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Geochemical characteristics and correlation of continuous charge mixing and biodegradation of heavy oil in southeastern Dongying Sag, Bohai Bay basin, China

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ABSTRACT

The Paleogene Shahejie Formation is the main source rock and reservoir in the Jiyang Depression, Bohai Bay Basin, East China. An organic geochemical analysis study was performed on nine oil samples and forty-three core extracted samples from Shahejie Formation reservoirs by GC–MS to elucidate the influence of biodegradation and charge mixing on molecular compositions. Biodegradation impacts many classes of compounds, but the ultimate compositions and physical properties of the oil are influenced strongly by mixing with later oil charge and biodegradation. All samples display biodegradation signatures, and continuous charge mixing is characterized by the relationship between *n*-alkanes to hopanes and hopanes to 25-norhopanes (25-NHs). The occurrence of *n*-alkanes in oil samples suggests multiple episodes of charging and that the petroleum accumulated in Caoqiao is mainly a mixture of previously biodegraded oils and later migrated fresh oils.

Conventional geochemical diagnostic parameters in the saturated hydrocarbon fraction are affected by biodegradation. Based on the intensity of n-alkanes, hopanes and 25-NHs, many samples from Caoqiao appear to have experienced both biodegradation and continuous charge. A wide range of geochemical parameter values from different components point to multiple oil charge mixing. The relationship between the absolute concentrations of n-alkanes to hopanes and hopanes to 25-NHs of the samples can qualitatively differentiate whether oil charge mixing occurs in reservoirs or not. The cross plot of n-alkanes and hopanes dynamically describes the processes of continuous charge mixing and biodegradation. The positive correlation between the concentrations of hopanes and 25-NHs may suggest that oil charge mixing and biodegradation proceed continuously, while the negative correlation may indicate charge stops due to some geological factors.

1. Introduction

An input of a later stage of light petroleum into previously biodegraded heavy oils is a widespread phenomenon (Holba et al., 1996; Masterson et al., 2001; Ross et al., 2010). Petroleum characteristics are affected by biodegradation and in-reservoir mixing (Zhang et al., 2014). Head et al. (2003) estimate that around biodegradation destroys 50% of light non-biodegraded oil of 36-API to a heavy 20-API biodegraded oil. Generally, oil accumulations containing a number of distinct charges, or that charge over time at different rates, or a mixture of severely biodegraded crude oil with a fresh oil charge exhibit mixed geochemical signatures due to differences of petroleum characteristics in each charge. Mixed geochemical signatures represent overprinting of the original hydrocarbon signatures (Ross et al., 2010), and is exacerbated by biodegradation, especially in basins that contain several suites of source rocks and have undergone multiple petroleum generation events (Zhang et al., 2014).

The actual sequence of compound group removal may not be consecutive and several compound groups may be affected by biodegradation at any given time, although at different rates (Wenger and Isaksen, 2002). However, as a general rule, straight chain *n*-alkanes are affected before branched alkanes, cyclic saturates and aromatic

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hydrocarbons (Wenger and Isaksen, 2002). Pronounced UCM hump in gas chromatographic traces, and 25-norhopanes (25-NHs) in oils that also contain a full suite of *n*-alkanes indicate extensive mixing of biodegraded and non-biodegraded oils (Volkman et al., 1983; Wenger and Isaksen, 2002).

When oil charge exceeds degradation in reservoirs, linear gradients in saturated hydrocarbon content are observed with depth, which usually reflects sub-linear variations in oil viscosity. However, once active charge ceases, the viscosity of oil in the base of oil columns experiences dynamic changes (Larter et al., 2008). A diffusive supply of nutrients from the water leg combined with the supply of substrate from the oil column allows biodegradation to occur at the oil-water contact (Head et al., 2003). Therefore, in many cases, oil mixing and/or biodegradation dominate final oil compositions and physical properties (Barnard and Bastow, 1991; Horstad and Larter, 1997; Larter et al., 2003). In this study, detailed molecular compositions have been determined for mixtures of biodegraded oils from the Paleogene strata of the Dongying Sag of Bohai Bay basin (East China) to clarify the processes of oil charge mixing in biodegraded reservoirs, and to analyze the differences of the petroleum characteristics caused by different charge intensities and biodegradation degrees.

2. Geological background

Bohai Bay Basin has an area of about 20×10^4 Km^2, and is located in eastern China, spanning over the North China Plain, Lower Liaohe Plain and Bohai Sea. It is a composite, petroliferous basin polymerized by Mesozoic and Cenozoic rifts (Allen et al., 1997; Ren et al., 2002), with source rocks primarily from the Shahejie and Dongying Formation (Hao et al., 2011). The oil and gas production of the basin account for about 40% of the nation's production.

Dongying Sag spans an area of 5700 Km^2, and is a sub-tectonic unit of the southeast Jiyang Depression, which lies in the north of the Shandong Province (Fig. 1). The Caoqiao area is located on the Chunhua-Caoqiao

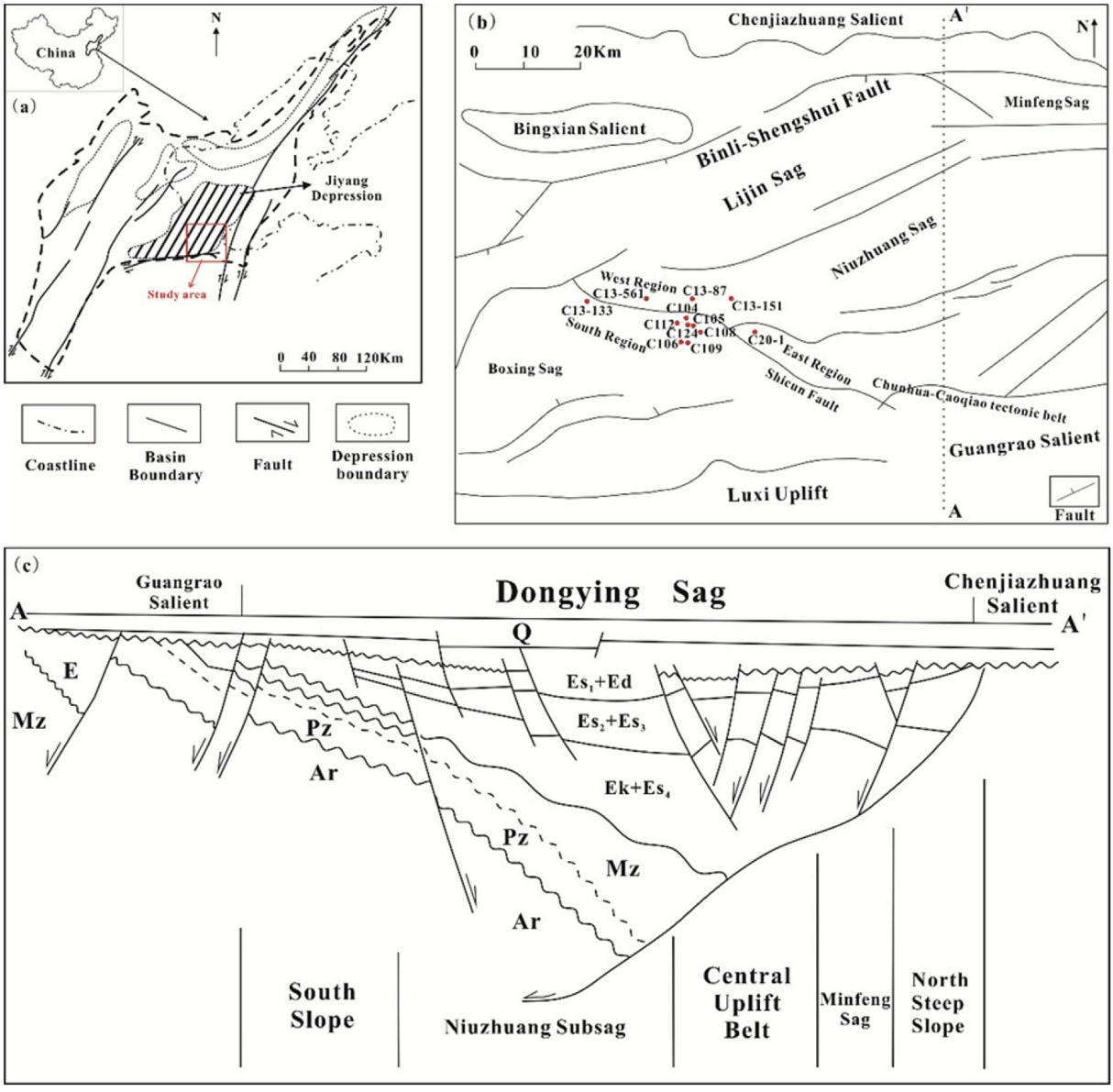

Fig. 1. (a): Location map of study area in Bohai Bay Basin. The square is the study area; (b): Tectonic map of Dongying Sag, the structural subdivision including South Slope Region; Central Uplift Belt and North Steep Slope Region. (c): Cross section across Dongying Sag showing the structural framework and the key stratigraphic intervals. Abbreviations: Ek = Kongdian Formation; Es = Shahejie Formation; Ed = Dongying Formation; Q = Quaternary; Mz = Mesozoic; Pz = Paleozoic; Ar = Archeozoic.