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Gas trasport and Gas hydrate distribution characteristics of Southern Hydrate Ridge: Results from ODP Leg 204

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Abstract : Geochemical analyses carried out on samples collected from cores on and near the southern summit of Hydrate Ridge have advanced understanding by providing a clear contrast of the two major modes of marine gas hydrate occurrence. High concentrations (15%-40% of pore space) of gas hydrate occurring at shallow depths (0-40 mbsf) on and near the southern summit are fed by gas migrating from depths of as much as 2 km within the accretionary prism. This gas carries a characteristic minor component of C2-C5 thermogenic hydrocarbons that enable tracing of migration pathways and may stabilize the occurrence of some structure II gas hydrate. A structure II wet gas hydrate that is stable to greater depths and temperatures than structure I methane hydrate may account for the deeper, faint second bottom simulating reflection (BSR2) that occurs on the seaward side of the ridge. The wet gas is migrating in an ash/turbidite layer that intersects the base of gas hydrate stability on the seaward side of and directly beneath the southern summit of Hydrate Ridge. The high gas saturation (>65%) of the pore space within this layer could create a two-phase (gas + solid) system that would enable free gas to move vertically upward through the gas hydrate stability zone. Away from the summit of the ridge there is no apparent influx of the gas seeping from depth and sediments are characterized by the normal sequence of early diagenetic processes involving anaerobic oxidation of sedimentary organic matter, initially linked to the reduction of sulfate and later continued by means of carbonate reduction leading to the formation of microbial methane.

1. Introduction

Ocean Drilling Program (ODP) Leg 204 was dedicated to coring and logging of the gas hydrate stability zone of the southern Hydrate Ridge, a topographic high in the accretionary complex of the Cascadia subduction zone, about 80 km west of Newport, Oregon. Hydrate Ridge is an area where gas hydrate occurs at or near the seafloor, and methane is venting into the water column. A regional bottom-simulating seismic reflection (BSR) suggests that gas hydrate is widespread. Nine sites were drilled during Leg 204, four sites (1245, 1246, 1244, and 1252) along a west-east transect north of the southern summit, four sites (1247, 1248, 1249, and 1250) on a north-south transect up to the summit of the ridge, and Site 1251 in a slope basin east of the ridge. Water depths ranged from 795 to 1210 meters below sea level (mbsl). A logging-while-drilling hole and multiple cored holes of varying depth were drilled at each site, except at Site 1252 where a single hole was cored. Presence of gas hydrates at all sites except 1252 was confirmed by multiple observations: physical recovery from cores, pressure core samples, chlorinity anomalies, low core temperatures, and sonic and resistivity log responses.

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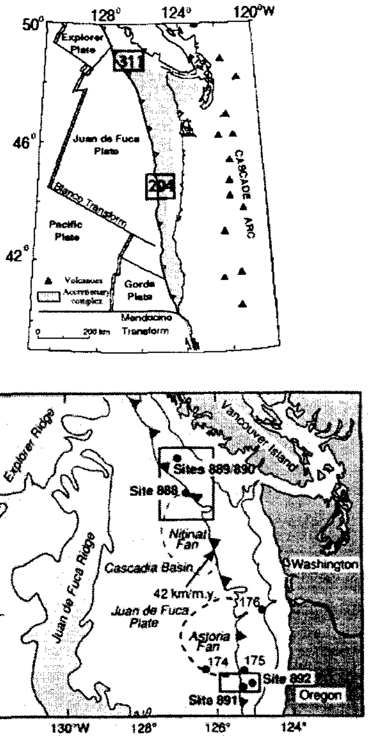

Fig. 1. Location map of the study area; ODP Leg 204 & IODP Expedition 311

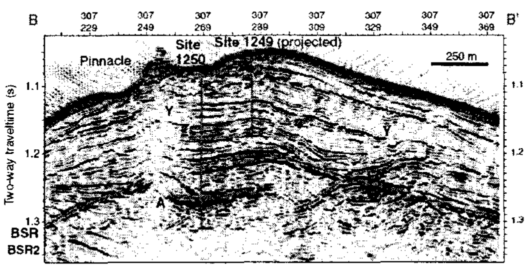

Fig. 2. Seismic sections of the study area. BSR, horizon Y and A are very distinct in the sections.

2. Methods

Four types of gas samples were collected during Leg 204-void gas, headspace gas, gas hydrate, and pressure core. Gas voids formed in the core liner were sampled by means of a core liner penetration tool with a 60-cm3 plastic syringe attached via a three-way stopcock. After sectioning of the core, nominal 5-cm3 plugs of sediment collected using cut-off syringes or a cork borer were outgassed in vials and the headspace gases analyzed according to standard ODP procedures (Pimmel and Claypool, 2001). Small pieces of gas hydrate recovered from cores were quickly cleaned, placed in 60-cm3 syringes and allowed to decompose. Aliquots of gas samples collected during prolonged degassing of PCS cores were also collected in syringes. After shipboard gas chromatographic analysis, aliquots of all except headspace gas were saved for shorebased analysis by injecting into septum-sealed evacuated containers. The headspace methane results were used to estimate dissolved methane content of shallow samples. Procedures for sampling and analysis of pore waters are detailed in the Explanatory Notes chapter of the Leg 204 Initial Reports volume (Shipboard Scientific Party, 2003a).

Isotopic analyses were performed at Woods Hole Oceanographic Institution (USA), and the detailed analytical procedures are given in Milkov et al. (2005). The carbon isotopic composition of the dissolved inorganic carbon from interstitial water samples was analyzed at Oregon State University (USA). Water samples were acidified with phosphoric acid in an online preparation system and the evolved CO_2 measured on a mass spectrometer.

3. Results and Discussion

There are four general patterns of C1/C2 composition illustrated by the different sites cored during Leg 204. At Sites 1245 and 1247 the C1/C2 values are high (105-104) in the uppermost 100-120 m beneath the seafloor, then decrease rapidly to low values (10^2) at depths (150-175 mbsf) corresponding to the occurrence of seismic horizon A, a high-amplitude feature found in cores to be an ash/turbidite layer. Sites 1244, 1246, and 1251 are on the landward (east side) of Hydrate Ridge and are not underlain by horizon A. These sites show a significant offset in C1/C2 values at the depth of the base of gas hydrate stability, from high to intermediate (10^3) values. Site 1252 is in a similar landward position with respect to the ridge, but shows a gradual decrease in C1/C2. Sites 1248, 1249, and 1250 at or near the summit of Hydrate Ridge show an inverse pattern to that typically found in ODP cores in that C1/C2 values are low to intermediate near the seafloor and increase to high values at depths of 50-100 mbsf. With further increase in depth at Sites 1248 and 1252, the C1/C2 values decrease again toward the BSR and horizon A.

Most of the measured 13C values for C3-C5 hydrocarbons are isotopically heavy (-27‰ to -23‰) compared with the 13C1 values. However, the 13C values of ethane appear to represent different populations, as shown in Figure F4, a plot of C1/C2 vs. 13C2. Ethane components in gas samples with relatively low C1/C2 ratios have isotopically heavy values (-32‰ to -28‰; Fig. 3), while ethane in samples with high C1/C2 values is light (-54‰ to -44‰).

One of the most important results of Leg 204 was determining the gas geochemistry, which defines the dominant migration pathways for gas from depth to the seafloor and results in venting of gas and formation of gas hydrates in surface sediments (Milkov et al., 2005). The pathways are localized in the summit region first by horizon A, a northeast-dipping high-amplitude reflector shown by coring to contain methane-rich gas at high gas saturation (40%-80%) levels, with a significant component of C2-C5 hydrocarbons of deeper, thermogenic origin. Second, by the intersection of horizon A with the base of the gas hydrate stability zone, and third by migration of gas through vertical gas chimneys above these intersections to the seafloor and near-surface sediments, and then laterally up to the topographic summit (Fig. 4).

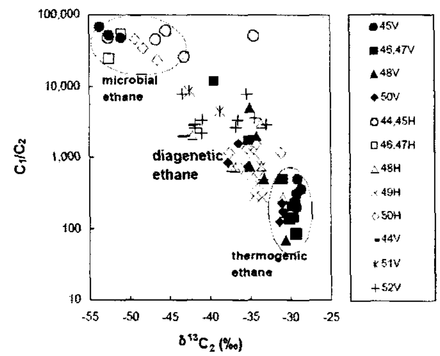

Fig. 3. Carbon isotopic composition of ethane component of gas samples plotted against the C1/C2 ratio of the gas. Samples are coded by the last two digits of the Site numbers, with open symbols and X representing hydrate-bound gases.

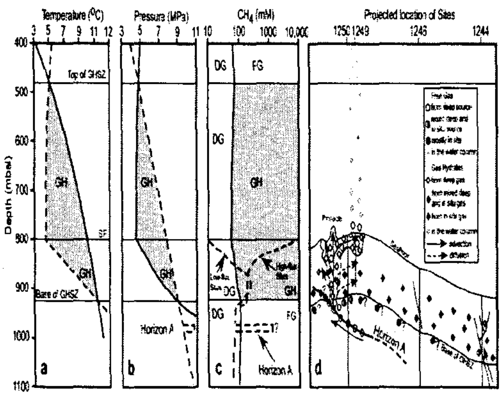

Fig.4. Gas transport and gas hydrate formation model at Hydrate Ridge based on the ODP Leg 204 data.

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