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Reservoir volume of gas hydrate stability zones in permafrost regions of China☆

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HIGHLIGHTS

- Comprehensive appraisal of thickness, area, lithology and porosity of hydrate stability zones.
- Detailed estimate of gas hydrate reservoir volume in permafrost in China.
- The significance of gas hydrates in permafrost in Northwest China.

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ABSTRACT

Gas hydrate is a promising energy resource. Permafrost regions in China are natural gas hydrate prospects. In this study, we summarized the conditions for gas hydrate formation, and analyzed the probable thickness and area of gas hydrate stability zones in the permafrost regions in China. Then the probability of porosity within the gas hydrate stability zones was estimated from lithology, burial history, and compaction curves. Finally, the total reservoir volume for gas hydrate stability zones in permafrost regions was estimated from the joint probability distribution of the effective thickness, area, and porosity. The probable total reservoir volume of the gas hydrate stability zones in the permafrosts in China is in the range of $2.995 \times 10^{12}\,m^3$ to $5.081 \times 10^{12}\,m^3$, with the best estimate at $4.002 \times 10^{12}\,m^3$. The Qinghai-Tibetan Plateau including Qilian (where the occurrence of natural gas hydrate has been proven by coring) has about 55% of the total reservoir volume of the gas hydrate stability zones in China, indicating it has a great resource potential. In the Mohe Basin the reservoir volume of the gas hydrate stability zone ranges from $0.49 \times 10^{12}\,m^3$ to $0.79 \times 10^{12}\,m^3$, suggesting it is a hopeful future resource exploration area. The best estimate of the total reservoir volume of the gas hydrate stability zones in Northwest China is $1.2 \times 10^{12}\,m^3$ which is considerable. However, occurrence of gas hydrate is yet to be confirmed by future exploration. These estimates provide much needed data for further gas hydrate resource exploration and evaluation, as well as environmental protection.

1. Introduction

1.1. Background

Natural gas hydrates are solid crystalline compounds of water and natural gas wherein the natural gas molecules (methane and higher carbon number hydrocarbon) occupy voids within the lattices of ice-like crystalline structures. They have remained stable over geological timescales and are present in marine and permafrost environments. Natural gas hydrate was discovered in the 1960s. Interests in natural gas hydrates as an energy source has grown steady since the 1980s and especially in the last two decades as more emphasis is placed on replacing coal with natural gas as a clean source of fossil fuel [1–5].

Natural gas hydrates have been found in many regions of the world. Marine gas hydrates have been found in the Gulf of Mexico [6,7], Atlantic Ocean [8], MacKenzie Delta [9], the Nankai trough [10] and the South China Sea [11,12]. Permafrost gas hydrates have been found in the North Slope of Alaska [13], Western Siberia [14,15] and Qilian

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Nomenclature

GHSZ	gas hydrate stability zone
T_{ground}	mean annual ground temperature
G_T	geothermal gradient below permafrost
MB	Mohe Basin
NW	Northwest China
QTP	Qinghai-Tibetan Plateau
P10	the high estimate, indicating there should be at least a 10% probability that the quantity will equal or exceed the high estimate
P50	the best estimate, indicating there should be at least a 50% probability (P50) that the quantity will equal or exceed the best estimate
P90	the low estimate, indicating there should be at least a 90% probability that the quantity will equal or exceed the low estimate

Mountain in China [16–19]. There has been small scale (single well) pilot production of natural gas from gas hydrates in Alaska [20–21], Nankai Trough [22] and South China Sea [23]. As recently as May 2017, a single well at the Shenhu basin in the South China Sea has produced 309,000 m^3 of gas over a period of 60 days [23]. However, none of these pilot wells produced at commercial rate. It has been reported that gas hydrate contributed to the gas production from the Messoyakha field in Western Siberia [24]. However, there is conflicting evidence as to how much of the production originated from gas hydrate [25].

Research in natural gas hydrates as an energy source can been categorized into three major areas. The first is scientific research with a focus on the physics and chemistry of natural gas hydrates [26–28]. Much work has been done in the area of understanding the crystalline structure of gas hydrates, their phase behavior and ways to produce natural gas by taking advantage of phase changes brought about by temperature, pressure and chemical composition changes such as depressurization, thermal stimulation and injection of chemical inhibitor [29,30]. It has also been found that the self-preservation effect of gas hydrate decomposition may also pose a limit to the rate of natural gas extraction from gas hydrates [31].

The second type of research focuses on the modelling of gas hydrate production by using numerical simulations [32–41]. Much of this work investigates the effect of using various well geometries (vertical versus horizontal) to produce from hypothetical gas hydrate reservoirs. However, the input data for some of these studies such as porosity, permeability, gas hydrate saturation and composition are assumed and not based on field measurements and are therefore limited in their applications.

The third area of research focuses on the geological, geochemical and geophysical research in identifying the source, migration path, seals and traps of gas hydrates found both deep ocean basins and the permafrost [18,19,42–44]. Unfortunately, very little work has been done on quantifying the vertical and areal extent of gas hydrate formations thus resulting in a wide disparity in the estimate of gas hydrate resource volume.

Existing research leaves a considerable knowledge gap concerning gas hydrate resource volume, reserve estimates i.e. recovery volume based on proven technology, and production rates using various recovery mechanisms [45].

Of foremost importance to the commercial production of gas hydrate is the question of resource volume, i.e. the volume of natural gas originally-in-place. The first step in answering this question is to determine the volume of the gas hydrate stability zone (GHSZ), i.e. the subsurface zone within which the pressure and temperature are conducive for the formation of natural gas hydrates. The second step is to determine the saturation of the gas hydrate in the GHSZ. In this paper, we focus on answering the first question for the permafrost regions in China. The reason to focus on the permafrost instead of ocean basin is our belief that feasibility of commercial production from gas hydrate in

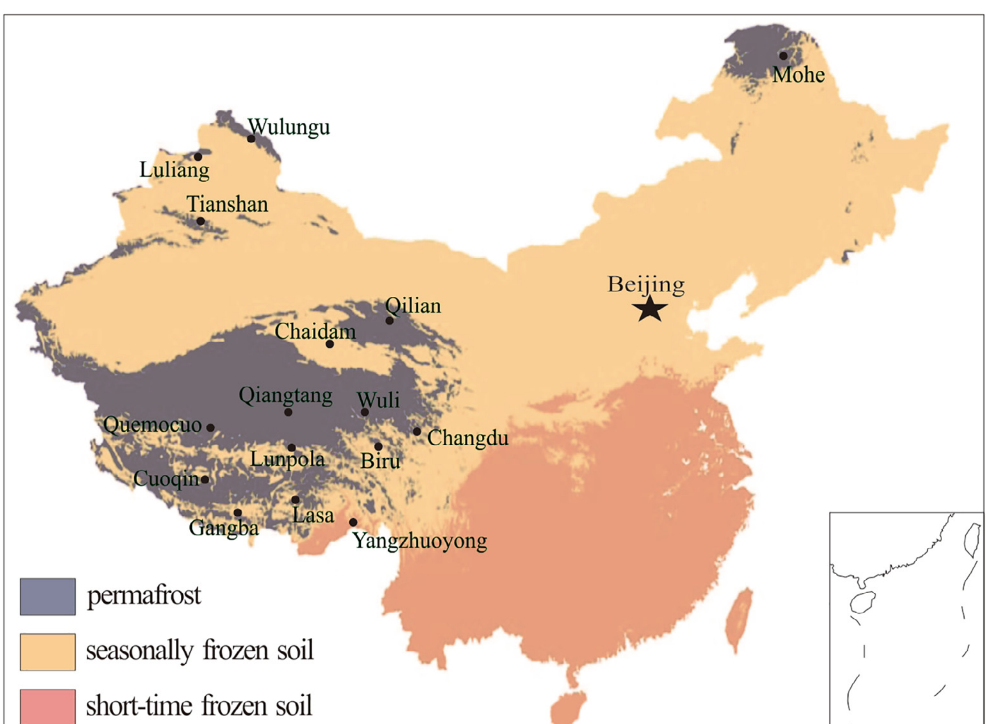

Fig. 1. The location of permafrost in China (modified from Wang et al. [85]).