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Research paper

Major and trace elemental compositions of the upper Carboniferous Batamayineishan mudrocks, Wulungu area, Junggar Basin, China: Implications for controls on the formation of the organic-rich source rocks

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ABSTRACT

The upper Carboniferous Batamayineishan mudstones are an important and effective gas source rock in the Wulungu area. These sediments are rich in organic matter, however, organic matter accumulation has not been studied before in these mudstones. The major and trace elements were used to reconstruct the depositional environments of these sediments and to improve our understanding of the factors controlling organic matter accumulation. Major and trace elements data indicate that: (1) paleoweathering was low to intermediate in the source terrain; (2) paleoclimate was hot and arid during late Carboniferous in the Wulungu area; (3) low paleoproductivity may have been induced by the low input of nutrients caused by the hot arid climate; (4) the Batamayineishan mudstones were deposited under a reducing environment; (5) organic matter accumulation in these studied deposits was mainly controlled by the input of higher plants rather than redox conditions and paleoproductivity.

1. Introduction

The Junggar Basin, located in north-western China, is one of the most successful conventional petroleum exploration areas in China, and is a promising target for commercial tight oil and gas in the following years (Da et al., 2010; Wang et al., 2010). The Junggar Basin is surrounded by the Zhayier, Yilinheibiergen-Bogeda, and Qinggedili-Kelameili mountains (Fig. 1). The Wulungu Depression, located in northern Junggar Basin, is an area of low degree of petroleum exploration (Fig. 2). A comprehensive study of organic petrology and organic geochemistry has recently been conducted on the Carboniferous Batamayineishan Formation, which has been proven to be the most important and effective gas source rocks in this area due to abundant organic richness (total organic carbon (TOC) = 0.30%–10.82%), humic kerogen (type III), and low to high thermal maturity (R_o = 0.67%–2.78%) (Luo et al., 2017b). Vitrinites and inertinites are the predominant maceral compositions in the Batamayineishan mudstones with insignificant liptinites (Luo et al., 2017b). The natural gas found in the Luliang Super-uplift adjacent to the Wulungu area is thought to originate from the Carboniferous mudrocks (Da et al., 2010; Wang et al., 2010). The volcanics and mudrocks in the Carboniferous Batamayineishan Formation are thought to have formed a self-contained generation and reservoir petroleum system (Zhu, 2009; Wang, 2016; Luo et al., 2017b). Thus, the Carboniferous Batamayineishan Formation in Wulungu Depression is the important exploration target for gas. However, the accumulation mechanism of the organic matter in the Carboniferous Batamayineishan mudstones has not been studied yet.

To date, no agreement has been reached as to the factors controlling the formation of organic-rich mudstones. Many authors have proposed different scenarios to explain strong organic matter enrichment in the sediments: (1) enhanced preservation of organic matter because of anoxic bottom waters (Demaison and Moore, 1980; Canfield, 1989; Hartnett and Devol, 2003); (2) enhanced primary productivity (Calvert, 1987; Pedersen and Calvert, 1990); (3) a combination of preservation and productivity (Arthur et al., 1987); (4) an incorporation of terrigenous detrital matter influx, preservation and productivity (Rimmer et al., 2004; Pujol et al., 2006).

Major and trace elements have been used widely to determine paleoenvironmental conditions of the mudstones (Nesbitt and Young,

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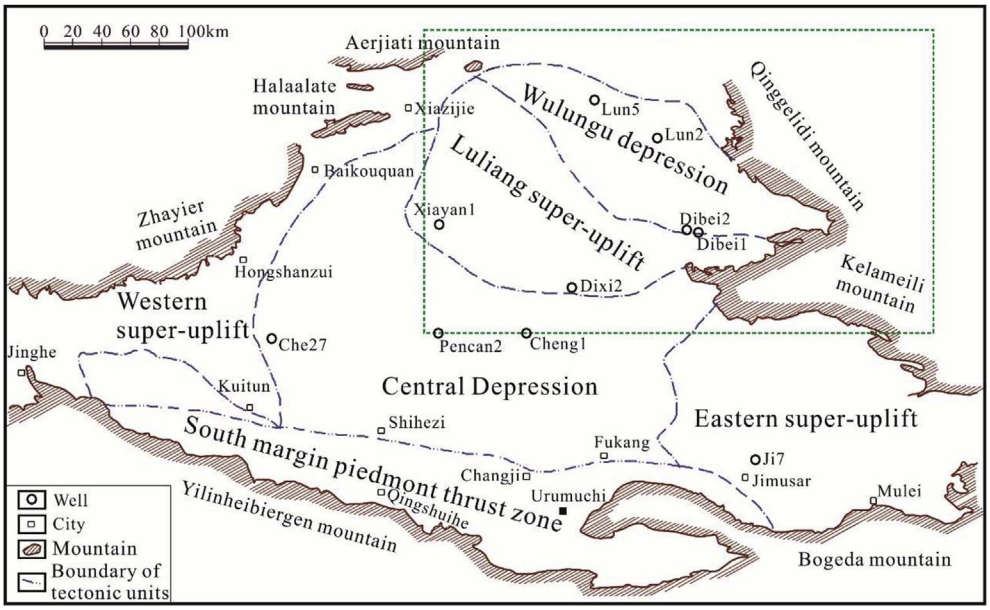

Fig. 1. The location of the studied area marked by the green box in northern Junggar Basin, northern China (Permission to use this figure was granted by Qingyong Luo). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

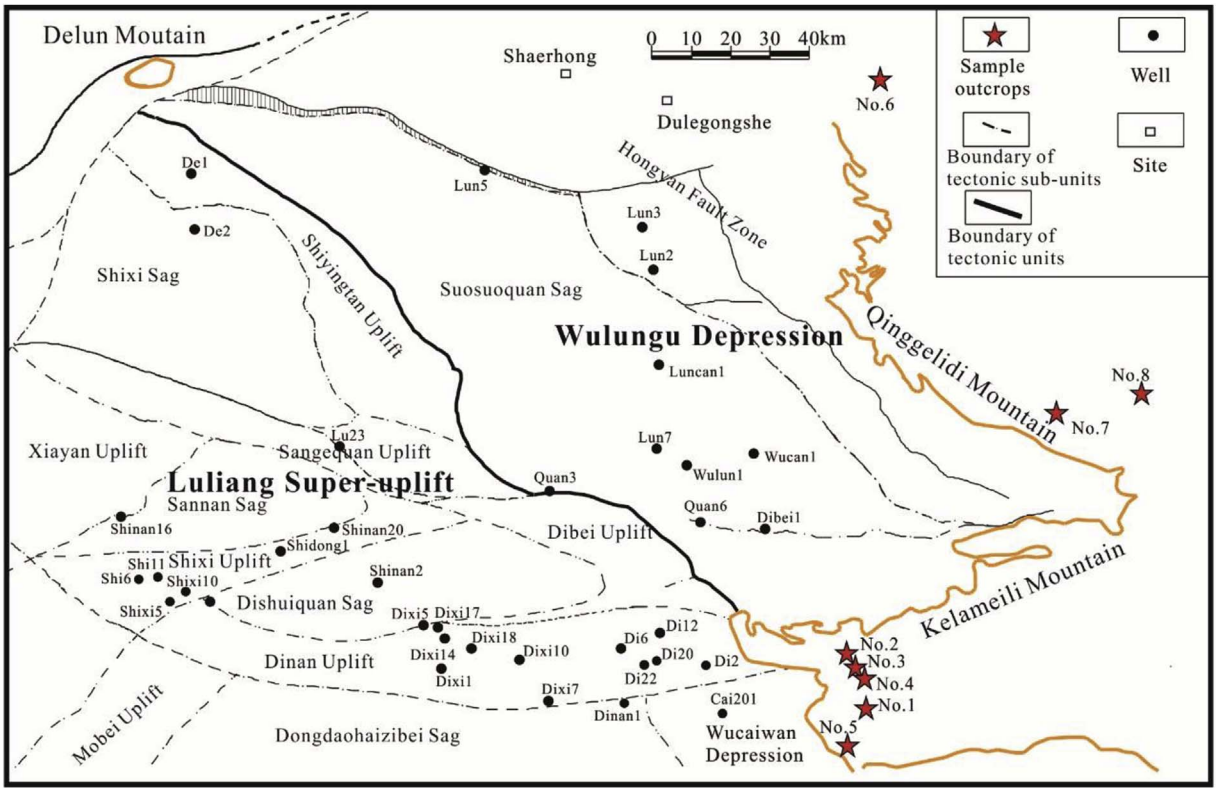

Fig. 2. The location of the studied mudstones, Wulungu area, northern China (Luo et al., 2017b).

1982; Fedo et al., 1995; Nesbitt et al., 1996; Algeo and Maynard, 2004; Algeo and Lyons, 2006; Tribovillard et al., 2006; Algeo and Tribovillard, 2009; Algeo et al., 2011). The chemical index of alteration (CIA) and the plagioclase index of alteration (PIA) were proposed to reconstruct the paleoweathering in the source terrain according to the weathering order of major oxides in the source rocks (Nesbitt and Young, 1982; Fedo et al., 1995). The degree of enrichment of redox-sensitive trace elements is influenced by the redox conditions, and thus their contents and ratios are useful to determine the paleo-redox environments (Algeo and Maynard, 2004; Tribovillard et al., 2006). The elements P and Ba are used widely to determine changes in paleoproductivity due to their positive correlation with productivity (Dymond et al., 1992; Murray et al., 1993; Dymond and Collier, 1996; Tyrrell, 1999; Luo et al., 2013; Zeng et al., 2015; Li et al., 2017; Li and Zhang, 2017).

In this study, major oxides and trace elements in the Batamayineishan mudstones were employed to elucidate source weathering, depositional environments, paleoproductivity and the factors controlling the organic matter accumulation of the deposits.