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Controls on biogenic gas formation in the Qaidam Basin, northwestern China

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ABSTRACT

Factors controlling biogenic gas generation were examined in the Quaternary Qaidam Basin of China, one of the youngest and largest biogenic gas-producing basins in the world. Indicators of microbial activity were found in higher permeability stratigraphic intervals, including high ratios of unresolved complex mixture/resolved compounds (U/R), as well as high ratios of methanogen biomarkers to normal alkanes, such as 2,6,10,14,19-pentamethylicosane/nC_{22} (ipC_{25}/nC_{22}) and squalane/nC_{26} (ipC_{30}/nC_{26}), from solvent organic extracts from 86 samples. Samples with the highest concentrations of ipC_{25}/nC_{22} and ipC_{30}/nC_{26} were the most highly biodegraded as shown by U/R ratios. Most intervals with high levels of methanogen biomarkers were characterized by groundwater with low total dissolved solids (TDS) and low Cl concentrations, thought to be related to meteoric water recharge. High H_2 concentrations were also related to low TDS (and Cl) formation water. Results demonstrate that meteoric water invasion was important in stimulating microbial activity.

1. Introduction

Biogenic gasses are widely distributed in the shallow portion of many sedimentary basins, and appear to be common in both unconventional and conventional petroleum reservoirs (Rice and Claypool, 1981; Martini et al., 1998; Shurr and Ridgley, 2002; Brown, 2011). Such accumulations account for as much as 20% of the world's discovered gas reserves (Rice and Claypool, 1981), and more economic reserves of biogenic gas are expected to be discovered in the future (Rice and Claypool, 1981; Kvenvolden, 1988, 1995; Kotelnikova, 2002; Shurr and Ridgley, 2002). Biogenic gas also forms one of the major sources of gas hydrates (Collett, 2002). However, many of the processes that drive active microbial methanogenesis in the subsurface, forming these gas reserves, are still uncertain.

The discovery of large biogenic gas accumulations points to significant biologic activity in the subsurface (Bates et al., 2011; Schlegel et al., 2011a,b), and to active present day formation of biogenic methane (Rice and Claypool, 1981; Daniels, 1984; Martini et al., 1998; McIntosh et al., 2002; Shurr and Ridgley, 2002; Jones et al., 2008; Ulrich and Bower, 2008; Bates et al., 2011; Schlegel et al., 2011a,b). Such gas deposits are often generated in self-sourced gas reservoirs rich in organic carbon, such as shallow coal-seams and organic rich shale units (Martini et al., 1998; Shurr and Ridgley, 2002; Brown, 2011). Methanogenesis can also form economic CH_4 accumulations in response to major freshwater intrusion events (Martini et al., 1998; McIntosh et al., 2002; McIntosh and Walter, 2005), indicating that the occurrence of biogenic gas is also controlled by hydrogeologic factors associated with meteoric water recharge (Vugrinovich, 1988; Martini et al., 1998; McIntosh et al., 2002; Shurr and Ridgley, 2002; Grasby et al., 2009, 2012; Bates et al., 2011; Schlegel et al., 2011b). This feature points to the importance of a range of conditions, including: organic matter content, the geochemistry of formation waters, as well as fluid-flow history, as controls on biogenic gas formation.

With about 320 billion cubic meters of proven biogenic gas reserves, the rapidly buried Qaidam Basin (Pang et al., 2005; Dang et al., 2008), located north of the Qinghai–Tibetan Plateau in northwest China, forms an ideal location to investigate primary controls on methanogenesis. We examined both formation water and organic matter geochemistry to evaluate the extent and controls on microbial activity. While previous work suggested that this biogenic gas was generated early in the basin history, during host rock sedimentation (Pang et al., 2005; Dang et al., 2008), our results demonstrate that post-deposition fresh water recharge had profound influence on microbial activity and that a semi-open hydrogeological regime was critical for gas generation in this basin.

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2. Geological setting

The geological history of the Qaidam Basin has been described in detail in previous studies (Gu and Zhou, 1993; Pang et al., 2005; Dang et al., 2008). In brief, the basin is located in the northern part of the Qinghai–Tibetan Plateau and is encircled by the Kunlun, Qilian and Altyn Mountains (Fig. 1a). In response to rapid Cenozoic uplift of the Qinghai–Tibetan Plateau, the Qaidam Basin became an evaporative inland lake that filled rapidly with thick salt deposits (Gu and Zhou, 1993; Pang et al., 2005; Dang et al., 2008).

The Sanhu Depression, located in the eastern part of the Qaidam Basin, was a depocenter during the Quaternary (Fig. 1b). The deposition rate during the Quaternary was very high, from 700 to 1200 m/Myr, accumulating up to 3200 m of clastic sediments. Deposition ceased with tectonic uplift at the end of the Quaternary and subsequently ~500 m of sediment was eroded in the Sebei area.

Quaternary sediments are mainly comprised of the Sebei Formation, consisting of a nonmarine sequence of mudstones (30%), silty mudstones (40%), coaly mudstones (8%), and pelitic siltstones (20%), which form the principal aquitards of the basin (Fig. 1c). These are interbedded with silty sand and fine sandstone units that form regional aquifers. The total organic carbon (TOC) content of mudstones is relatively low, ranging from 0.2% to 0.4%, with an average of 0.3%. The TOC in coaly mudstones is much higher, ranging from 2% to 40%, with an average of 9% (Pang et al., 2005; Dang et al., 2008). The organic matter is mainly type III–II2, with Ro values of 0.20% to 0.40% (Pang et al., 2005; Dang et al., 2008). Therefore sediments in the basin are thermally immature and have never been heated sufficiently to generate thermogenic gas at any point in the basin history.

The Qaidam Basin is the youngest natural gas-producing basin in China and one of the largest biogenic gas forming regions in the world. There are seven biogenic gas fields discovered to date, with total proven reserves of 320 billion cubic meters (Dang et al., 2008). Biogenic gasses are mainly produced from the north belt of the Sanhu Depression. The three main gas fields (Sebei-1, Sebei-2, and Tainan), located near the depocenter of the basin, have total gas reserves of about 0.27×10^{12} m^3 and only 0.05×10^{12} m^3 of natural gas are found in four other small gas fields (Taiji, Yike, Yanhu, and

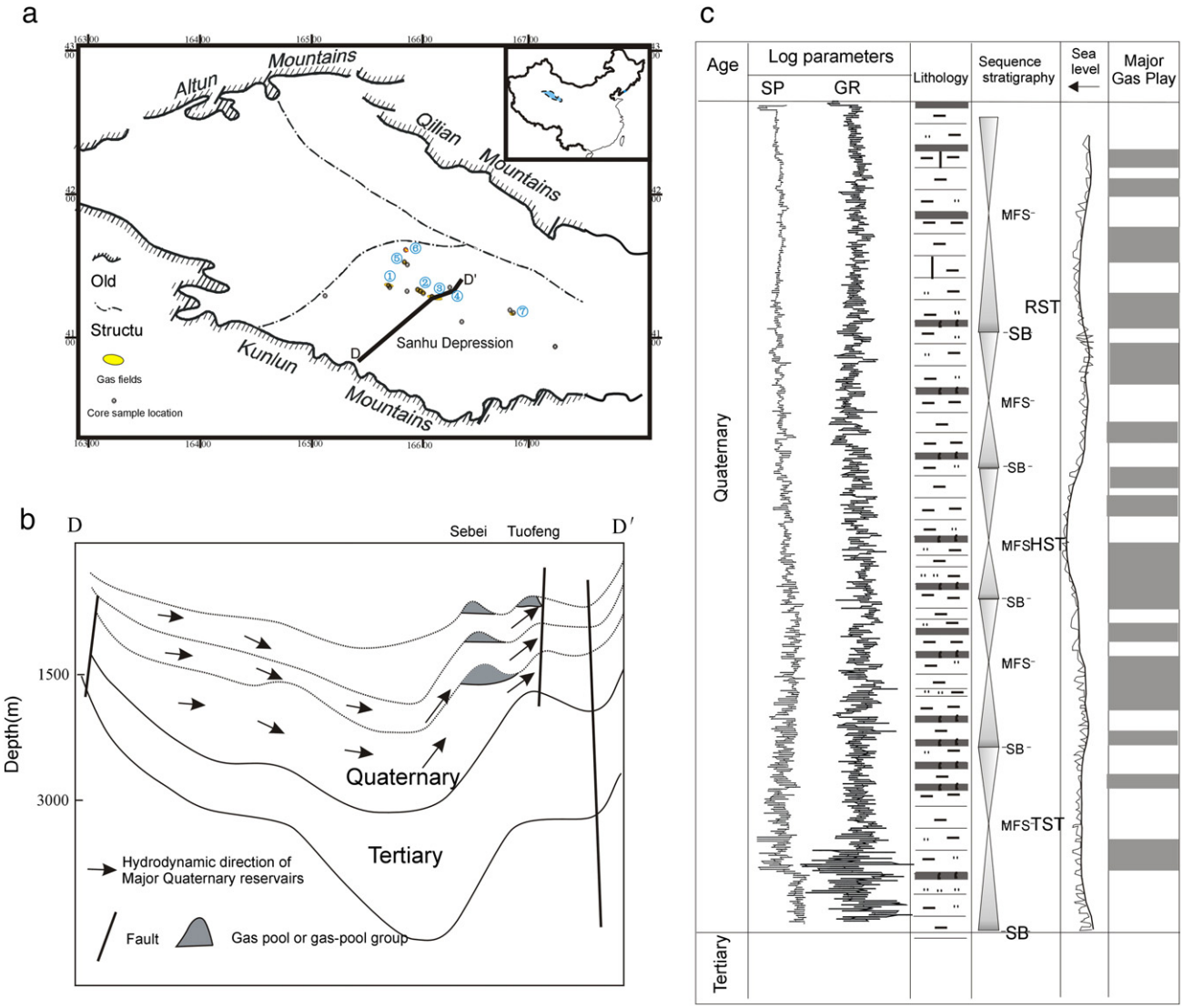

Fig. 1. Geological background of the study area. (a) Sketch map of the Qaidam Basin, NW China; Gas fields are mainly located at the northern part of the Eastern Depression. ①—Tainan gas field; ②—Sebei 1 gas field; ③—Sebei 2 gas field; ④—Tuofeng gas field; ⑤—Taiji gas field; ⑥—Yike gas field; ⑦—Yanhu Gas field. (b) Stratigraphic across section of the Eastern Depression (see Fig. 1a for location). The hydrodynamic direction was from the south to the north in the Quaternary in the Sanhu area (Sun et al., 2003; Dang et al., 2008). (c) Integrated stratigraphic column of the Quaternary in the Sebei structure belt of Sanhu area.