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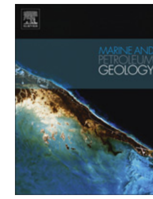

Gas source for gas hydrate and its significance in the Qilian Mountain permafrost, Qinghai

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ABSTRACT

Gas source for gas hydrate is not clear yet in the Muli of Qilian Mountain permafrost. In this paper a case is illustrated in the hole of DK-2 during gas hydrate drilling; gas composition and isotopes of gas hydrate and its associated gases are analyzed; organic geochemistry on mudstone, oily shale, coal, oil & gas indications are correlated within the interval of gas hydrate occurrences; the aim is to discuss the source of gases from gas hydrate and its implication to gas hydrate exploration in the study area. Results from gas composition and isotopes of gas hydrate and its associated gases reveal that the origin of gases from gas hydrate is mainly concomitant with deep oil or crude oil in the study area. Parameters for the abundance, type and thermal evolution of organic matter in mudstone, oil shale, coal in the same interval of gas hydrate occurrence suggest that these strata, especially within gas hydrate stability zone, play little role in gas sources for gas hydrate. Reservoir pyrolysis results for oil & gas indication-bearing cores reveal that oil & gas indications are closely associated with gas hydrate within its interval, indicating that they may serve as a sign of gas hydrate in the study area.

1. Introduction

Gas hydrate is a crystal material formed from water and light gases (such as CH_4, C_2H_6, C_3H_8, i-C_4H_{10}, H_2S, CO_2, etc.) under low temperature and high pressure conditions (typically around 273.15 K and 3–5 MPa) when gas concentration is greater than its solubility (Sloan, 1998, 2003, 2004). In nature, gas hydrate occurs widely in marine sediments at water depth of more than 300 m (about 3 MPa) (Kvenvolden et al., 1993) and in permafrost in greater than 130 m below ground (about 3.5 MPa) (Shi and Zheng, 1999). Due to great significance in energy resources (Kvenvolden et al., 1993), latent feedback to environment (Dickens, 2004), and possible submarine hazards (Mienert et al., 2005) or impact on safety of drilling platform (McConnell et al., 2012), gas hydrate becomes one of hot fields for survey and research.

After gas hydrate was first discovered in the Messoyakha gas field in the western Siberia permafrost, Russia, in 1960s (Makogon, 2010), some relevant gas hydrates were continuously found in the Mackenzie delta permafrost, Canada (Bily and Dick, 1974; Dallimore and Collett, 2005) and in the Mount Elbert permafrost of Alaska, USA (Collett et al., 2011), and other marine gas hydrates were also found offshore East Korea (Kim et al., 2011), India (Shankar and Riedel, 2011) and New Zealand (Schwalenberg et al., 2010) in latest years. At present, about 230 locations of gas hydrate were mapped out around the world (Makogon, 2010).

In China, gas hydrate was successfully sampled by drilling in the Qilian Mountain permafrost in 2008 (Lu et al., 2011; Zhu et al., 2009) after it was discovered in the northern continental slope of the South China Sea in 2007 (Wu et al., 2009). In total, eight scientific drilling wells, namely DK-1, DK-2, DK-3, DK-4, DK-5, DK-6, DK-7 and DK-8, were completed in the Qilian Mountain permafrost, among which gas hydrates were encountered in wells of DK-1, DK-2, DK-3, DK-7 and DK-8, where their distance was no more than 30 m. On the contrary, only some anomalous phenomena associated with gas hydrate, indicated by (1) release of flammable gas from the well when gas hydrate bearing layers were penetrated, (2) a large amount of gas release when gas hydrate bearing cores were placed within airtight conditions, (3) anomalously low core temperatures measured by a Flir infrared camera, etc., were observed in wells of DK-4, DK-5 and DK-6, although there were several hundred meters to 1000 m away from any one of DK-1, DK-2, DK-3, DK-7 and

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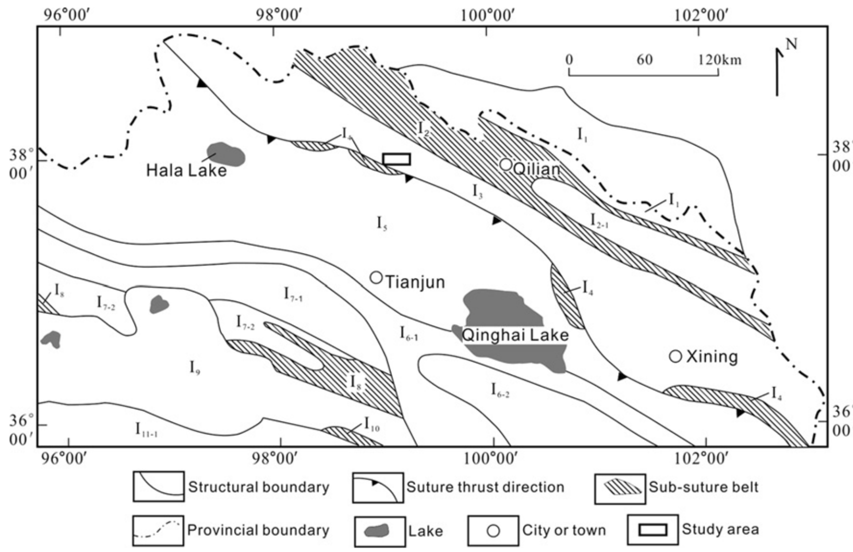

Figure 1. A sketch map of tectonics in the Qilian Mountain permafrost (modified from Zhang and Yang, 2007) I_1-the Alashan continental block; I_2-the North Qilian suture in Neoproterozoic to Early Paleozoic era; $I_{2\text{-}1}$-the Qilian-Menyuan magmatic arc belt in middle to late Early Paleozoic era (O–S); I_3-the Middle Qilian continental block; I_4-the South Shule Mt-Laji Mt suture in Early Paleozoic era; I_5-the South Qilian continental block; I_6-the Zongwulong Mt-South Qinghai Mt fault-depression trough in Late Paleozoic to Early Mesozoic era (D-T_2); $I_{6\text{-}1}$-the Zongwulong Mt-Xinghai aulacogen (D–P); $I_{6\text{-}2}$-the Zeku back-arc foreland basin ($T_{1\text{-}2}$); I_7-the Oulongbuluke continental block; $I_{7\text{-}1}$-the Ebo Mt marginal craton basin; $I_{7\text{-}2}$-the Dingzikou-Amunike Mt-Maoniu Mt magmatic arc belt in Neoproterozoic to late Early Paleozoic era (Pt_3-S); I_8-the marginal North Qaidam suture; I_9-the Qaidam block; I_{10}-the Qimantage-Doulan suture; I_{11}-the middle East Kunlun continental block; $I_{11\text{-}1}$-the middle East Kunlun magmatic arc belt (Pt_3-J).

DK-8 (Lu et al., 2010a). On the one hand, it shows that gas hydrate distribution is complex (Lu et al., 2010b); on the other hand, it reveals that controlling factors for gas hydrate accumulation are unknown. In theory, gas hydrate is formed under suitable temperature and pressure conditions when gas source is sufficient (Sloan, 1998). In the Qilian Mountain permafrost, gas source may be a decisive factor for gas hydrate formation. Analyses on composition and isotope ratio of gases from gas hydrate indicate that hydrocarbon gases are thermogenic in the Qilian Mountain permafrost (Lu et al., 2010c), whereas it is thought of being from coal-bed methane (Zhu et al., 2010). There is a remarkable fact that intervals of gas hydrate occurrences are well developed with coal-bearing strata, oily shale, and oil & gas indications (such as oil stain, oil patch, oil immersion) which are often accompanied by gas hydrate in the Qilian Mountain permafrost (Lu et al., 2010b). In this paper the connection of gas source for gas hydrate with coal, mudstone, oily shale, and oil & gas indications is discussed with the help of conventional natural gas diagram, organic petrology and geochemistry.

2. Geological setting in the Muli of Qilian Mountain permafrost

Wells of DK-1, DK-2, DK-3, DK-4, DK-5, DK-6, DK-7 and DK-8 were located in the Muli of Qilian Mountain permafrost, which belongs to the Sanlutian mining area of the Muli coal field. It is tectonically situated in the western Middle Qilian block formed in Caledonian Movement (513–386 Ma), adjacent to the South Qilian structural zone (Fig. 1; Feng, 1997), and it is also situated in the Muli Depression of the South Qilian Bain (Fu and Zhou, 1998, 2000). The Muli coal field is the biggest coal field in Qinghai province. Its destination layer is Jurassic lacustrine coal-bearing stratum, including Jiangcang Formation (J_{2j}) and Muli Formation (J_{2m}) of middle Jurassic (Wen et al., 2011). It is nowadays alpine-typed permafrost in the Qilian Mountain area, and is about 1×10^4 km^2 in area in total, among which continuous permafrost has about −2.4 to −1.5 °C and island permafrost has about −1.5 to 0 °C on the yearly average in the atmosphere. The permafrost is about 50–139 m in thickness (Zhou et al., 2000).

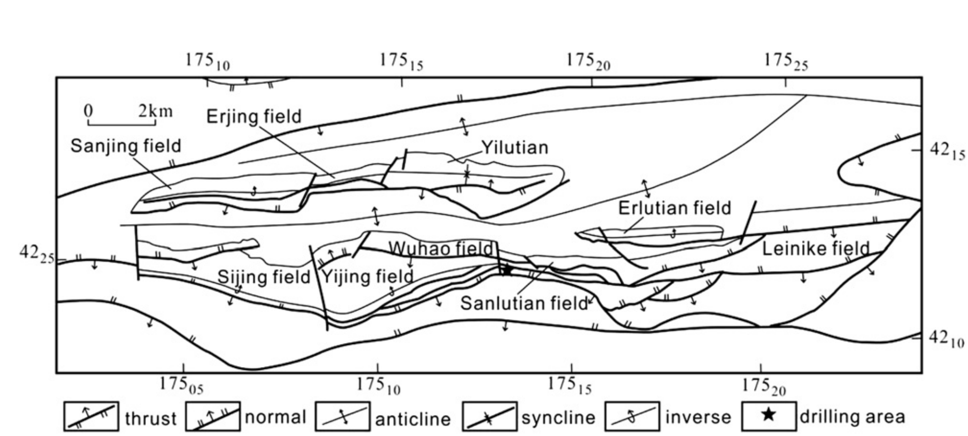

Figure 2. Structural pattern in the study area (modified from Wen et al., 2011).