Marine and Petroleum Geology 64 (2015) 347–362

Contents lists available at ScienceDirect

Marine and Petroleum Geology

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

Research paper

Deposition of coal and oil shale in NE China: The Eocene Huadian Basin compared to the coeval Fushun Basin

Susanne A.I. Strobl [a, c, *], Reinhard F. Sachsenhofer [a], Achim Bechtel [a], Qingtao Meng [b], Pingchang Sun [b]

[a] Department of Applied Geosciences and Geophysics, Montanuniversitaet Leoben, Peter-Tunner-Straße 5, Leoben 8700, Austria
[b] College of Earth Sciences, Jilin University, Changchun 130061, China
[c] Federal Ministry of Science, Research and Economy, Division Minerals Policy, Denisgasse 31, 1200 Vienna, Austria

A R T I C L E I N F O

Article history:
Received 16 October 2014
Received in revised form
12 March 2015
Accepted 15 March 2015
Available online 26 March 2015

Keywords:
Huadian Basin
Fushun Basin
Depositional environment
Organic geochemistry
Coal
Oil shale

A B S T R A C T

The Huadian and Fushun basins, located along the DunMi fault zone (NE China), are filled with non-marine coal- and oil shale-bearing sediments of Eocene age. Despite similar tectonic setting, the habitat of coal and oil shale differs significantly. During this study the depositional environment of organic-rich sediments in the Huadian Basin and factors controlling differences between both basins were investigated. Early in the history of the Huadian Basin, thin coaly and bituminous mudstones accumulated in shallow lake environments (Pyrite Member). Water depth increased during deposition of the Oil Shale Member, but did not exceed a few tens of meters preventing stable water column stratification. Moreover, deposition of fan delta sediments interrupted accumulation of fine-grained rocks. Nevertheless, algal blooms and oxygen-depleted conditions resulted in accumulation of 13 thin (<7 m) oil shale layers. Oil shale quality varies between different layers due to variable portions of terrestrial organic matter. Ash-rich coal layers mined in the Huadian Basin developed during the regressive late stage of basin evolution (Carbonaceous Shale Member). Biomarkers indicate a change from an angiosperm-to a gymnosperm-dominated vegetation. In the Fushun Basin, a single 120-m-thick coal seam formed during early basin subsidence. Subsequently, high subsidence rates established deep lacustrine conditions with photic zone anoxia and a water depth probably exceeding 150 m. Stable, strictly anoxic conditions allowed accumulation of a 300-m-thick oil shale layer. The main factor controlling differences between the Huadian and Fushun basins is tectonic subsidence.

High subsidence rates in the Fushun Basin favored deposition of thick coal during the transgressive stage and of oil shale in a deep lake. In contrast minor subsidence in the Huadian Basin resulted in a lake with moderate water depth and deposition of several oil shale layers with varying quality. In this basin economic coal developed only during the regressive stage.

1. Introduction

World-class coal and oil shale deposits have been formed during Eocene time along the Dunhua-Mishan ("DunMi") fault zone in northeastern China (Fig. 1). The economically most important deposit is located within the Fushun Basin, where a single, up to 120-m-thick coal seam overlain by 300-m-thick oil shale is exploited in a huge openpit mine (Liu et al., 2009; Sun et al., 2013; Strobl et al., 2014a, 2014b). The annual oil shale production is 11 mio. t yielding 330,000 t of shale oil.

Coal and oil shale is also produced in the Huadian Basin, where a high number of coal and oil shale layers, only a few meters thick, is mined underground. Main mining activities in the Huadian Basin are concentrated in its eastern part (Gonglangtou district). Compared to the Fushun Basin, annual oil shale production is minor (about 1.3 mio. t). The produced oil (70,000–80,000 t/a) is used as ship fuel. Both, in the Fushun and Huadian mining districts, oil shale is defined by an oil yield exceeding 3.5 wt.%.

Obviously, major differences in the thickness and distribution of coal and oil shale layers exist between the non-marine Huadian and Fushun basins, although both basins are located at the same strike-slip zone and formed roughly contemporaneously.

* Corresponding author. Department of Applied Geosciences and Geophysics, Montanuniversitaet Leoben, Peter-Tunner-Straße 5, Leoben 8700, Austria. Tel.: +43 1 711 00 8513.
E-mail address: strobl_susanne@yahoo.de (S.A.I. Strobl).

http://dx.doi.org/10.1016/j.marpetgeo.2015.03.014
0264-8172/

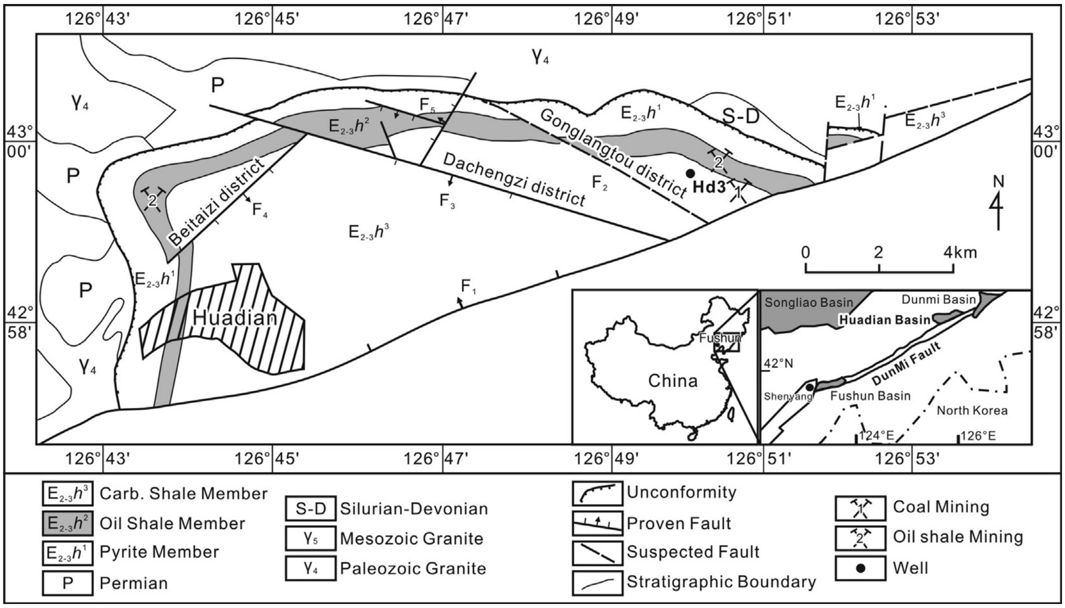

Figure 1. Geological map of the Huadian Basin [modified according to Sun et al. (2013)]. An overview map with special focus on the location of the Huadian and Fushun basins and the DunMi fault zone is shown as inset [modified according to Meng et al. (2012), Strobl et al. (2014a; 2014b)].

Whereas the depositional environment of coal and oil shale in the Fushun Basin has been studied recently (Strobl et al., 2014a, 2014b), only total organic carbon (TOC) contents, hydrogen index (HI) values, oil yield (Sun et al., 2013) and some petrographic data (Xie et al., 2014) are available from the Huadian Basin.

Therefore, the present study has two major aims: to reconstruct the depositional environment of coal and oil shale layers in the Huadian Basin and to compare it with that of coal and oil shale in the coeval Fushun Basin.

To reach the goals, core samples from borehole Hd3 (Fig. 1), representing the fill in the Huadian Basin (Huadian Formation) in the eastern part of the basin, have been studied using bulk geochemical proxies, maceral and biomarker data. The borehole was selected because continuous TOC and HI profiles are available (Sun et al., 2013). The depositional environment and the architecture of the coal and oil shale layers are compared with results of a similar study in the Fushun Basin (Strobl et al., 2014a, 2014b).

2. Geological setting of the Huadian Basin

The non-marine Huadian Basin is an E–W trending halfgraben basin located along the DunMi fault zone (Fig. 1). The Eocene basin fill (Huadian Formation) is up to 1500 m thick and overlies various basement units including granite, Lower Paleozoic and Permo-Carboniferous sedimentary rocks. Outcrops of the Huadian Formation are rare because of a Quaternary cover up to 15 m thick. The Huadian Formation is subdivided from bottom to top into three members: Pyrite Member, Oil Shale Member, and Carbonaceous Shale Member (Liu et al., 2009; Sun et al., 2011, 2013).

The Pyrite Member represents the early, shallow stages of basin evolution. It comprises conglomerates and red mudstones near its base overlain by varicolored calcarenitic fine-grained sandstones, mudstones and coaly layers deposited in alluvial fan, fan delta, and shallow lake environments. The presence of pyrite crystals in fractures and pore spaces, interpreted to be hydrothermal in origin by Sun (2010), is eponymous for this member.

The Oil Shale Member was deposited during the expansion and deepening of the lake (Sun et al., 2013). It was dated as Middle Eocene based on a mammalian fauna (Zhang et al., 1986; Beard and Wang, 1991; Manchester et al., 2005). The total thickness of this member ranges from 65 to 244 m. The total number of oil shale layers varies from 6 to 26, but only 13 layers (numbered from top to bottom) are suitable for shale oil exploitation (Wang et al., 2005). Note that compared to Sun et al. (2013), the numbering of oil shale layers was modified based on new well correlations. Top and bottom of the Oil Shale Member are set at the top of oil shale layer 1 and the bottom of oil shale layer 13, respectively. Significant differences exist between oil shale deposited in the lower, middle and upper parts of the Oil Shale Member: Oil shale with relative high thickness (up to 7 m), but low to moderate quality occurs in the lower part (layers 13–8), whereas thin (<3 m) oil shales with high quality are found in the middle part (layers 7–4). Low quality oil shale, less than 2 m thick, occurs in the upper part (layers 3–1). The lateral extent of the oil shale layers increases upwards within the lower part, reaches a maximum in the middle part and decreases upwards in the upper part (Sun et al., 2013). Only layers 7 to 4 are currently mined underground. The average TOC content of the Oil Shale Member is 3.6 wt.%. The highest TOC value of a 1-m-thick interval occurs in the middle part (30.0 wt.%; Sun et al., 2013; Fig. 2, gray solid line).

Shallow lacustrine conditions prevailed during deposition of the Carbonaceous Shale Member. It represents the final filling stage of basin evolution. Economic coal seams accumulated along the lake margins are accompanied by bituminous shale (Sun et al., 2013).

3. Samples and methods

A total of 96 core samples were taken from borehole Hd3 (Fig. 1) within the depth interval of 23.1–515.5 m. This interval represents the whole Huadian Formation consisting of Pyrite (14 samples), Oil Shale (73 samples), and Carbonaceous Shale (9 samples) members. Sample selection was based on the average TOC content of 1-m-thick intervals provided by Sun et al. (2013; Fig. 2, gray solid line). Special focus has been taken on the oil shale and coaly layers. Bulk geochemical analyses were performed on all 96 samples.