Energy Conversion and Management 73 (2013) 186–194

Contents lists available at SciVerse ScienceDirect

Energy Conversion and Management

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

Gas hydrate formation and accumulation potential in the Qiangtang Basin, northern Tibet, China

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ARTICLE INFO

Article history:
Received 13 December 2012
Accepted 20 April 2013
Available online 20 May 2013

Keywords:
Gas hydrate
Petroleum system
Temperature–pressure condition
Mud volcano
Qiangtang Basin

ABSTRACT

The Qiangtang Basin is the biggest residual petroleum-bearing basin in the Qinghai–Tibet Plateau, and is also an area of continuous permafrost in southwest China with strong similarities to other known gas-hydrate-bearing regions. Permafrost thickness is typically 60–180 m; average surface temperature ranges from −0.2 to −4.0 °C, and the geothermal gradient is about 2.64 °C/100 m. In the basin, the Late Triassic Tumen Gela Formation is the most important gas source rock for gas, and there are 34.3×10^8 t of gas resources in the Tumen Gela Formation hydrocarbon system. Seventy-one potential anticline structural traps have been found nowadays covering an area of more than 30 km^2 for each individual one, five of them are connected with the gas source by faults. Recently, a large number of mud volcanoes were discovered in the central Qiangtang Basin, which could be indicative of the formation of potential gas hydrate. The North Qiangtang depression should be delineated as the main targets for the purpose of gas hydrate exploration.

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 [1]. Recently, gas hydrate has attracted great interest from the scientists [2–9] as an unconventional energy resource. Estimates of world gas hydrate reserves are very high ranging from 14 to 34,000 trillion m^3 for permafrost areas and from 3100 to 7,600,000 trillion m^3 for oceanic sediments [10]. Commercial production of just 15% of these gas reserves would provide the world with energy for 200 years at the current level of energy consumption [11].

Although marine settings house the majority of global gas hydrate resources, permafrost is also an important area for the formation and occurrence of gas hydrate [10]. The Qinghai–Tibet Plateau permafrost is the largest permafrost area in China, covering an area of about 150×10^4 km^2 [12]. Recently, gas hydrate was collected successfully in the Muli region of the Qilian Mountain permafrost area (Fig. 1a) in the northeast Qinghai–Tibet Plateau, which confirmed the existence of gas hydrate accumulations in the high-mountain permafrost areas [12,13].

The Qiangtang Basin, situated in the northern part of the Qinghai–Tibet Plateau, has the lowest average surface temperature in China and widespread development of permafrost, and is also the biggest residual petroleum-bearing basin in the Qinghai–Tibet Plateau. According to the regional survey for oil and gas, more than 200 oil and gas shows have been found from Mesozoic formations [14]. There is a good hydrocarbon exploration prospect for the well-developed thick Mesozoic marine sediments with the maximum 13,000 m in the basin [14]. In the past years, great importance has been attached to trap in the activity of gas hydrate exploration and research [6,7,15–18]. Gas hydrate deposits are gathered in a large anticline crest, or uplift site [19,20]. Seventy-one potential anticline traps have also been found in the Qiangtang Basin to this date. Recently, a large number of mud volcanoes were discovered in the central Qiangtang Basin [21]. Gas hydrates are often associated with deep-water mud volcanoes [22]. These data indicate that the Qiangtang Basin could hold potential gas hydrate resource.

In recent years, the Chengdu Institute of Geology and Mineral Resources underook a detailed study of gas hydrates in the Qiangtang Basin, including geological, geophysical, drilling, and geochemical investigations. Using data from these investigations, as well as previous research, this article summarizes the petroleum-geology and temperature–pressure conditions of gas hydrate formation in the Qiangtang Basin, and proposes favorable targets for gas hydrate exploration. Meanwhile, it can provide a template for exploring gas hydrate in other similar permafrost areas.

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http://dx.doi.org/10.1016/j.enconman.2013.04.020

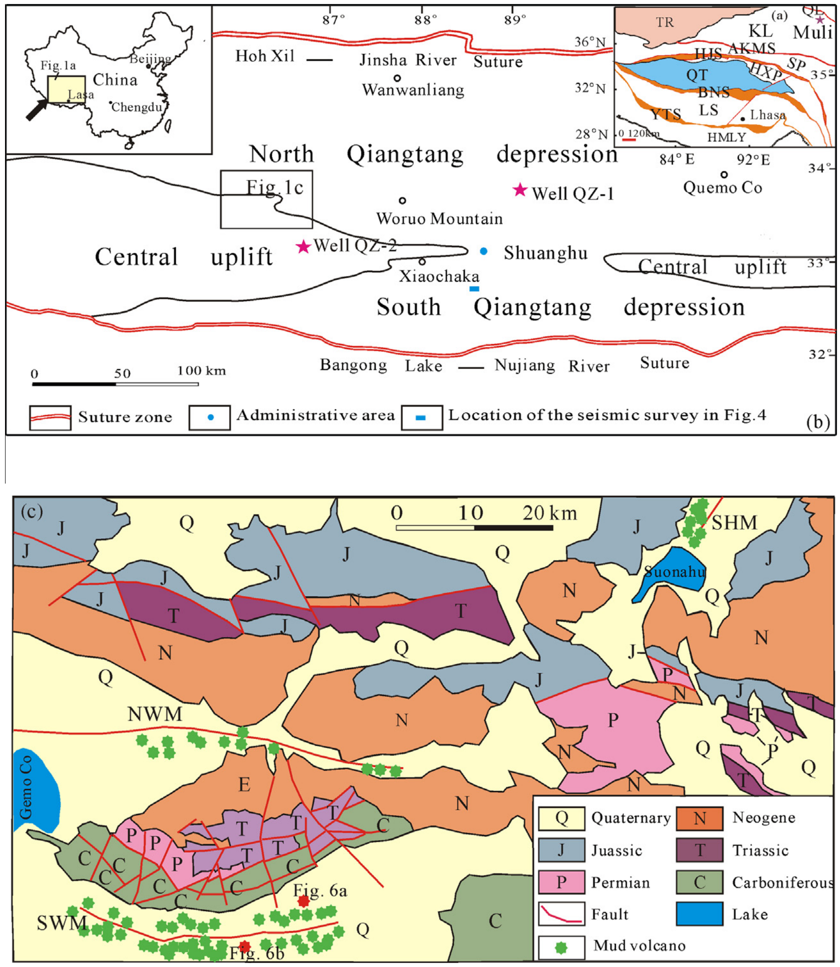

Fig. 1. (a) Map of the Tibetan Plateau showing major Terranes (after Ref. [33]). (b) Simplified tectonic map of Qiangtang Basin (modified from Ref. [33]). (c) Simplified geological map of the Wanghuling area showing the distribution of mud volcanoes (modified from Ref. [21]). TR, Tarim basin; QL, Qilian Mountain; KL, Kunlun terrane; AKMS, Anyimaqen–Kunlun–Muztagh suture; HJS, Hoh Xil-Jinsha River suture; SP = Songpan–Ganzi flysch complex; HXP, Hoh Xili piedmont zone; QT, Qiagtang basin; BNS, Bangong Lake-Nujiang River suture; LS, Lhasa terrane; YTS, Yarlung Tsangpo suture; HMLY, Himalayas; SWM, South Wanghuling mud volcano group; NWM, North Wanghuling mud volcano group; SHM, Suonahu mud volcano group.

2. Geological setting

From north to south, the Tibetan Plateau is composed of the Kunlun–Qaidam terrane, the Songpan–Ganzi flysch complex, and the Qiangtang and Lhasa terranes, which are separated by the east-striking Anyimaqen–Kunlun–Muztagh, Hoh Xil-Jinsha River and Bangong Lake-Nujiang River suture zones, respectively (Fig. 1a). It is generally accepted that the paleo-Tethys represented by the present Hoh Xil-Jinsha River suture was probably open in the Early Carboniferous time and closed by Permian to Late Triassic time [23–29]. The mid-Tethys branch between the Lhasa and Qiangtang terranes was open by the Late Triassic to Early Jurassic time and closed along the Bangong Lake-Nujiang River suture during the Late Jurassic time [14,30–32].

The Qiangtang Basin, marked by the Hoh Xil-Jinsha River suture zone to the north and the Bangong Lake-Nujiang River suture zone to the south, consists of the North Qiangtang depression, the central uplift and the South Qiangtang depression (Fig. 1b). During Permo-Triassic time, the Paleo-Tethys Ocean closed by northward subduction beneath the Kunlun terrence and southward subduction beneath the Qiangtang terrence [23–27], resulting in a large-scale regression in the Qiangtang Basin. During this interval, most parts of the Qiangtang Basin were uplifted and exposed to erosion. Meanwhile paleo-weathering crusts occurred widely in the Qiangtang Basin [33–35]. Subsequently, these weathering crusts were overlain unconformably by a succession of volcanic–volcaniclastic strata that mark the onset of the Mesozoic Qiangtang Basin [35–37]. As a result, the sediments are almost exclusively Mesozoic marine deposits, including the Late Triassic Tumen Gela Formation (or Nadi Kangri Formation), Early to Middle Jurassic Quemo Co Formation (or Sewa/Quse Formation), Middle Jurassic Buqqu and Xiali Formations, Late Jurassic Suowa Formation, and Early Cretaceous Bailong Binghe (or Xueshan Formation) (Table 1). These strata crop out in the South Qiangtang depression and in the North Qiangtang depression, while Paleozoic marine sedimentary sequences are locally preserved in the central uplift.

3. Gas hydrate petroleum system

3.1. Gas source Rocks

Gas source rocks are certainly of great important to the formation of gas hydrate. The total gas resources in the hydrocarbon systems of the Qiangtang Basin amount to 42.8×10^8 t based on basin-modeling methods, of which 34.3×10^8 t are in the Late Triassic Tumen Gela Formation hydrocarbon system [14]. Therefore, the Tumen Gela Formation is the most important gas source rock in the Qiangtang Basin.