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Time series analysis of hydrologic data obtained from a man-made undersea LPG cavern

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ABSTRACT

Characteristics of hydrologic time series data obtained from an undersea LPG (butane and propane) storage cavern were analyzed in time and frequency domains. The analyzed data included cavern seepage rates, cavern operating pressures (gas pressures), water levels of monitoring boreholes in and around the cavern, surrounding tidal levels and site precipitations of long and short periods. The seepage rates showed annual periodic behaviors, which were related to seasonal LPG use pattern. The gas operating pressures were the most dominant controlling factor for the seepage rates. The tidal level revealed an apparent negative cross-correlation with the seepage rate. However, the long-term close correlation between the tidal level and the seepage rate might be attributed to coincident concurrence of the seasonal LPG use and the tidal level variation. The water levels of the monitoring boreholes showed significantly different auto-correlations and spectral densities with locations. The water levels near the butane cavern exhibited high memory effects and low cross-correlations with the tidal level while those of the propane cavern exhibited short memory effects and relatively higher cross-correlations with the tidal level. The difference in all the hydrologic responses (seepage and water level) of the two caverns to the outer stresses such as precipitation, gas operating pressure and tidal level, can be mostly related to the hydrogeologic stratification surrounding the caverns. The low permeable silty clay layer is very thick above the butane cavern while it is very thin about the propane, such that greater hydraulic connection to the overlying sea could be expected.

1. Introduction

Recently, artificially excavated underground hard rock caverns have been increasingly used to store oil or liquefied petroleum gas (LPG) (Lee and Song, 2003; Tezuka and Seoka, 2003; Yamamoto and Pruess, 2004). Success of the gas storage is mostly dependent on the hydrogeological conditions surrounding the caverns (Cha et al., 2006). The caverns generally consist of a construction shaft, access tunnels, main storage rooms, and a water curtain protection system. The water curtain, generally installed for most inland storage caverns, provides a hydraulic barrier to the leakage of gases. If the hydraulic pressure towards the cavern is appropriately maintained, the gas leakage will be minimal (Goodall et al., 1988; Liang and Lindblom, 1994). The undersea cavern, constructed under the seabed, will have an additional natural hydraulic barrier, which is the overlying seawater layer (Lee and Cho, 2008).

Construction of the undersea cavern is a challenging task, which involves many engineering works, including the construction of an artificial island for undersea excavation, prevention of cavern roof collapse, and seepage control (Lee and Cho, 2008). Seepage into the underground cavern is affected by a variety of hydrogeological factors, including site rainfall, cavern operating pressure, hydraulic conductivity of surrounding rocks, integrity of cavern wall grouting, groundwater level (hydraulic pressure) around the cavern, and atmospheric pressure (Kim et al., 2000; Ko et al., 2002). The cavern operating pressure is directly related to loading and unloading of the oil or LPG, which in turn mainly depends on the amount of use (or consumption pattern) by large scale consumers (gas stations and factories) and domestic use. In the case of the undersea caverns, the tidal level and permeability of the seabed can also play an important role in controlling the cavern seepage.

Many underground oil and LPG storage caverns have suffered from unexpected operational problems after construction, including substantial water level decline around the cavern, microbial clogging of rock fractures and mineral encrustation on seepage removal pumps (Barbo and Danielsen, 1980; Geostock, 1992; Ko et al., 2002; Lee and Lim, in press), which would hamper sustainable operation and long-term maintenance of the caverns. In order to avoid or mitigate the undesirable problems, regular and continuous monitoring is generally conducted for the groundwater level, cavern seepage, operating pressure and the chemistry of seepage water and surrounding groundwater. The objectives of this study are to analyze the hydrological time series data obtained from an undersea LPG storage cavern on the western coast of Korea, and to obtain understanding of the hydrogeological condition with the goal to optimize the cavern maintenance activities.

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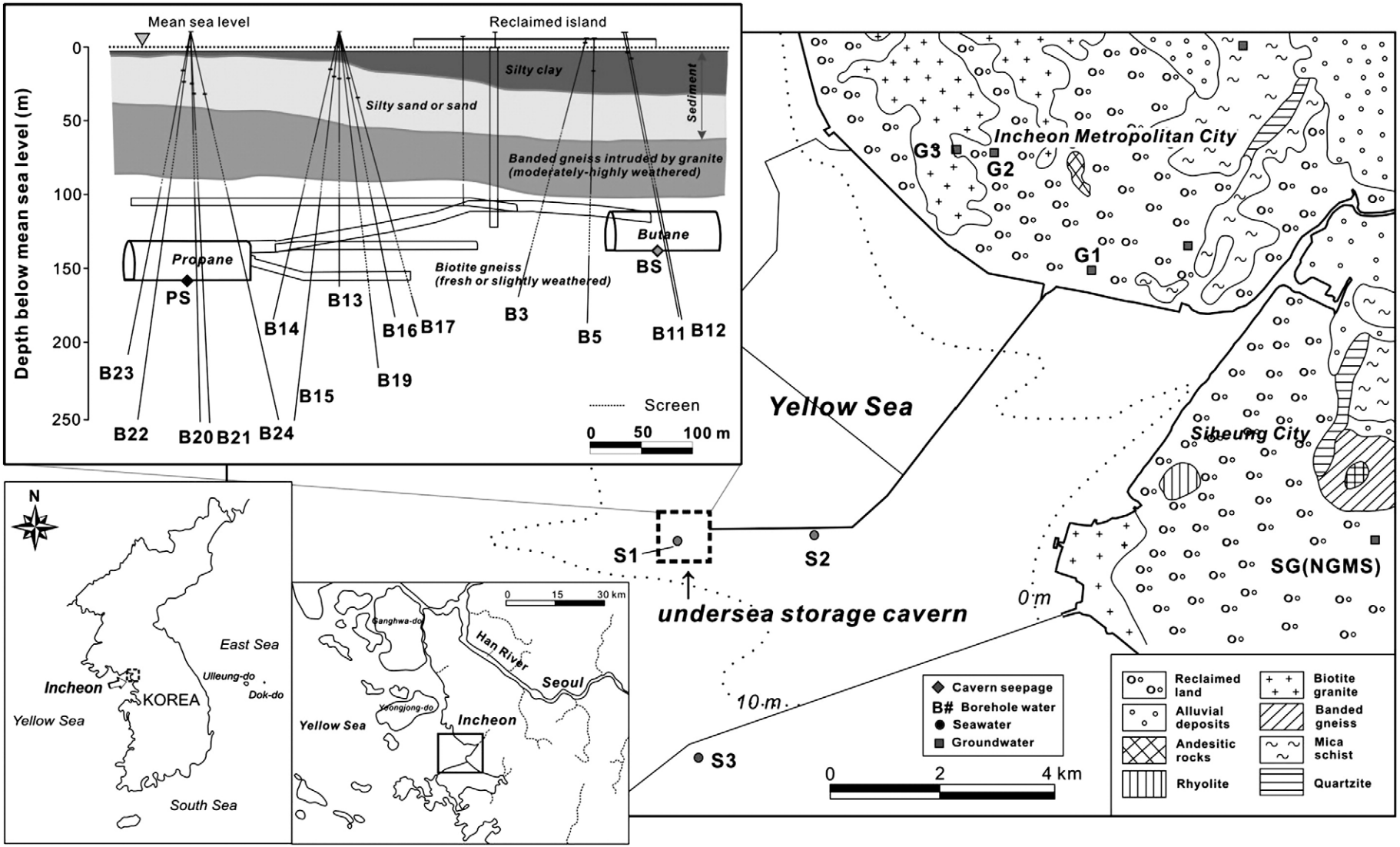

Fig. 1. Location of the studied undersea cavern showing monitoring borehole and wells in and around the caverns. The figure was modified from Lee and Cho (2008).