Cold Regions Science and Technology 66 (2011) 93–104

Contents lists available at ScienceDirect

Cold Regions Science and Technology

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

Gas hydrate occurrences in the Qilian Mountain permafrost, Qinghai Province, China

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ARTICLE INFO

Article history:
Received 21 January 2010
Accepted 20 January 2011

Keywords:
Gas hydrate
Permafrost
Characteristics
Qilian Mountain
China

ABSTRACT

Four scientific experimental wells were drilled in the Qilian Mountain permafrost of Qinghai Province, China, in 2008 and 2009. Gas hydrate was obtained from three of four wells and its related anomalous phenomena were observed in all the four wells. Raman spectroscopy was used in the laboratory to evaluate the type of clathrates recovered from these sites, including structures containing large and small cages of hydrocarbon gases. Gas hydrate and associated anomalies occur mainly in fractured mudstone, oily shale, siltstone, and fine-grained sandstone. Secondary occurrences were also present in the pore space of fine to medium grained sandstone in a zone between 133 and 396 mbs. This interval was vertically discontinuous and horizontally did not appear to correlate between wells. Gas hydrate occurrences in these wells are not solely related to lithology and are strongly controlled by fissures in the Qilian Mountain permafrost. Gas geochemical characteristics reveal that gas hydrate is primarily composed of CH_4, with secondary components of C_2H_6, C_3H_8, and CO_2. Raman spectra analysis indicates a sII gas hydrate structure. Gas composition and carbon and hydrogen isotope geochemistry show that gases from gas hydrate are mainly thermogenic with a biogenic fraction. In the study area, gas hydrate and its related anomalous phenomena are confined to the gas hydrate stability zone which is constrained by permafrost pressure and temperature conditions. Core observations indicate that individual gas hydrate occurrences are controlled by fissures. It is speculated that, when hydrocarbon gases reach the gas hydrate stability zone, they form into gas hydrate that occurred preferably in fissures beneath the permafrost.

1. Introduction

Gas hydrate, also known as "flammable ice," 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 in nature 260–300 K and 3–50 MPa) when gas concentration is greater than its solubility (Sloan, 1998; Kvenvolden, 1995; Makogon et al., 2007). Structure I methane hydrate, the most common in nature, occurs in marine subsurface sediments (Kvenvolden, 1995). Structure II gas hydrate may exist in permafrost sediments (Shi and Zheng, 1999). Because gas hydrates represent a concentrated form of natural gas, they are being considered as a possible future energy source (Kvenvolden, 1995; Milkov and Sassen, 2002). The dynamic behavior of gas hydrate in natural environments may also have a feedback on climate change (Dickens, 2004) and pose a potential geohazard (Mienert et al., 2005), including causing potential complications to conventional drilling and production operations (Collett and Dallimore, 2002).

Since gas hydrate was first discovered in the Messoyakha gas field of the western Siberia permafrost, Russia, in 1960s (Makogon et al., 2007), other permafrost associated gas hydrates have been sampled in the Mount Elbert Well of Alaska, USA (Hunter et al., 2010), and the Mackenzie Delta, Canada (Dallimore et al., 1999; Dallimore and Collett, 2005). A production of permafrost gas hydrate at the Mallik site in the Mackenzie Delta (Dallimore and Collett, 2005) demonstrated the viability of gas production from gas hydrate (Walsh et al., 2009).

The Qinghai–Tibet plateau permafrost is an extensive area in China, with an areal extent of about 150×10^4 km^2. In recent years, geological, geophysical, and geochemical investigations and studies were conducted in the Qinghai–Tibet plateau permafrost, resulting in the identification of prospective gas hydrate bearing areas within the region (Zhang et al., 2001, 2007; Huang et al, 2002; Liu and Han, 2004, Chen et al., 2005; Wu et al., 2006; Lu et al., 2007, 2009; Zhu et al., 2006). Of these, the Qilian Mountain permafrost is a significant prospect area (Zhu et al., 2006). In 2008 and 2009, a series of experimental exploration wells were drilled in the Muli area of the Qilian Mountain permafrost to verify the predictions of geology and of gas hydrate occurrence based on past geochemical anomalies (Zhu et al., 2006). To date, hydrates identified in the natural environment have been limited to marine and Arctic occurrences. High elevation

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0165-232X/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.coldregions.2011.01.008

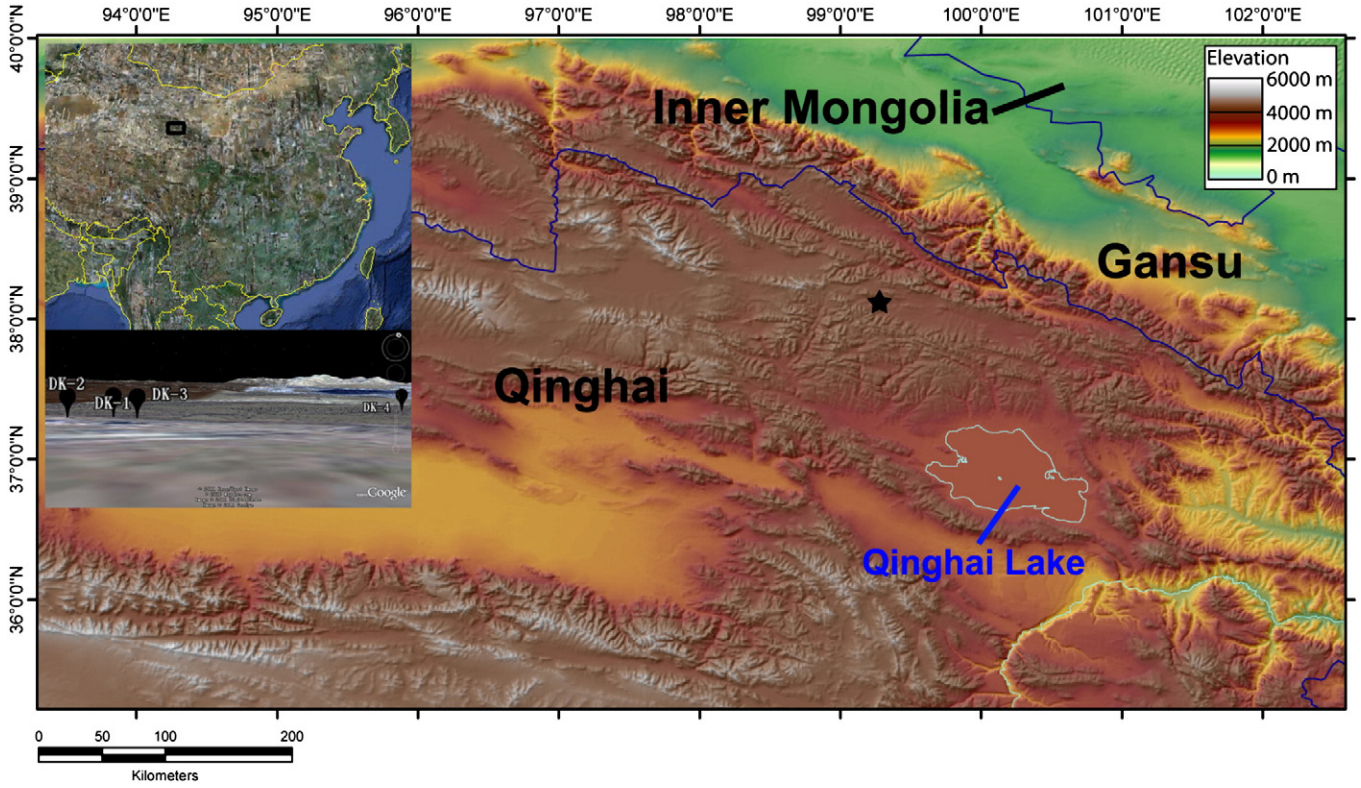

Fig. 1. Location and geomorphology for the study area (by courtesy of Dr. R. Boswell). Note: black box and star indicate the study area and the drilling area, respectively; the upper inset map shows a zoomed out view to the study area; the lower inset map reveals a zoomed in view to the drilling area and the locations of the four drilling locations.

occurrences documented by this study are a first case. Hence, this province is a unique and new region for natural gas hydrates to have been found. The aim of this paper is to summarize the geological and geochemical characteristics of gas hydrate bearing intervals from this drilling and to provide a preliminary insight into gas hydrate distribution and concentration.

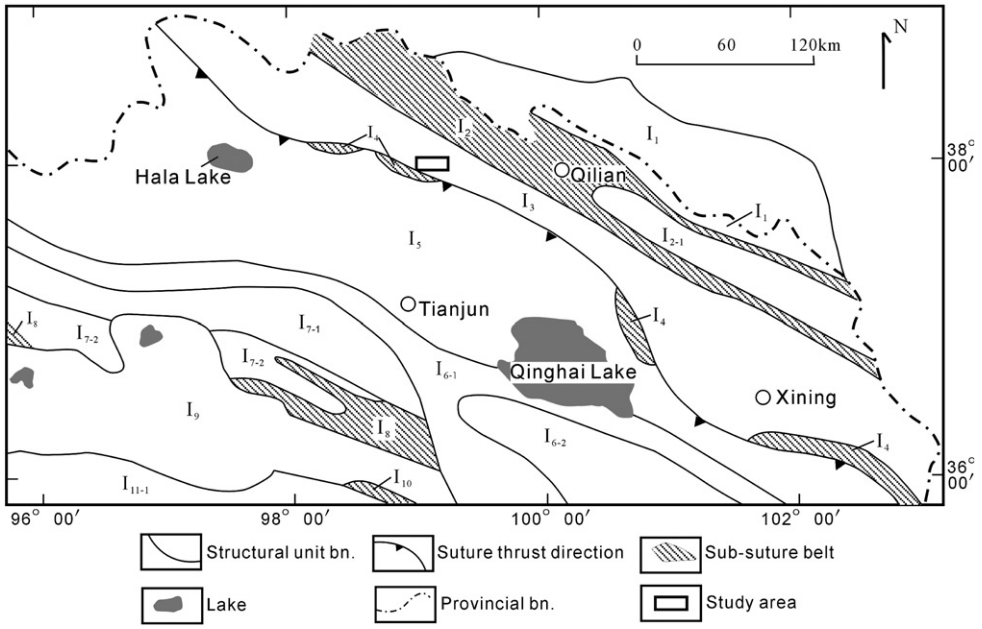

Fig. 2. The sketch of tectonic units in the Qilian Mountain area (modified from Qinghai No. 105 Coal Geological Exploration Team, 2006). I_1, the Alashan continental block; I_2, the North Qilian suture in Neoproterozoic to Early Palaeozoic era; $I_{2\text{-}1}$, the Qilian–Menyuan magmatic arc belt in middle to late Early Palaeozoic era (O–S); I_3, the Middle Qilian continental block; I_4, the South Shule Mountain–Laji Mountain suture in Early Palaeozoic era; I_5, the South Qilian continental block; I_6, the Zongwulong Mountain–South Qinghai Mountain fault–depression trough in Late Palaeozoic to Early Mesozoic era ($D–T_2$); $I_{6\text{-}1}$, the Zongwulong Mountain–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 Mountain marginal craton basin; $I_{7\text{-}2}$, the Dingzikou–Amunike Mountain–Maoniu Mountain magmatic arc belt in Neoproterozoic to late Early Palaeozoic 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 ($Pt_3–J$).