Journal of Asian Earth Sciences 79 (2014) 16–30

Contents lists available at ScienceDirect

Journal of Asian Earth Sciences

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

Depositional environments and sequence stratigraphy of the Late Carboniferous–Early Permian coal-bearing successions (Shandong Province, China): Sequence development in an epicontinental basin

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ARTICLE INFO

Article history:
Received 10 February 2013
Received in revised form 29 August 2013
Accepted 2 September 2013
Available online 19 September 2013

Keywords:
Sedimentary facies
Sequence stratigraphy
Coal-bearing succession
Carboniferous
Permian
North China epicontinental basin

ABSTRACT

This study focuses on the Late Carboniferous–Early Permian coal-bearing successions in Shandong Province, North China in order to understand the depositional processes and sequence-stratigraphic framework in an epicontinental basin. Based on detailed analysis of eleven facies, five facies assemblages (FAs) were recognized in the studied succession. FA1–3 are present mainly in the Benxi and Taiyuan formations, and consist of mixed siliciclastic and carbonate lithofacies, representing eluvial-lagoon, barrier-lagoon, and tidal-flat environments. FA4 occurs in the Shanxi formation and consists mainly of interbedded medium to fine sandstone, siltstone, mudstone, and coal lithofacies, representing river-dominated deltaic environments. FA5 is characterized by interbeds of trough cross-stratified coarse sandstone, and silty mudstone, mainly in the Lower Shihezi Formation, which was deposited in meandering river channel and floodplain. Three third-order sequences were established based on the vertical arrangement of facies assemblages and identification of physical surfaces (i.e., subaerial unconformity, transgressive surface, and regressive surface). Each sequence comprises a transgressive systems tract (TST) and a high-stand systems tract (HST). TST of sequence 1 is composed of eluvial lagoonal deposits (FA1), whereas HST formed in lagoon-barrier and tidal-flat settings (FA2 and FA3). TST of sequence 2 formed in a barrier-lagoon system (FA2), whereas HST is characterized by repetitive accumulation of interbedded limestone, sandstone, mudstone, and coal, deposited under lagoonal and tidal-flat settings (FA2 and FA3). TST of sequence 3 comprises FA2, and HST mainly FA4, deposited in a river-dominated shallow-water delta system. Sequence 3 is overlain by a fluvial sequence (FA5). The three third-order sequences in the Shandong region are generally correlated with those in the Taebaeksan Basin (South Korea), the eastern part of the North China Block. The relative sea-level curves established in the two regions show a generally similar long-term rising trend.

1. Introduction

Peat deposits (later transformed into coal beds under suitable conditions) may be preserved under various depositional settings in response to relative sea-level fluctuations, and therefore, are often used as sequence-stratigraphic indicators (e.g., Diessel, 1992; Chesnut, 1996; Jerrett et al., 2011; Wang et al., 2011). The Late Paleozoic coal-bearing successions have been intensively studied worldwide in terms of depositional processes of coal beds, sequence stratigraphy, and glacio-eustatic sea-level changes (e.g., Busch and Rollins, 1984; Nelson et al., 1985; Ferm and Weisenfluh, 1989; Bennington, 1996; Garcésa et al., 1997; Holz et al., 2002; Eble, 2002; Waldron and Rygel, 2005; Desjardins et al., 2009; Flint et al., 2011). These studies mostly concentrated on coal-bearing successions in passive continental margin basins or foreland basins (e.g., Limarino et al., 2006; Rygel et al., 2008; Desjardins et al., 2009; Nakazawa et al., 2009), which provided an insight into sequence development in these sedimentary basins. However, sequence development in epicontinental basins has been rarely reported, due to complex interaction among topographic reliefs, siliciclastic influx, carbonate production, and local hydrodynamics which makes it hard for basin-scale sequence-stratigraphic correlation (e.g., Osleger and Montañez, 1996; Chen et al., 2011, 2012; Lee and Chough, 2011).

The North China Block formed a large coal-accumulating epicontinental basin during the Late Carboniferous to Early Permian (Liu, 1990; He et al., 1991; Li et al., 2002), although it was argued that the basin was transformed into a foreland basin during the Early–Middle Permian (e.g., Meng and Ge, 2001). The succession

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http://dx.doi.org/10.1016/j.jseaes.2013.09.003

comprises a thick (178–369 m), siliciclastic-dominated, shallow-marine and paralic deposits, unconformably overlying the Middle Ordovician carbonates (Kim et al., 2001). The succession contains economically important coal-bearing deposits, and also bears certain paleoenvironmental implications for the Late Carboniferous to Early Permian glacial period (Liu, 1990; He et al., 1991; Shao et al., 1999; Chen, 2000; Li et al., 2001; Lv et al., 2009). In this paper, we present detailed sedimentological characteristics and a sequence-stratigraphic framework for the Late Carboniferous to Early Permian coal-bearing successions in the Shandong region (North China). This study will not only facilitate coal prediction and assessment in this region, but also provide a basis for future investigations into tectonic evolution of the North China epicontinental basin as well as sedimentary responses of the epicontinental sea to glacial-eustatic changes.

2. Geologic setting

The North China Block is bounded by the Qinling–Dabie Orogen in the southwest, the Tanlu Fault in the east, and the Hinggan Fold Belt in the North (Li et al., 2010, 2012; Zhai and Santosh, 2011, 2013). Marine sedimentation started from the Late Carboniferous in the North China Block and was replaced by continental environments from middle to late Early Permian. The study area (midwest Shandong Province) is one of the geological subdivisions of the North China Block, and is bounded by the Bohai Bay Basin in the north, the Tanlu Fault in the east, the Hantai Fault in the South, and the Liaokao Fault in the west (Fig. 1). It covers an area about 320 km north–south and 280 km west-east, and consists of a thick Late Carboniferous–Early Permian coal-bearing succession (Liu, 1990; Chen and Liu, 1995; Querol et al., 1999). The succession consists of the Benxi, Taiyuan, and Shanxi formations in ascending order (Fig. 2). The Benxi Formation (~20.6 m thick) mainly comprises bauxite and (sandy) mudstone. The Taiyuan Formation (~179.3 m thick) consists mainly of greenish-gray mudstone, limestone, sandstone, and coal seams. The Shanxi formation (~136.3 m thick) is characterized by thick-bedded sandstone and mudstone, and a few coal beds.

3. Sedimentary facies

The present study is based on a detailed sedimentary facies analysis of the Benxi, Taiyuan, and Shanxi formations (Late Carboniferous to Early Permian) in Zibo section and ten cores in Shandong Province, China (Fig. 1). Eleven sedimentary facies are classified and described in terms of lithology, grain size, and sedimentary structures, as well as color, texture, bed geometry, and fossil contents (Table 1). These facies are grouped into five facies assemblages (FA1–5), representing shallow-marine to fluvial environments (Table 2).

3.1. Facies assemblage 1 (FA1)

3.1.1. Description

FA1 consists mainly of bauxite (BA) and mudstone (Mh), characteristic facies of the Benxi Formation (Fig. 3). It unconformably

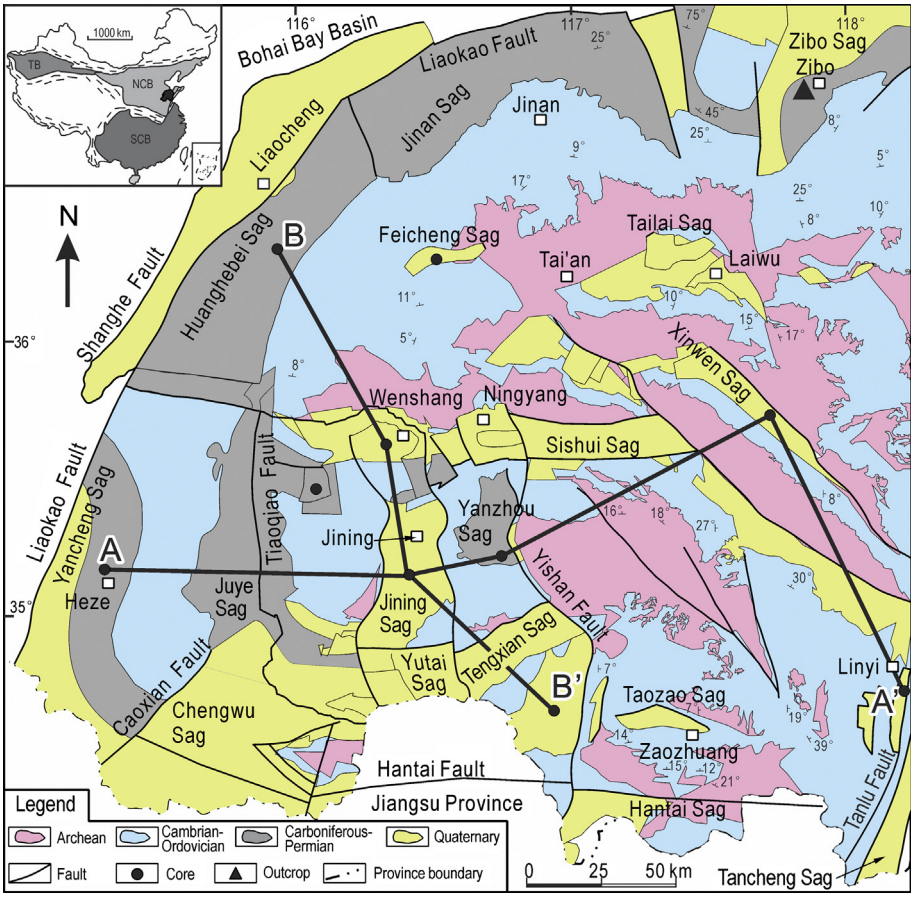

Fig. 1. Simplified geological map of the Shandong region, China, showing studied outcrop sections and cores of the Carboniferous–Permian coal-bearing successions. The inset map shows the major tectonic boundaries and subdivisions. NCB: North China Block, SCB: South China Block, TB: Tarim Block. The black area in the inset map indicates the location of studied region.