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Depositional environment, sequence stratigraphy and sedimentary mineralization mechanism in the coal bed- and oil shale-bearing succession: A case from the Paleogene Huangxian Basin of China

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ABSTRACT

It has been a long dispute in the forming mechanism of coal and oil shale in coal-and oil shale-bearing succession because the depositional environments between coal and oil shale are distinctly different. In this study, the Huangxian Basin was chosen as a typical example to study the mechanism of sedimentation of the coal and oil shale. Eleven facies and four facies associations have been recognized from petrologic, sedimentological and paleogeographic characteristics. The four facies were formed in alluvial fan, fan delta, braided stream, braided stream delta, shore-shallow lake-lacustrine bog, shallow lacustrine and deep lacustrine environments. Two types of sequence boundaries (regional unconformities and regional exposed non-sedimentary surfaces) and double systems tract boundaries (maximum flooding and first flooding surfaces) are identified. Sequence stratigraphic frameworks with two sequences (each including three systems tracts) are established to analyze the depositional evolution. We find that the Huangxian Basin is a paralic continental faulted lacustrine basin with four different types of coal bed and oil shale combinations: oil shale/coal bed/oil shale (OS-CB-OS), coal bed/oil shale (CB-OS), coal bed/mudstone/oil shale (CB-M-OS) and oil shale/coal bed (OS-CB). The formation mechanisms of the coal bed and oil shale associations are interpreted to be: a) the basin first experienced transgression, giving rise to the CB-OS or CB-M-OS combinations where oil shale was overlain by coal beds, and b) continental, non-lacustrine deposition developed in the basin and was terminated by subsequent transgression, forming lacustrine deposits. Later, the basin was silted into a peat swamp that was subsequently interrupted by transgression or terrigenous clastic deposition, eventually forming OS-CB-OS or CB-OS combinations. Through analyzing depositional evolution of the basin we conclude that lowstand system tracts tend to develop CB-OS associations; expanding system tracts tend to develop CB-OS, CB-M-OS and OS-CB-OS combinations; and highstand system tracts tend to develop OS-CB combinations.

1. Introduction

Coal beds and oil shale are two types of sedimentary rocks formed in different depositional environments. Peat swamps (coal bed) were present between water and dry land (Diessel, 1992), while oil shale was formed by the preservation and aggregation of algae in deep-water environments (Cameron et al., 1994). Coal–forming environments are various including fan, braided channels, meandering river, barrier-lagoon, tidal flat and delta plain and so on (Cadle et al., 1993; Caldera and Gibling, 1994; Banerjee et al., 1996; Greb and Weisenfluh, 1996; Holz, 1998; Valero et al., 1997; Diessel et al., 2000;Caldera and Gibling, 1994; Li et al., 2014). So coal can be found in the process of transgression or regression stages (Diessel, 1992; Kalkreuth and Davies, 1996; Li et al., 1998). Many coal-forming processes have been proposed, such as coal-formation in a continental environment (during regression) (Diessel, 1992) and in the process of transgression (Diessel, 1992; Li et al., 1998). In the view of sequence stratigraphy (Li et al., 2001), coal beds can be developed in every systems tract in a depositional sequence. Oil shale can be formed and preserved in special conditions, such as tectonic subsidence, and specific paleoclimates and paleogeographies. The main factors responsible for water stratification changes during different periods are geological condition

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changes. Lake stratification was formed by one or several factors among tectonic movements, climate and transgressions (Bradley, 1966; Eugster et al., 1973; Desborough, 1978). The organic matter (algae) could be deposited and preserved because of the lake stratification (Bradley, 1966; Eugster, et al., 1973; Desborough, 1978). So many depositional environments (inland lakes, lakes/swampes, lagoon, paralic environments etc.) can develop oil shale (Bechtel et al., 2012; Li et al., 2005; Wolela, 2010; Bai et al., 2006). Although Oil shale can be found in different system tracts (Wang et al., 2016; Bai et al., 2006), highstand system tracts can be found to formed oil shale (Wang et al., 2016). At present, coal beds and oil shale bearing successions have been found in many basins, such as the Fushun Basin (Meng et al., 2012), Huadian Basin (Sun et al., 2013), Songliao Basin (Bechtel et al., 2012), Ethiopia's Delbi-moye Basin (Ahmed, 2004), Mae Sot Basin in Thailand (Curiale and Gibling, 1994), and Liard Basin in the Early Carboniferous Visean rocks in northern Canada (Potter et al., 1993). Currently, the studies of coal- and oil shale-bearing successions mainly focus on the hydrocarbon generation potential of oil shale, organic geochemical characteristics (Sun et al., 1998, 2013, Wang et al., 2011), and paleoenvironmental evolution (Meng et al., 2012; Ahmed, 2004; Bechtel et al., 2012). It is difficult to explain their formations with a single model when the coal and oil shale were both formed in the same basin because a set of special conditions and controlling factors must exist to make the environments to change quickly. This is also very important for predicting the coal and oil shale distributions. We use the Huangxian Basin as a case to study the mechanism of the coal and oil shale co-forming by studying its sequence stratigraphy.

The Huangxian Basin is a Cenozoic basin located in the eastern part of China and was deposited with a coal and oil shale rock series from the Eocene to Oligocene of Paleogene (Li et al.,1998). There are several reasons for us to choose Huangxian Basin as a case study. First, the coal and oil shale of the basin have been exploited for many years, as they have great mining value (Li et al., 1998) and abundant geological data have been accumulated. Second, there are many types of coal bed and oil shale combinations, while only one or two combination types were observed in other basins. A coal bed can exist as a roof or a floor of an oil shale or between oil shale layers, frequently reflecting the change of the sedimentary environments (Liu et al., 2009a, 2009b). Third, Huangxian Basin has a special geological setting, with a synsedimentary fault to the south (Wang, 2007) and is open in the north to the sea. These indicate that the basin has experienced many transgressions (Chen, 1988; Wang et al., 2001; Xu et al., 2012). Activity on the synsedimentary fault can influence transgressions, which may frequently cause changes from an environment that favors peat swamp formation to another that favors oil shale formation (Sun et al., 1998; Wang, 2000). The depositional sequence of the Huangxian Basin, controlled by transgressions, synsedimentary fault, basement subsidence, and sediment supply, has special characteristics (Li et al., 1998; Xu et al., 2006). These characteristics are required for the formation of both coal and oil shale in the same basin. Although many studies have been published on the sedimentary sequence, tectonics, transgressions in the Huangxian Basin (Lv et al., 2015, 2016), there are still two unresolved questions: (1) how did transgression influence on coal and oil shale sedimentary mineralization processes and (2) which stage

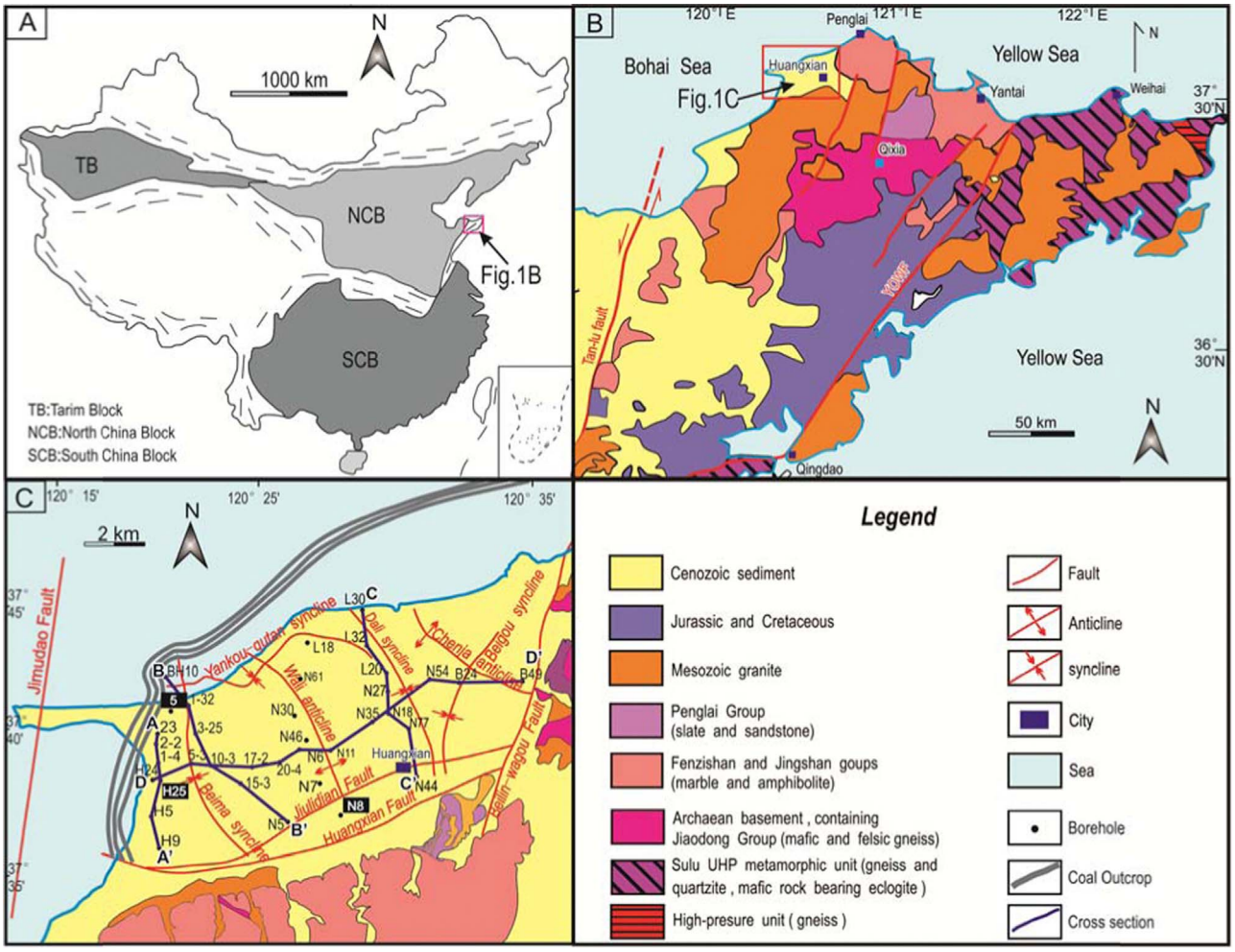

Fig. 1. Regional location and regional geotectonic map of Huangxian Basin. A is the location of Shandong Province of China, B is the Huangxian location in Shandong Province, C is the Huangxian Basin geological picture and the well location.