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# Feasibility of gas production from a gas hydrate accumulation at the UBGH2-6 site of the Ulleung basin in the Korean East Sea

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ABSTRACT

We investigate the feasibility of production from a marine hydrate accumulation that has the properties and conditions of the UBGH2-6 site at the Ulleung basin in the Korean East Sea. The 20 m-thick system is in deep water (2160 m) but close to the ocean floor (with its top at 140 mbsf), and is characterized by alternating mud (near hydrate-free) and sand (hydrate-rich) layers. The layered stratigraphy and the presence of mud layers preclude the use of horizontal wells and necessitate vertical wells. The analysis indicates that production from such a hydrate accumulation is feasible, but the production rates are generally modest. The production rate $Q_p$ peaks at about 1.45 ST m$^3$/s=4.4 MMSCFD at about $t$=1 year, and continuously declines afterward. Sensitivity analysis indicates that cumulative production increases with a declining initial hydrate saturation, an increasing intrinsic permeability of the sand layers and an increasing thermal conductivity of the porous media, while the effect of porosity is non-monotonic: production initially increases with a decreasing porosity, but the trend is later reversed. However, the sensitivity to these parameters is limited, and does not alter the overall predictions of modest production potential. The geomechanical situation appears challenging, as significant subsidence (exceeding 3.5 m at a depth of 20 m below the sea floor, and 1.5 m at the top of the hydrate deposit) is estimated to occur along a large part of the wellbore, and yielding and failure within the 20 m-thick system are possible early in the production process. However, there is significant uncertainty in the predictions of the geomechanical system behavior because they are not based on measured system properties but only on estimates/assumptions from analogs.



## 1. Introduction

### 1.1. Background

Gas hydrates are solid crystalline compounds composed of gas molecules (referred to as guests) that occupy the lattices of ice crystal structures (called hosts). The general reaction of hydrate formation or dissociation is described by

$$G+N_H\ H_2O=G\cdot N_H H_2O+Q_H \tag{1}$$

where G is a hydrate-forming gas, $N_H$ is the hydration number, and $Q_H$ is the enthalpy of hydration/dissociation.

Favorable conditions for the stability of hydrates involve high pressure $P$ and low temperatures $T$. Natural gas hydrates in geological systems occur in areas associated with a gas source (thermogenic or biogenic), and in settings where the $P$ and $T$ conditions that are conducive to hydrate stability exist: in the arctic and in deep oceans. Of the various gases G in natural hydrates ($C_nH_{2n+2}$, $H_2S$, $CO_2$, $N_2$), methane $CH_4$ is the most common ingredient, occurring in overwhelming abundance. Its $N_H$ varies between 5.75 (for complete hydration) and 7.2 (Sloan and Koh, 2008), with an average value of $N_H$=6.

Although there is an extraordinarily wide variability in the various estimates of the size of the hydrocarbon resource trapped in hydrates (Milkov, 2004; Klauda and Sandler, 2005; Sloan and Koh, 2008), ranging between $10^{15}$ and $10^{18}$ ST m$^3$, the consensus is that it is vast. Even when the most conservative estimate is considered, it exceeds the total energy content of the known conventional fossil fuel resources by at least a factor of two. This being the case, and further assuming that only a fraction of the most conservative estimate of the resource is recoverable, its magnitude is sufficiently large to command attention as a potential energy source (Makogon, 1997; Dallimore and Collett, 2005).

Dwindling conventional hydrocarbon supplies, rapidly expanding global demand for (and the corresponding rises in the cost of) energy, and the environmental desirability of $CH_4$ as a "clean" fuel serve to further augment this interest. Additionally, lack of other

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(or limited) hydrocarbon resources in countries where access to energy is a critical (and possibly a national security) issue can only add to the incentive to investigate gas hydrates as an energy source. The emerging importance of hydrates as a potential gas resource was the impetus behind the proliferation of recent studies evaluating the technical and economic feasibility of gas production from hydrate deposits (Dallimore and Collett, 2005; Hong and Pooladi-Darvish, 2005; Kurihara et al., 2005; Moridis et al., 2007, 2009, 2011a, 2011b, 2011c, 2011d; Moridis and Reagan, 2007a, 2007b; Moridis and Sloan, 2007; Kurihara et al., 2008Gerami and Pooladi-Darvish, 2009; Kurihara et al., 2010a, 2010b). It also provided the motivation for this study on the assessment of the promise and difficulties of production from offshore hydrates accumulations in Korea, a country with limited conventional hydrocarbons, a large population, a high standard of living, high energy prices, and a large and expanding economy with an ever-increasing appetite for energy (all these factors making it an ideal candidate for the exploitation of hydrates).

### 1.2. Geology of the Ulleung basin

We focus on the marine hydrate deposits in the Ulleung basin of the Korean East Sea, i.e., a semi-closed marginal sea enclosed between the Eurasian continent and the Japanese islands. The East Sea consists of three deep basins: the Ulleung, the Japan, and the Yamato (Fig. 1).

The Ulleung basin, located at the southwestern corner of the East Sea, is a bowl-shaped pull-apart basin formed by extension of continental crust during the Late Oligocene to Early Miocene (Chough et al., 2000). A narrow and steep-sloped continental shelf marks the western boundary of the basin. A plateau with numerous ridges and troughs forms the northern boundary. The south and east sides of the basin are broad and gently sloped (Fig. 1). The water depth in the basin ranges between 1500 and 2300 m, gradually deepening toward the north and the northeast (Ryu et al., 2005). The sediment thickness in the basin is substantial, increasing from approximately 5 km at the center of the basin (Ludwig et al., 1975) to 10 km in its southern part (Park, 1992). Seismic stratigraphic analysis showed that the sediments in the Ulleung basin consist of four distinctive subdivisions deposited in early Miocene to Quaternary (Kwon and Chough, 2005).

### 1.3. Earlier studies on hydrates in the Ulleung basin

Preliminary surveys conducted by the Korea Institute of Geoscience and Mineral Resources (KIGAM) between 2000 and 2004 indicated a significant potential for gas hydrate occurrence in the Ulleung basin (Park, 2006). The potential presence of gas hydrates in the basin was suggested by several gas-related features identified by the geophysical surveys, including (1) a shallow gas zone in the southwestern part of the basin, identified by high-resolution chirp sub-bottom profiles and echo-sounding images; (2) gas-charged sediments and upward fluid migration, implied by acoustic turbidity and columnar structure of acoustic blanking in surveys of the area; (3) gas seepages on the continental slope, recognized by highly reflective, hyperbolic signals in the water column in echo-sounding images; and (4) gas-related structures (pockmarks and domes) on the continental slope of the Ulleung basin, detected by echo-sounding images (Park, 2006).

Further indications of favorable conditions for the formation of natural gas hydrates in the region were provided by the analysis of piston core samples recovered from the western Ulleung basin (Ryu et al., 2005). These showed rapid sedimentation rates, high heat flow, and high total organic carbon and residual hydrocarbon gas, all conditions conducive to hydrate formation. KIGAM collected several hydrate samples from shallow sediments at a water depth of 2072 m near the center of the basin, at a distance of about 100 km south of the Ulleung islands. Hydrates (99% $CH_4$) intercalated in clayey sediments were found intermittently in the 6.5–7.8 m interval below the seafloor.

On the basis of these indications and observations of hydrate presence in the Ulleung basin, KIGAM conducted the Ulleung Basin Gas Hydrate Expedition 1 (UBGH1) scientific expedition in late 2007. This effort led to the detection of thick hydrate deposits (reported to be on the order of 100 m) at water depths between 1800 m and 2100 m (Chun, 2008; Kim, 2008; Park, 2008), and to the retrieval of cores from the drilling locations to a depth of 200 m below the sea floor (mbsf). The data analysis indicated gas hydrates with significant saturations either in fractured mud or in thin-bedded turbidite sand layers at three coring sites (Park et al., 2008). All these data were used (Chun, 2008; Park, 2008) to provide a first insight into the characteristics of the hydrate accumulations in this area and to evaluate the technical and economic feasibility of gas production from promising accumulations. As part of this effort, Moridis et al. (2009) provided a first evaluation of the gas production potential of the Ulleung Basin hydrates, resorting to significant assumptions about the largely unknown (at the time) geometry, stratification, boundaries, types and conditions of the deposit.

### 1.4. The 2010 Ulleung Basin Gas Hydrate Expedition (UBGH2)

The second expedition (UBGH2) in the basin in 2010 (Fig. 2) conducted logging-while-drilling and coring at 13 sites to better identify the overall distribution of gas hydrate in the Ulleung Basin and to locate gas hydrate reservoirs that could be potential targets of future production tests (Ryu et al., 2012). Examinations of core and well-log data from the UBGH2 drill sites suggest that the UBGH2-6 location has relatively good gas hydrate reservoir quality properties in terms of the individual and cumulative thicknesses of hydrate-bearing sediments (HBS) with desirable textures (sandy). Hemipelagic muds that are frequently intercalated with turbidite sands dominate the sediments at the site, as evidenced from core samples. These sands are usually thin-bedded, and consist mainly of well-sorted coarse silt to fine sand particles. Anomalies in the infrared temperature, pore water chlorinity and pressure data from several cores indicate that gas hydrate zones (GHZ) in the vicinity of the UBGH2-6 site occur within the 112–154 mbsf range. The gas hydrates are preferentially associated with the turbidite sands, in which they act as "pore-filling" material. The HBS identified in the cores are medium-to-thick bedded and well-correlated to significant (high) excursions in the log resistivity, density, and velocity curves. Based on pore-water chlorinity measurements and data obtained from core depressurization studies, the gas hydrate saturation $S_H$ in the HBS were estimated to range from 12% to 79%, with an average of 55%.

### 1.5. Objectives

The objective of this study is to determine by means of numerical simulation the *technical* feasibility of gas production from a hydrate accumulation that is characterized by the properties and conditions encountered at the UBGH2-6 site at the Ulleung basin in the Korean East Sea. Thus, we are investigating both the gas production potential of the accumulation, and the corresponding geomechanical response of the geologic system during the course of production.

## 2. System description and production strategy

### 2.1. System description and geometry

The water depth at the UBGH2-6 site is 2160 m. Preliminary information available at the time of the study indicated that the