Geological process of gas hydrate formation in the eastern Nankai Trough, off central Japan

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The Nankai Trough runs along the off southwest Japan at the convergent margin of the Philippine Sea Plate subducting beneath the southwest Japan arc. The existence of BSRs has been extensively recognized by seismic surveys, and natural gas hydrates have been recovered in this area. In January to May 2004, METI/JOGMEC-MH21 conducted the drilling of the METI Tokai-oki to Kumanonada wells including drillings, loggings and long-term borehole temperature monitoring by DTS/FBG. This study intends to clarify the present occurrence of gas hydrate and to reveal the geological factors controlling the process of gas hydrate behavior in the Nankai Accretionary prism.

High resolution geochemical study of the interstitial waters and sediments was conducted at two locations in the Nankai Trough. Site 13 was located on the Dai-ichi Tenryu Knoll, 30km southwest off Tokai area where the double BSRs were recognized. Site 4 was located on the northern flank of the Daini-Atsumi Knoll. Gas hydrates were mostly concentrated in sandstone layers of alternating turbidite beds of very fine to medium sandstone and clay/siltstone. The upper limit of gas hydrates occurrence can be attributed to lithology. Pore-saturations of gas hydrates were estimated to be 65 to 80 % at Site 13, and to be 20 to 80 % at Site 4. Cl–baselines (=the original in situ Cl- concentration) at both sites showed contrasting and characteristic patterns, which have been never observed before. Cl- baseline at Site 13 gently increased from seawater value (560 mmol/L) to 700 mmol/L at 100 mbsf. Below 100 mbsf, the Cl- baseline anomalously enriched (600-880 mmol/L). Cl- baseline at Site 4 was observed to be kept at around the seawater value down to 250 mbsf. At the depth of 250 mbsf, they show the slightly lower value (ca. 500 mmol/L), then rise to 681 mmol/L at 295.8 mbsf. At 295.8 mbsf, Cl- baseline was sharply folded back, and radically decreased down to 335 mbsf. Below 335 mbsf, Cl- concentrations were radically restored to the seawater value.

Data from the formation temperature at Site 13 show that the lower BSR corresponds to the present base of gas hydrate stability (BGHS). It indicates that the BGHS has moved down 45m (from the upper BSR to the lower BSR). BGHS is also required to move down 35 m at Site 4 to form its characteristic Cl- baseline pattern. Considering the effect of eustatic sea-level change, net uplift is calculated to be 2mm/yr at Site 13, and 0 mm/yr at Site 4, in order to explain the observed shifts of BGHS.

The formation and dissociation of gas hydrate at Site 13 and Site 4 is summarized as follows: (1) Sea level had fallen toward the Last Glacial Maximum, and the BGHS moved upward. Methane and heavy oxygen enriched water moved upward as a response to gas-hydrate dissociation: (2) Released methane was again trapped above the new BGHS, and gas hydrates have been concentrated within sandy sediments. The upper BSR in the Dai-ichi Tenryu Knoll area (Site 13) was formed at this time. In the Daini-Atsumi Knoll area (Site 4), released methane would be partly oxidized by sedimentary oxides and hydroxides causing an increase in alkalinity, then carbonates with heavy oxygen were precipitated: (3) the BGHS has migrated downward following the transgression over the last 18000 yr. In the Daini-Atsumi area, the relic-BSR corresponding to the upper BSR in the Dai-ichi Tenryu Knoll area would disappear by rapid accumulation of gas hydrate by high methane flux, whereas in the Dai-ichi Tenryu Knoll area, it would remain long after the BGHS migration due to lower methane supply. Eustatic sea-level change has brought the hydrostatic pressure change, and gas hydrate stability zone would also change. However, the amount of additional gas hydrate accumulation would obliterate or facilitate the development of the relic BSR behind.