Distribution and Acoustic Characteristics of Shallow Gas in the Korea Strait Shelf Mud off SE Korea

DAE CHOUL KIM
GWANG HOON LEE
YOUNG KYO SEO
GIL YOUNG KIM

Department of Environmental Exploration Engineering
Pukyong National University
Busan, Korea

SEOK YUN KIM
JEONG CHANG KIM

Department of Oceanography
Pukyong National University
Busan, Korea

SOO CHUL PARK

Department of Oceanography
Chungnam National University
Daejon, Korea

ROY WILKENS

Hawaii Institute of Geophysics and Planetology
University of Hawaii
Honolulu, Hawaii, USA

Shallow gas in the Korea Strait shelf mud (KSSM) off SE Korea, revealed by high-resolution subbottom profiles, is associated with acoustic blanking, acoustic turbidity, seepages with plumes in the water column, and seafloor depressions. The acoustic blanking, characterized by strong, consistent top reflection and wipeout below, is most dominant. The seaward edge of the acoustic blanking zone generally coincides with the 100-m water-depth contour, suggesting that the water depth (the

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Address correspondence to Gwang Hoon Lee, Department of Environmental Exploration Engineering, Pukyong National University, Busan 608-737, Korea. E-mail: gwanglee@pknu.ac.kr

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pressure) may control the distribution of shallow gas. The acoustic turbidity, characterized by diffuse top reflection, is a dark smear, partially blanking the data below. The seepages with plumes, characterized by vertical smearing and disturbed seafloor, are seen only along the shallowest, landward edge of the acoustic blanking zone. This may suggest that the decreased gas solubility at shallow water depths, caused by the lowered pressure, increases the volume of free gas in the sediments, facilitating the gas escape. The seafloor depressions, interpreted as pockmarks, are accompanied by cone-shaped acoustic masking, which is probably the reflection from a narrow vent of gas. The gas-related acoustic anomalies appear to occur mostly in the upper, recent mud of the KSSM. Neither permeable beds nor faults, which can act as vertical migration pathways for deep thermogenic gas, are evident in the recent mud. We interpret that the bacterial degradation of organic matter in situ is the main source for the gas in the KSSM. The upwelling off SE Korea may be an important source for the increased organic matter in the area.

**Keywords** shallow gas, acoustic blanking, acoustic turbidity, Korea Strait shelf mud

The most conspicuous sedimentary features in the inner shelf of Korea are the mud belts that have formed during the last postglacial sea-level rise (ca. 15,000 yrs BP) (Figure 1) (Park et al. 1999). The Korea Strait shelf mud (KSSM) off the southeastern coast of Korea is particularly interesting because of the extensive shallow gas. Gas in shallow marine sediments has been documented in over 100 locations worldwide (Fleischer et al. 2001). The presence of gas within sediments significantly alters sediment physical properties, thereby reducing sediment strength and sediment sound speed and attenuating and scattering acoustic energy (Anderson and Hampton 1980, Wheeler 1990). In high-resolution subbottom profiles, the gas-bearing sediments appear as acoustic turbidity, acoustic masking or blanking, and enhanced reflections (Judd and Hovland 1992). Gas emission also forms pockmarks and domes on the seafloor and plumes in the water column (Field and Jennings 1987, Judd and Hovland 1992). Gas venting from the gas-bearing sediments may be making a significant contribution to atmospheric methane, which is one of the most important greenhouse gases (Fleischer et al. 2001, Hovland et al. 1993).

Choi et al. (1997) first reported the acoustic turbidity in high-resolution subbottom profiles from the KSSM. Park et al. (1999) confirmed the extensive distribution of the acoustic turbidity in the KSSM. Park et al. (1999) further suggested that high primary productivity in the coastal waters off the southeastern coast of Korea, due to coastal upwelling (Lee and Na 1985, Lee and Kim 2003, Lee et al. 2003), has provided large amounts of organic matter to the KSSM and that the bacterial decomposition of the organic matter has produced gas. The acoustic turbidity in the KSSM usually occurs at about 3–5 m below the seafloor, locally reaching the water-seabed interface (Park et al. 1999). Sediment cores that penetrated the uppermost part of the acoustic turbidity in the KSSM have a strong methane odor even after weeks in a refrigerated container (Jung J. H., personal communication 2002). The in situ sound velocities decrease abruptly when these gas-charged sediments are encountered (Gorgas et al. 2003). X-radiographs taken on the cored sediments from the KSSM also show numerous microcracks that are probably due to the expansion of gas bubbles during core retrieval (Gorgas et al. 2003).
Despite these observations, however, the detailed distribution and acoustic characteristics of the shallow gas in the KSSM remain poorly understood. In this study, we analyzed high-resolution subbottom profiles from the KSSM: (1) to describe the acoustic characteristics of the shallow gas, (2) to map its areal distribution, and (3) to discuss its origin. The data used in this study consist of about

Figure 1. Location of the Korea Strait shelf mud (KSSM). The heavy lines in the main figure represent location of chirp profiles. In the regional map, KSSM, Korea Strait shelf mud; CSSM, central South Sea mud; SEYSM, Southeast Yellow Sea mud (adapted from Park et al. 1999). Contours are water depths in meters.
400 km of Chirp (2–7 kHz) profiles (Figure 1), collected on the RV Tamyang of Pukyong National University in 1999 and 2000, using a Datasonics Chirp system (CAP 6000). A combination of GPS and radar systems was used for navigation.

**Regional Setting**

The study area includes the Korea Strait shelf off the southeastern coast of Korea (Figure 1). The Korea Strait shelf becomes wider to the south where the outer shelf is occupied by the NE-SW trending trough. The outer shelf is largely dominated by relict coarse-grained sediments, whereas the inner shelf (<70–100 m water depth) is almost completely covered by the KSSM. The principal source for the muddy sediments of the KSSM is the Nakdong River, which is the only major river system in the southeastern coast of Korea (Park et al. 1999). About two-thirds of the fine-grained sediments from the Nakdong River are carried northeastward by strong shelf currents and deposited along southeastern Korea, forming the KSSM (Park et al. 1999). The KSSM extends to the southwestern shelf of the East Sea (Sea of Japan), covering over 2,400 km² of the surface area (Park et al. 1999). It consists of two stratigraphic units: (1) the recent mud, deposited since the mid-Holocene (ca. 5,000–6,000 yrs BP) when sea level reached nearly its present position, and (2) the transgressive mud, deposited during the postglacial transgression (ca. 15,000–ca. 6,000 yrs BP) (KIGAM 2000). A thin transgressive sand layer separates the recent and transgressive muds. This sand layer corresponds to a prominent reflector in high-resolution subbottom profiles, forming the acoustic basement.

The organic carbon contents of the recent mud of the KSSM range from 0.6-1.35% near the mouth of the Nakdong River and from 1.25–2.21% away from the river mouth (Park et al. 1999). The higher organic carbon contents away from the river are probably due to high surface-water productivity, resulting from the upwelling off the southeastern coast of Korea (Park et al. 1999). The C/N ratios (8.0–30.0) of the organic matter in the cored sediments from the KSSM are between those of marine (ca. 6.0) and terrestrial (>20.0) organic matter (Nakai et al. 1982), suggesting mixed marine and terrestrial sources (Park et al. 1999).

**Acoustic Types of Shallow Gas and Gas Escapes**

The acoustic types of shallow gas and gas escapes in the KSSM, classified on the basis of their acoustic signatures and geometry, include: (1) acoustic blanking, (2) acoustic turbidity, (3) gas seepages with plumes in the water column, and (4) seafloor depressions with cone-shaped acoustic masking. The areal distribution of these acoustic types is shown in Figure 2. The acoustic blanking (Figure 3A), which was described generally as acoustic turbidity in earlier studies in the area, is characterized
Figure 3. Chirp profiles showing various acoustic anomalies in the KSSM. (A) Acoustic blanking is characterized by very consistent and strong top reflection and complete wipeout of seismic data below. The sides of the acoustic blanking are generally steep, almost vertical, with rounded edges. (B) Acoustic turbidity looks like a dark smear, characterized by a variable degree of disturbance and irregular or diffuse upper boundary. (C) Seepages with plumes in the water column are characterized by vertical smearing and disturbed seafloor reflection. (D) Seafloor depressions are accompanied by cone-shaped acoustic masking. Cone-shaped acoustic masking with no apparent seafloor depression is also seen.
by very consistent and strong top reflection and complete wipeout of seismic data below. It is most dominant, covering almost 70% of the survey area. The acoustic blanking is comparable to the acoustic masking described by Hovland and Judd (1988) and to the acoustic blankets described by Taylor (1992) and Garcia-Gil et al. (2002). The seaward edge of the acoustic blanking generally coincides with the 100-m water-depth contour (Figure 2). The depth to the top of the acoustic blanking from the sea surface (Figure 4), computed assuming a sediment sound velocity of
Figure 4. Depth (in meters) of the top of the acoustic blanking from sea surface. The top of the acoustic blanking deepens gradually seaward from about 50 m to over 100 m.
1,550 m/s (Kim et al. 1992), increases gradually with water depth from less than 50 m to over 100 m. The sides of the acoustic blanking are generally steep, almost vertical, with rounded edges. Dome-shaped acoustic blanking is also seen in the southernmost part of the study area.

The acoustic turbidity (Figure 3B), characterized by a variable degree of disturbance, looks like a dark smear. The upper boundary of the acoustic turbidity is generally irregular or diffuse and relatively weak compared to that of the acoustic blanking. Reflectors can occasionally be recognized below the acoustic turbidity zones. The acoustic turbidity is seen only in the southernmost part of the study area. Here, a narrow acoustic blanking zone appears gradually to change to the acoustic turbidity to the northeast (Figure 2).

The seepages (Figure 3C) are characterized by vertical smearing and disturbed seafloor reflection. Weak but distinct plume-like features are seen in the water column immediately above the seepages. It is difficult to map the individual seepages because of their diffuse character and often weak appearance. The gas seepages generally occur in association with acoustic blanking, causing the upper boundary of the acoustic blanking to be diffuse and weak. At least two gas-seepage fields are seen along the landward edge of the acoustic blanking zone.

Two seafloor depressions, accompanied by cone-shaped acoustic masking (Figure 3D), are observed in the northernmost part of the study area. The tip of the cone-shaped acoustic masking in one seafloor depression appears to extend into the water column. Cone-shaped acoustic masking with no apparent seafloor depression is also seen.

**Discussion**

Shallow gas in marine sediments originates from either biological (biogenic) or abiological (thermogenic) processes. Biogenic gas is produced by bacterial degradation of organic matter at low temperatures, whereas thermogenic gas is produced by high-temperature cracking of organic compounds at considerable burial depths (Missiaen et al. 2002). The recent discovery of a commercially viable gas accumulation at the subsurface depth of over 2,500 m, approximately 40 km east of the KSSM, indicates the presence of deep thermogenic gas in the southwestern East Sea (Lee and Kim 2002). The migration of thermogenic gas into the shallow subsurface depths requires migration pathways such as permeable carrier beds, faults, and unconformities. A deep core (>50 m) collected from the southern part of the KSSM (KIGAM 2000) penetrated about 30-m thick recent mud, consisting almost entirely of mud. The gas-related acoustic anomalies in the KSSM appear to occur mostly in this homogenous mud, which is not likely to contain vertical permeable beds that would facilitate the migration of deep thermogenic gas. The high-resolution sub-bottom profiles also do not suggest any offsets or faults in the recent mud where some reflectors are seen.

We interpret that the gas causing the acoustic anomalies in the KSSM has been generated mostly in situ by the bacterial degradation of organic matter. The organic carbon contents (1.25–2.21%) of the cored sediments in the study area are about two times those (0.6–1.35%) in the proximal area of the Nakdong River dispersal system (Park et al. 1999). The C/N ratios (8.04–18.13) of the organic matter in the cored sediments in the study area also suggest that a large portion of the organic matters was derived from marine plankton (Park et al. 1999). Thus, the upwelling off the
southeastern coast of Korea is probably a very important source for the increased organic matter in the study area.

The depth of the acoustic blanking from the sea surface in the study area increases gradually seaward from about 50 m to over 100 m. The seaward edge of the acoustic blanking coincides largely with the 100-m water depth although the KSSM extends further seaward for about 10 km to over 200-m water depth. This may suggest that the areal distribution of the shallow gas is limited by the water depth and thus the pressure, which together with the temperature is the main controlling factor in the solubility of gas in pore water. The increase in pressure with depth increases the solubility of gas in pore water, which in turn decreases the volume of free gas in sediments. The increase in pressure may limit the generation of free gas in the sediments beyond the 100-m water depth in the study area. The seasonal fluctuation of the depth to the top of the acoustic turbidity zone, caused by temperature-dependent solubility of gas in pore water, has been documented in a few cases (e.g. Hagen and Vogt 1999, Wever and Fiedler 1995).

The acoustic turbidity, characterized by the diffuse and weak top reflection, is probably due to the relatively low volume (<1%) of free gas in the sediments (Fannin 1980). Some reflectors can be followed beneath the acoustic turbidity, suggesting that the attenuation of the acoustic energy at the top of the shallow gas is not so severe as that causing the acoustic blanking. The strong reflection associated with the top of the narrow acoustic blanking zone in the southernmost part of the study area appears to become weak and diffuse to the northeast, changing into an acoustic turbidity. This is probably due to the gradual decrease of the volume of free gas in the sediment.

The seafloor features with acoustic anomalies in the KSSM include the seepages with plumes in the water column and the depressions with cone-shaped acoustic masking. The seepages are seen only along the shallowest, landward edge of the acoustic blanking zone. This may suggest that the decrease in pressure with the decreasing water depth decreases the solubility of gas, causing an increase of the volume of free gas in the sediments along the landward edge of the acoustic blanking zone. As a result, the gas is released to the overlying water column. The lowered pressure may also reduce the sealing effect of the sediments, further helping the gas vent.

The seafloor of the study area is very smooth and no significant topographic features are recognizable from the seismic profiles except for the two depressions with cone-shaped acoustic masking in the northernmost part of the area. The seafloor depressions are most likely pockmarks, caused by the removal of seafloor sediments by escaping gas (Judd and Hovland 1992). The cone-shaped acoustic masking is probably the reflection from a point reflector, which represents a narrow, vertical vent of gas. The cone-shaped acoustic masking with no apparent seafloor depression is probably the reflection from an out-of-plane gas vent.

References


