBM since extraction of CBM began in 2006, and it has fully implemented the production of CBM wells. To analyze the formation of inter-well interference and its stage, a monitoring area was set up in the Fanzhuang block (see Fig. 1). Nine batches of CBM samples were collected from the producing CBM wells; the average sampling interval was 15 days, and the sampling amount was approximately 150 times.

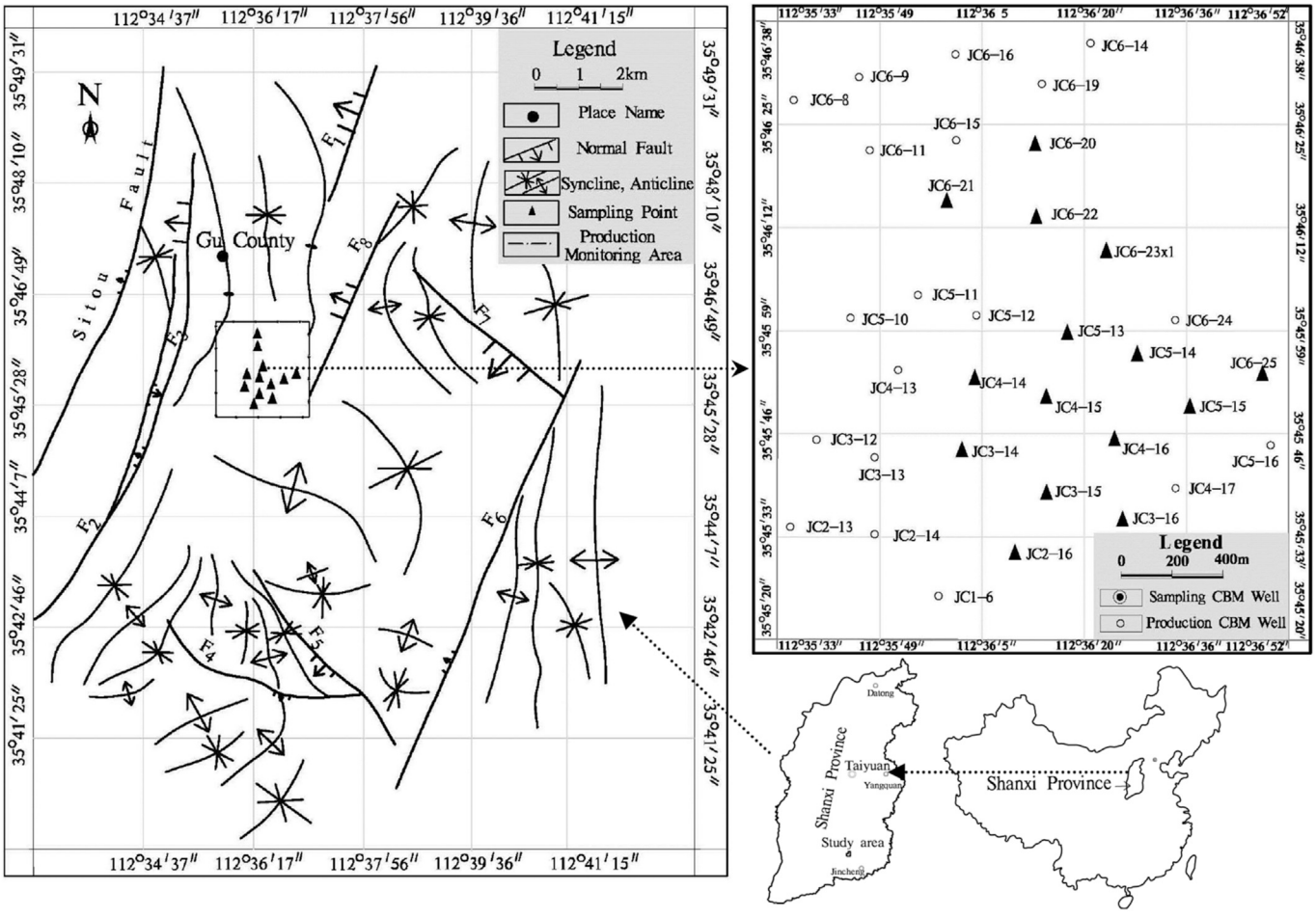

Fig. 1. Schematic map of structure in studied area and sampling spots.