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Gas origin and migration in marine and terrestrial gas hydrate-bearing sediments

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Abstract. Gas origin and migration in marine gas hydrate-bearing sediments in the Nankai Trough and terrestrial permafrost-associated sediments in the Mackenzie Delta are investigated using gas molecular and isotopic data. In the Nankai Trough, $\delta^{13}C$ and δD values of CH_4 show that the CH_4 in gas hydrates is generated by microbial reduction of CO_2. The sediments are composed mainly of sand and shale layers and gas hydrates are concentrated only in sand layers, suggesting that the gas migrated and accumulated selectively to permeable sand layers. The migration process may be related to the geological settings in the Nankai Trough, where fluid flows are active through thrust systems in the accretionary prism. In the Mackenzie Delta, $\delta^{13}C$ and δD values of CH_4 show that the gas in gas hydrate is generated by thermogenic decomposition of kerogen. The kerogen in the sediments is immature for in situ thermogenic hydrocarbon generation. Thus, gas migration from deep mature zone is required for the formation of the thermogenic gas hydrates.

1 Introduction

Gas hydrates are solids comprised of water molecules forming a lattice of cages, which enclose gas molecules, predominantly methane. Natural gas hydrates are mainly found in slope or rise sediments of outer continental margins below water depths of about 300 m and to a lesser extent, in polar permafrost regions (Kvenvolden, 1995). The amount of methane contained in gas hydrates is currently estimated to be between 10^{15} to 10^{17} m^3 (Kvenvolden, 2000), considered an important natural resource in the future. Natural gas hydrates are also believed to be a factor in global climate changes (Haq, 2000) and submarine geologic hazards (Paull et al., 2000). In this paper, gas origin and migration are studied for two gas hydrate accumulations. One is located near the Nankai Trough off the eastern coast of Japan. The other is located in the Mackenzie River Delta of northern Canada.

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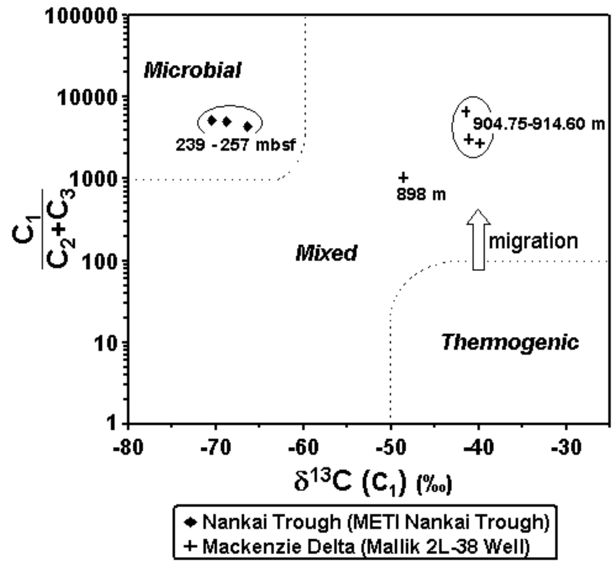

Fig. 1. $C_1/(C_2+C_3)$ ratios vs $\delta^{13}C$ values of methane in gas hydrates. Genetic classification is modified from Bernard (1978).

2 Gas origin and migration in the Nankai Trough gas hydrate-bearing sediments

In the Nankai Trough, a 2355 mbsf (m below seafloor) deep exploratory well was drilled in the eastern Nankai Trough, offshore central Japan, in late 1999 to early 2000.

Carbon and hydrogen isotope compositions of methane and hydrocarbon compositions in gas hydrate-bearing shallow sediments in the Nankai Trough show that the methane is generated by microbial reduction of CO_2 (Figs. 1 and 2). The $\delta^{13}C$ values of CH_4 range from -96 to -63‰ in the upper 300 m sediments. Both $\delta^{13}C$ values of CH_4 and CO_2 become more positive with increasing depth. The preferential depletion of $^{12}CO_2$, progressive decrease in microbial activity with depth and upward gas migration through the sediments column explain the $\delta^{13}C$ depth profiles. In deeper horizons, the origins of gases change from microbial to thermogenic at around 1500 mbsf. Gases shallower than 1500 mbsf have lighter δ^{13}C values of CH_4 (lighter than −59‰), while gases deeper than 1500 mbsf have heavier δ^{13}C values of CH_4 (−48 to −35‰), typical for gases generated by thermal decomposition of organic matter.

The measured TOC (total organic carbon) in the Nankai Trough is around 0.5%, which is considered too low for in situ formation of gas hydrate. Consequently, some gas migration and accumulation processes are required for the concentrated formation of the gas hydrates (up to 80% in pore space) in the Nankai Trough. This process may be related to the geological setting of the Nankai Trough, where fluid flow containing methane is active through thrust systems within Nankai accretionary prism sediments. The sediments are composed mainly of sand and shale layers and gas hydrates are concentrated only in sand layers, suggesting that the gas migrated and accumulated selectively to permeable sand layers. There is, however, no indication of thermogenic gases in shallow sediment including the hydrate-bearing intervals suggesting that the fluid migration is rather local and restricted to the shallow sediments.

3 Gas origin and migration in the Mackenzie Delta gas hydrate-bearing sediments

In 1998, a 1150 m deep gas hydrate research well, Mallik 2L-38, was drilled in the Mackenzie Delta, Canada. The data of core analyses and geophysical loggings show that several gas hydrate layers occur between 890 and 1110 m depths.

δ^{13}C values of CH_4 show that the origin of hydrocarbons changes with depths. Twenty-six gas samples were collected by the headspace method from 50 m to 1150 m depths. Gases in the upper 500 m sediments show light δ^{13}C values of CH_4 ($<$ −72‰), indicating their microbial origin, whereas the gases in the sediments between 890 m to 1150 m, including the gas hydrate-bearing intervals, show relatively constant δ^{13}C values of CH_4, ranging from −45 to −40‰, suggesting that the gas was generated by thermal decomposition of organic matter. δ^{13}C values of CH_4 become heavier smoothly with depths from −75‰ at 500 m to −56‰ at 750 m. In this interval, the origin of gas is interpreted to change gradually from microbial to thermogenic.

Carbon and hydrogen isotope compositions of CH_4 and molecular compositions of dissociated gas hydrate samples show that the origin of gas trapped in gas hydrate structure is thermogenic. Gas hydrate samples were recovered between 897 and 922 m. Methane isotope composition of one gas hydrate sample at 898 m is −49‰, and those of the three samples from 904.75 m to 914.60 m are around −40‰ (Fig. 1). Hydrogen and carbon isotope compositions of methane in the gas hydrate samples suggest that the origin of hydrate-dissociated methane is thermogenic (Fig. 2). The molecular compositions in this interval are relatively rich in methane and poor in higher hydrocarbons compared to ordinary thermogenic gases (Fig. 1). This could be due to long migration of the gases. Since methane is more mobile than higher molecular hydrocarbons in the sediments, gas compositions gradually change to methane-rich in migration process.

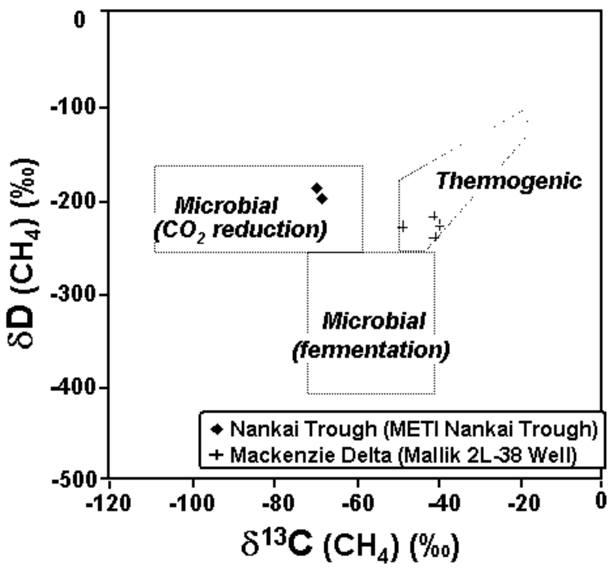

Fig. 2. δD vs δ^{13}C values of methane in gas hydrates. Genetic classification is modified from Schoell (1988).

Based on the geochemical maturity parameters, the entire drilled sediments are interpreted to be immature for hydrocarbon generation. Therefore, the thermogenic gases present in hydrate structures and sediments in the deeper section of the Mallik 2L-38 well should be generated and migrated from much deeper thermally mature sediments. The results of long gas migration are supported by the molecular and isotope compositions of gases as mentioned above.

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