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Application of light hydrocarbons (C_5–C_7) in Paleozoic marine petroleum of the Tarim Basin, NW China

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ABSTRACT

The Cambrian–Lower Ordovician (Є-O_1) and Middle–Upper Ordovician (O_{2-3}) sourced oils from the Tarim Basin were distinguished based on their C_5–C_7 light hydrocarbons compositions. Relative to Є-O_1 sourced oils, O_{2-3} sourced oils are characterized by relatively lower abundance of cycloalkanes, higher *n*-heptane/methylcyclohexane values ($F < 1.0$) and aromatics content (i.e., benzene and toluene). The difference in light hydrocarbons compositions between the Є-O_1 and O_{2-3} sourced oils is mainly determined by their source facies, rather than by secondary alterations. For most analyzed samples, Mango's parameter, K1 values, are close to 1.0. The ZS1C condensate, derived from Є-O_1 rocks, has a distinct light hydrocarbons composition. The most obvious signature of the ZS1C condensate is abnormally high toluene content and abnormally high K1 value. Previous work has confirmed that the ZS1C condensate was altered by intense thermochemical sulfate reduction (TSR) and possesses a distinct geochemical composition, such as high dibenzothiophenes (DBTs) concentrations and high $\delta^{34}S$ values of dibenzothiophenes. The abnormally high toluene abundance and K1 values also probably result from TSR alteration. Furthermore, the oils affected by TSR alteration from the east of Tazhong center anticline have been confirmed to possess abnormally high K1 values (>1.0). It seems that TSR alteration has a controlling effect on the kinetics course of C_7 light hydrocarbon formation, and the abnormally high K1 values can be used as an indicator of TSR alteration in the Tarim Basin.

1. Introduction

The Tarim Basin is one of the most petroliferous basins in China, with multiple source rock intervals, multiple charge phases and a variety of modification processes (Huang et al., 1999; Li et al., 2000; Xiao et al., 2000; Yang et al., 2003). Significant amounts of commercial marine petroleum have been found mainly in the Tabei and Tazhong uplift areas. The produced oils range from condensates, light oils, and normal black oils to heavy oils, with their source rocks thought to be Cambrian–Lower Ordovician (Є-O_1) or Middle–Upper Ordovician rocks (O_{2-3}, Xiao et al., 1996; Hanson et al., 2000; Zhang et al., 2000a). In the last decade, the identification of marine oils source rocks in the basin has made considerable progress (Fan et al., 1990; Graham et al., 1990; Wang et al., 1992; Hanson et al., 2000; Liang et al., 2000; Zhang et al., 2000a, 2000b, 2005a; Zhao, 2001; Sun et al., 2003; Wang and Xiao, 2004; Xiao et al., 2005; Cai et al., 2009). However, with the advancement of deep exploration, this task has been hindered by light hydrocarbons (with relatively high thermal maturity) or condensate oils, in which biological markers are usually difficult to measure because of their low concentrations (Williams, 1974; Philippi, 1975; Thompson, 1983).

Light hydrocarbons (LHs) make up about 30% of a crude oil, which are more abundant in condensates and light oils (up to 90%, Hunt et al., 1980). Therefore, information derived from these components is more representative of the bulk of light oils/condensates. The LHs have been widely utilized in petroleum geochemistry studies for determining oil groups derived from the same source rock, prediction of maturity, alteration of crude oils due to water washing, biodegradation or evaporative fractionation, and even influence of source lithofacies (Thompson, 1983, 1988; Mango, 1990a, 1990b, 1997; Halpern, 1995; ten Haven, 1996; Odden et al., 1998; Magnier and Trindade, 1999; Lafargue and Le Thiez, 1996; Wever, 2000; Jarvie, 2001). For condensates and light oils where biological marker data are unavailable or unobtainable, the utilization of light hydrocarbons has been useful for oil group classification and source rock identification. However, the published geochemical data on marine oils from the Tarim Basin have focused on the C_{15+} fraction of the petroleums, with little attention to the light fractions.

The objective of this study is to attempt to classify the Paleozoic marine oil groups of the Tarim Basin and identify their source

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rocks through their light hydrocarbons compositions. Furthermore, the abnormally high K1 values for the oils from the east of the Tazhong center anticline were discussed.

2. Geological setting

The Tarim Basin, located in northwestern China, is one of the world largest frontier basins, with an area of 560,000 km^2 (Fig. 1). It is a Paleozoic cratonic basin developed on the basement of pre-Sinian continental crust, overlain in the south and north by Mesozoic–Cenozoic foreland depressions (i.e., Southwest and Kuqa Foreland Depression, Li et al., 1996). The detailed geological characteristics of the entire Tarim Basin have been summarized by numerous investigations (e.g. Li et al., 1996; Jia and Wei, 2002; Zhang and Huang, 2005). The cratonic region mainly consists of the Manjiaer Depression and the adjacent Tabei and Tazhong Uplifts. The largest Paleozoic marine pool of the basin, Tahe Oilfield, lies in the Tabei Uplift and borders the Manjiaer Depression to the southeast and Awati Depression to the southwest (Fig. 1).

All sedimentary strata (Sinian to Quaternary) are preserved in the cratonic region, with a total thickness of 16 km of sedimentary rocks accumulated in the Manjiaer Depression (Huang et al., 1999; Zhang, 1999; Jin et al., 2008; Wang et al., 2008). The sedimentary environments underwent evolution from an early Paleozoic marine carbonate platform, to late Paleozoic alternating marine and continental deposits, and finally to Mesozoic and Cenozoic terrigenous clastic deposits (Ren et al., 2011). However, there are only two main source rocks in the cratonic region of the basin, i.e., the Cambrian–Lower Ordovician and the Middle–Upper Ordovician. The former is currently at the overmature stage with equivalent vitrinite reflectance (%Ro) of 2.0–4.0, whereas the latter is mature and mainly in the oil generation window (Hanson et al., 2000; Zhang et al., 2000a). It is generally assumed that the Lower–Middle Cambrian rocks were deposited under an oxygen deficit sedimentary environment with more phosphorite and black shale, while the Middle–Upper Ordovician rocks were deposited in an under-filled marginal basin and slope environments and consist mainly of argillaceous limestones and marlstones, with more planktonic algal organic facies (Zhang et al., 2000a; Sun et al., 2003; Jia et al., 2007; Yu et al., 2011; Li et al., 2012). Oils and gases derived from the source rocks are accumulated in the Cambrian-Ordovician carbonate reservoirs and in the overlying Carboniferous, Triassic, Jurassic and Cretaceous sandstones, as a result of lateral and vertical migration (Graham et al., 1990; Jia and Wei, 2002; Zhang et al., 2002; Wang et al., 2008).

3. Samples and methods

Twenty-one oils from the Paleozoic marine petroleum systems of the Tarim Basin were analyzed. The samples represent various petroleum types, from biodegraded heavy oils to condensates. The API gravities of these oils range from 15.8 to 57.8 (Table 1).

All of the analyzed samples can be classified into two genetic groups. Most of the oils from the Tabei Uplift have been identified to be derived from O_{2-3} carbonate source rocks (Table 1, Zhang et al. 2000a, 2000b, 2002, 2005a; Wang et al., 2004; Ma et al., 2004; Zhang and Huang, 2005; Li et al., 2015; Song et al., 2016). A few samples, including T904, TD2, LK1, YN2 and ZS1C oils, are considered to originate from $Є$-O_1 rocks (Ma et al., 2005; Zhang and Huang, 2005; Li et al., 2010, 2015; Song et al., 2016).

Gas chromatography (GC) of the oil was performed using an Agilent 6890A gas chromatograph equipped with a fused silica column (HP-PONA, 50 m × 0.20 mm i.d. × 0.5 μm film thickness) and a flame ionization detector (FID, 300 °C). The injected sample

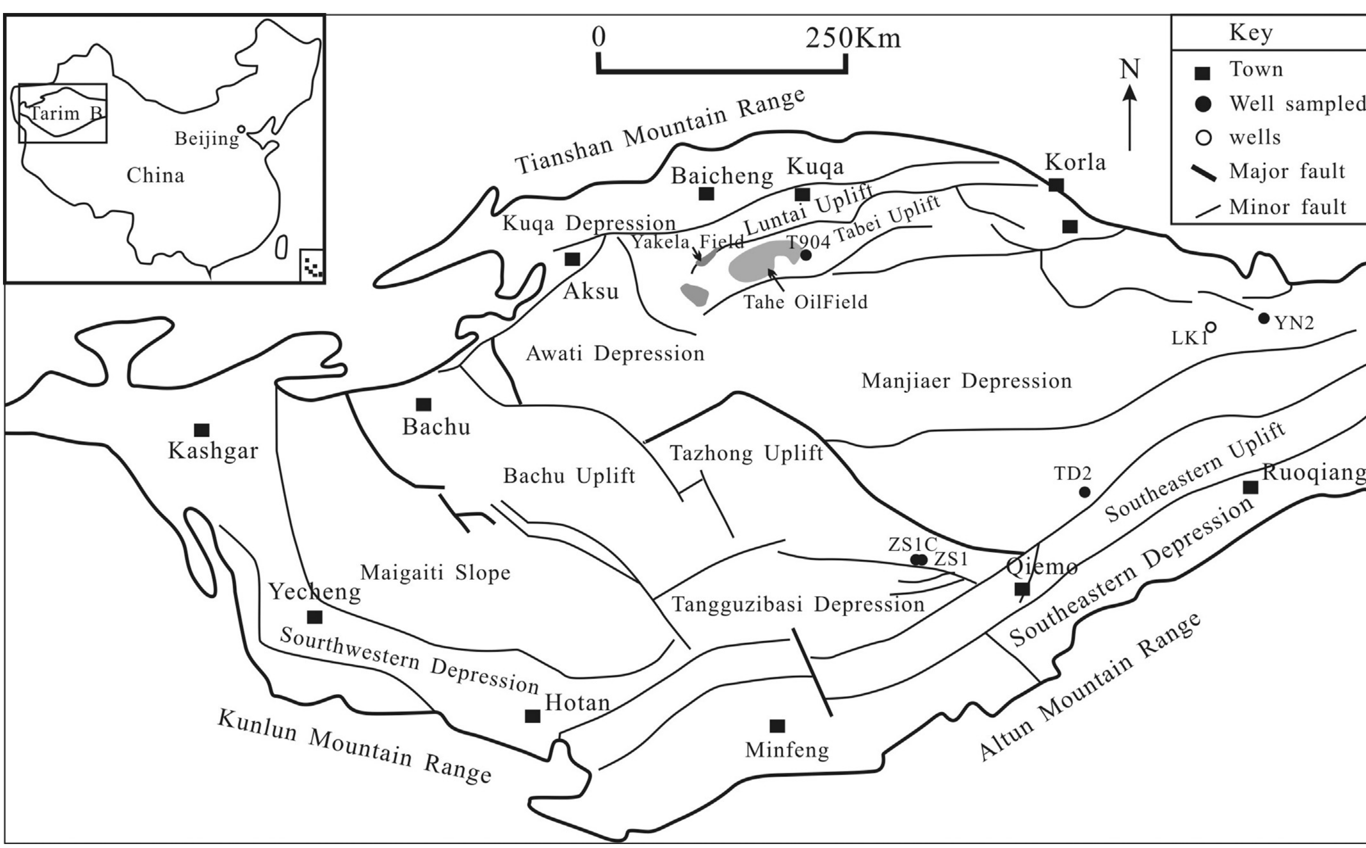

Fig. 1. Map showing major tectonic terrains in the Tarim Basin, China.