Marine and Petroleum Geology 35 (2012) 166–175

Contents lists available at SciVerse ScienceDirect

Marine and Petroleum Geology

journal homepage: www.elsevier.com/locate/marpetgeo

Gas hydrate formation and its accumulation potential in Mohe permafrost, China

Xingmin Zhao*, Jian Deng, Jinping Li, Cheng Lu, Jian Song

Institute of Mineral Resources, CAGS, 26 Baiwanzhuang, Beijing 100037, China

ARTICLE INFO

Article history:
Received 9 August 2011
Received in revised form
24 March 2012
Accepted 12 April 2012
Available online 27 April 2012

Keywords:
Gas hydrate
Permafrost
Petroleum geology
Mohe region
China

ABSTRACT

The Mohe region is an area of continuous permafrost in northernmost China with strong similarities to other known gas-hydrate-bearing regions. Permafrost thickness is typically 20–80 m; average surface temperature ranges from −0.5 °C to −3.0 °C, and the geothermal gradient is roughly 1.6 °C/100 m. We estimate that 204.66 × 10^{12} m^3 of hydrocarbon gases have been generated in the Mohe basin from nearly 1000 m middle Jurassic dark mudstones, providing ample gas source for gas hydrate formation. Numerous folds in the shallow section provide opportunities to trap gas within sandstones and siltstones reservoirs bounded by competent mudstone seals. Gas migration to the shallow section is enabled via fault fracture zones and fracture systems. Based on core description and observations of gas releases from drilled wells, we infer that the Mohe region could hold large quantities of natural gas in the form of gas hydrate.

1. Introduction

Gas hydrate, also known as methane hydrate for its methane-dominated composition, is an ice-like crystalloid solid compound that forms mainly from water and methane molecules under low temperature and high pressure. Actually, gas hydrate is a kind of special-form (solid) or special-type (unconventional) natural gas (Pan, 1986; Dai et al., 1989; Zhang and Zhang, 1989). In nature, gas hydrate frequently occurs either in submarine sediments on continental shelves or in association with permafrost (Sloan, 1998; Majorowicz and Hannigan, 2000; Makogon et al., 2007; Makogon, 2010). Gas hydrate has significant implications for energy resources, geohazards, and climate change (Kvenvolden, 1988a, b; Macdonald, 1990; Nisbet, 1990; Paull et al., 1991; Maslin et al., 1998; Bouriak et al., 2000; Milkov et al., 2000; Kennedy et al., 2001; Collett, 2002, Collett et al., 2009) and has attracted great interest from the scientists from many disciplines.

Although marine settings house the majority of global gas hydrate resources, permafrost is an important area for the formation and occurrence of gas hydrate, particularly those occurrences within sand reservoirs that have the greatest current potential for energy production. An example from the Yamal Peninsula in west Siberia indicates that the relic of gas hydrate probably occur 60–80 m below permafrost for its self-preservation effect (Chuvilin et al., 1998; Yakushev and Chuvilin, 2000), suggesting that gas hydrate may have an even more widespread distribution in permafrost than commonly thought. Recently, gas hydrate was found in Qilian mountains permafrost in Qinghai Province, China (Zhu et al., 2010), in a similar to that of the Mohe area.

The Mohe area, situated in the northernmost portion of China (Fig. 1), has the lowest average surface temperature in China and widespread development of permafrost. In the past few years, a range of geochemical, geological, and geophysical investigations have provided confirmation of the existence of the necessary elements for a well-developed gas hydrate petroleum system (after Collett et al., 2009) in the basin.

2. Regional geological setting and its control of gas hydrate formation

The Mohe basin occupies roughly 21,300 km^2 of China north of N 52° 20′. The region is among the least explored for hydrocarbons in China. Paleogeographically, the Mohe basin is attributed to Mongolia-Okhotsk ocean (Zhang et al., 2003; Wu et al., 2006) and is currently tectonically situated on the Eerguna micro-plate within the Okhotsk folded belt (Zhang et al., 2003) on the sutured boundary between the Siberia plate and the Northeast China put-together plate. The southern margin of the basin is marked by Proterozoic granite (Fig. 1). Tectonic processes, including Mongolia-Okhotsk ocean crust subduction, interaction between the Siberia plate and China plate, and subsequent underthrusting of Pacific plate etc., have significantly influenced both the depositional

* Corresponding author. Tel.: +86 10 68999069.
E-mail address: xxmmzh@163.com (X. Zhao).

0264-8172/$ – see front matter
doi:10.1016/j.marpetgeo.2012.04.003

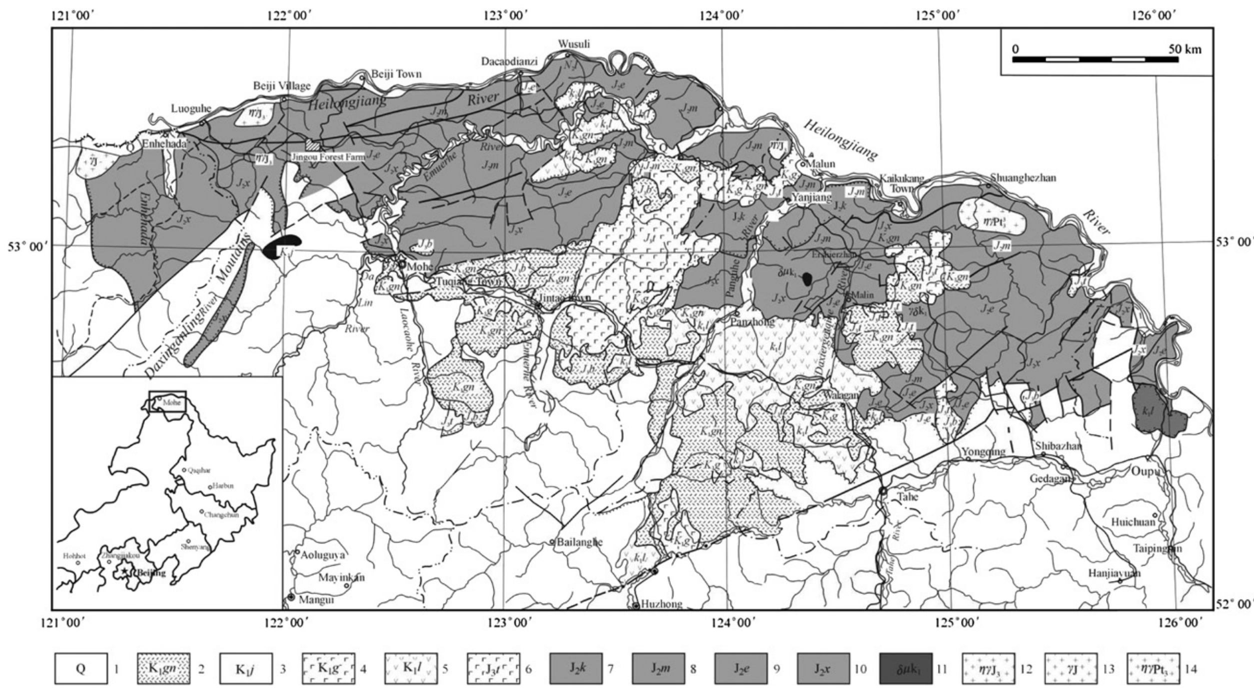

Figure 1. Geological map of Mohe basin. 1—Quaternary system; 2—Ganhe Formation; 3—Jiufengshan Formation; 4—Guanghua Formation; 5—Longjiang Formation; 6—Tamulangou Formation; 7—Kaikukang Formation; 8—Mohe Formation; 9—Ershierzhan Formation; 10—Xiufeng Formation; 11—Diorite-porphyrite of early Cretaceous; 12—monzonitic granite of late Jurassic; 13—Jurassic granite; 14—monzonitic granite of new Archean.

(including source rocks, reservoirs, and seals) and structural (including the development of trapping geometrys and fault/fracture related migration pathways).

Mohe basin is a continental basin formed through the Mesozoic. The approximately 6000 m or more of strata fill consists of clastic and volcanic rocks of the middle and upper Jurassic (with minor Cenozoic sediments) which lies upon Devonian basement. The middle Jurassic, which is the majority of the basin fill, is mostly made up of fluvial and lacustrine terrigenous clastics of the Xiufeng, Ershierzhan, Mohe, and Kaikukang Formations (Table 1). The Ershierzhan and Mohe Formations occur widely throughout the basin and include the majority of source rocks and reservoir rocks for potential gas hydrate formation. The Xiufeng Fm, also widely distributed in the region, primarily embraces reservoir rocks. The Kaikukang Fm is restricted to the northeast part of the basin. The upper Jurassic occurs only locally and primarily consists of volcanic and pyroclastic rocks interbedded with fluvial and lacustrine terrigenous clastic formations. During the late stage of basin filling, the interaction among Siberia plate, Northeast China put-together plate and Pacific plate resulted in the development of many northeast-to-east northeast striking overthrust faults and associated faults, alternating depressions and uplifts, as well as large-scale volcanic eruption in the region (Zhang et al., 2003). These faults make up the primary conduits for continuous hydrocarbon-supply to the shallow section. The uplifts or salients act as the traps for gas hydrate accumulation.

3. Gas hydrate petroleum system

3.1. Thickness of permafrost and geothermal gradients

Permafrost is continuously spread throughout Mohe region (Zhou et al., 2000; Jin et al., 2009) and thickens to the northwest. Thickness of permafrost ranges has been alternatively reported as ranging from 50 to 100 m (Zhou et al., 2000) and from 0 to 60 m (Jin et al., 2009). Our geophysical surveying from 2003 to 2004 indicates that the thickness of permafrost to the west of the Jingou Forest Farm is about 20–80 m with thickness up to 140 m or so locally. These thicknesses are comparable to those reported in other gas-hydrate-bearing regions including Qilian mountains region in China (Zhu et al., 2010) and Yamal Peninsula in Siberia where is speculated on gas hydrate occurring (Chuvilin et al., 1998; Yakushev and Chuvilin, 2000).

Geotemperature, which is usually characterized by ground surface temperature, geothermal heat flow and gradient, has a profound impact on occurrence of gas hydrate. Prior data (Wang and Huang, 1988a, b) indicate that the surface temperature of the permafrost in northeastern China is between 0.5 and −2.5 °C; geothermal flux is from 30 to 71 mW/m^2; and geothermal gradient is from 1.0 to 4.54 °C/100 m. As far as it is further concerned, Mohe region has the lowest surface temperature of −1.0 to −2.5 °C, the northeast part of Inner Mongolia shows the lowest geothermal heat flow of 40 mW/m^2, and the north area of Heilongjiang Province has the lowest geothermal gradient of 1.2 °C/100 m. Our data reveal, however, that the surface temperature and geothermal gradient in Mohe region is from −0.5 to −3.0 °C and around 1.6 °C/100 m respectively, which is similar to those of Messoyakha in Siberia (−8 to −12 °C (Romanovsky et al., 2007) and 1.0–3.0 °C/100 m (Makogon, 2010)), Prudhoe Bay on Alaska North Slope (−4.6 °C to −12.2 °C (Kamath et al., 1987) and 1.5 °C–5.2 °C/100 m (Collett et al., 2011), and Qilian Mountains area in China (−1.5 °C to −2.4 °C and 2.2 °C/100 m; Zhu, personal correspondence). Consequently, Mohe permafrost has a favorable geothermal condition of gas hydrate formation.

3.2. Temperature-pressure condition of gas hydrate formation

Temperature and pressure requisite for gas hydrate formation (Sloan and Koh, 2008) have a decisive effect on the phase balance of gas hydrate petroleum system. In the subsurface, temperature and pore pressure are dominant controls on the stability of gas hydrate. In general, the thickness of the gas hydrate stability zone can be