Mud Volcano Activity Confirmed at the Kumano Basin Edge Fault Zone

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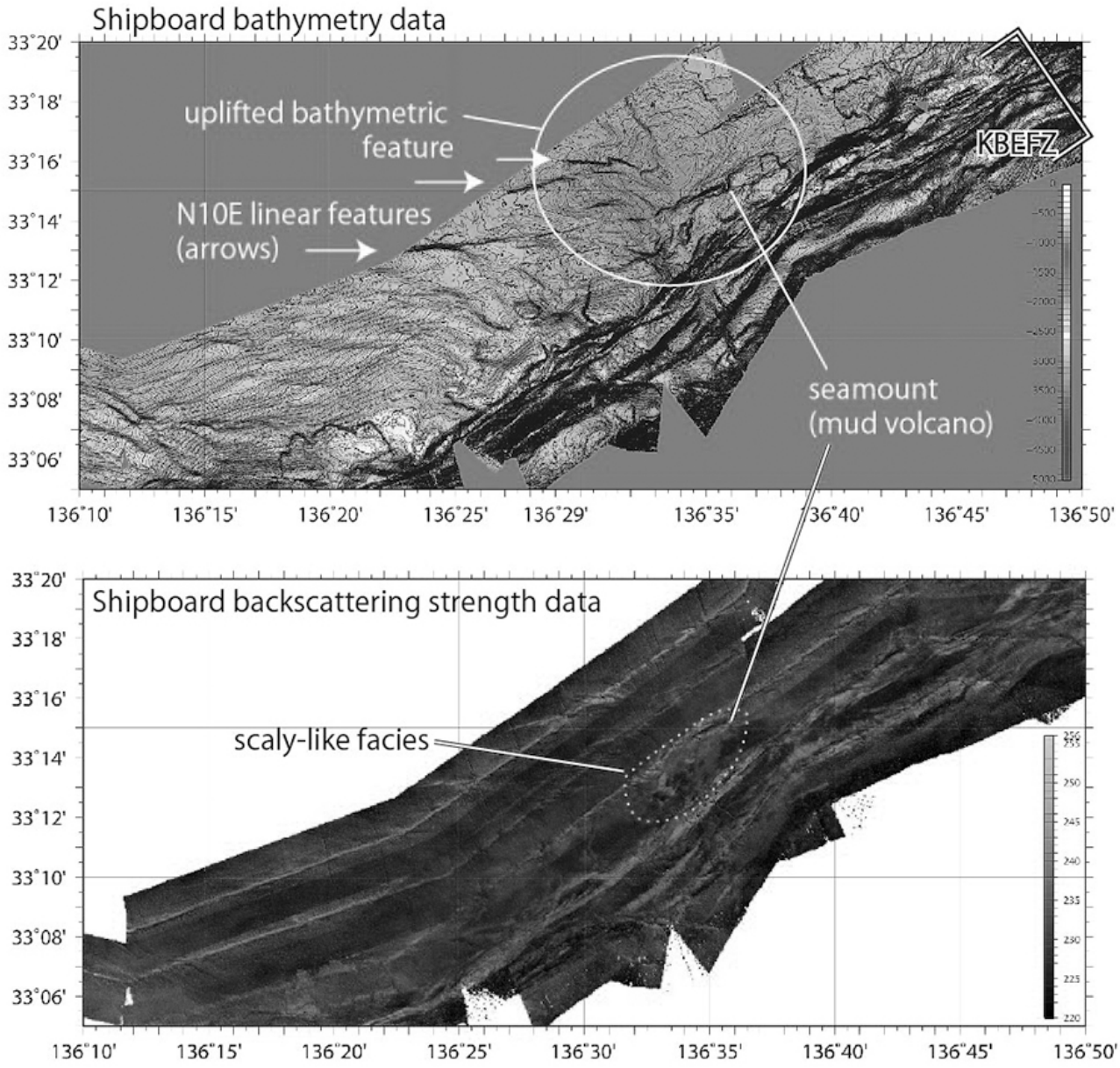
[Introduction]
Mud volcano activity at the Kumano Basin Edge Fault Zone (KBEFZ) was suggested almost 10 years ago, based on the 3D seismic observation of the Nankai Trough seismogenic zone experiment (NanTroSEIZE). The KBEFZ is a tectonic feature along the seaward edge of the Kumano forearc basin (Moore et al., 2009; Martin et al., 2010). The KBEFZ has steep ridges and valleys and is continuous from Tenryu-submarine valley to the east and off-Muroto area to the west. Our acoustic observation using R/V Yokosuka and AUV-Urashima (JAMSTEC) in June 2015 confirmed its mud volcano activity at the southwestern part of the Kumano Basin, the top of the KBEFZ.
[Observed results]
Cruising speed and altitude of the AUV-Urashima during our cruise was 2.0~2.5 knots and 100 m, respectively. Three kinds of acoustic observation equipment mounted on the AUV are multi-beam echo sounder (MBES, 400 kHz, Seabat7125), sidescan sonar (SSS, 120 kHz, EdgeTech2200), and sub-bottom profiler (SBP, 1~6 kHz charp, EdgeTech2200). A pH sensor was installed on the tail of the AUV. R/V Yokosuka obtains bathymetry data in parallel with backscattering strength of the seafloor using hull-mounted MBES (KongsbergEM122, 12 kHz) with ~7 knots.
Bathymetry data obtained by AUV indicates that there is a small seamount at a location of the suggested mud volcano, whose size is ~500 m-diameter and ~80 m-relative height from surrounding seafloor. The seamount has a caldera-like concave feature on its western flank. The SSS indicates a swell in the concave feature and mega-ripple marks on the swell. The pH sensor indicates a negative anomaly just above the concave feature. The SBP indicates an acoustically transparent body below the seamount that drags sub-seafloor sediment layers upward. There results indicate that the seamount is mud volcano (MV). On seafloor, immediately northwest to the seamount, MBES indicates a fault scarp and SSS indicates a region of high backscattering strength, suggesting some hard materials on the fault scarp and upper side of the seafloor. At the ~5.5 km southwestern part of the seamount (MV), we discover that there are acoustically-observed chimney-like features with a few meters of height.
The shipboard MBES observation indicates that the seamount (MV) is settled at the southeastern part of the uplifted bathymetric feature, diameter is ~12 km, at the southwestern Kumano Basin. The uplift seems cut by linear features trending oblique to the KBEFZ (N30E~N40E near the uplift). A N10E trending linear feature cutting uplift seems continuous from the northern fault to the seamount (MV), with changing its trend (N30E at the seamount (MV) and N10E for westward). Backscattering strength (shipboard MBES) indicates scaly-like characteristic facies covering the area of the seamount (MV) and acoustically-observed chimney-like features, over at least 3 km by 7 km area.
[Interpretation and future work]
The N10E trending linear feature is a part of normal fault (Moore et al., 2013). Based on our observation -some hard materials on the fault scarp and upper seafloor near the seamount (MV) (AUV SSS), the N10E trending feature may play a role of fluid transportation from deep within the underlying accretionary prism. The seamount (MV) is a part of scaly-like facies (shipboard MBES) which is a wedge-shaped part between two obliquely trending KBEFZ and N10E trending features, and a part of uplift of southwestern Kumano Basin. Two-dimensional seismic observation (CDEX Technical Report., 2005) indicates acoustic transparent body below sediment layers at the uplifted

bathymetric feature. We suspect that mud volcano activity may relate to the uplifted bathymetric feature and obliquely trending (N10E) faults near the KBEFZ. In the next stage, we aim to get samples from the MV etc. and try to extract geological activities from DONET observatory system working in the neighborhood.

Keywords: Kumano Basin Edge Fault Zone, Mud Volcano, Acoustic Observation



Origins of water and methane in submarine mud volcanoes off Tanegashima

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Submarine mud volcanoes occur along the margins of convergent plates and are formed by the vertical intrusion of low density, deformable sediments from the deep subsurface to the seafloor. Several mud volcanoes have been found at off Tanegashima Island along the northern Ryukyu Trench. Since 2012, we performed an intensive topographic survey of submarine mud-volcanic structures off Tanegashima Island and observed clear mud-flow channels suggestive of the recent mud-volcanic activities at MV#1 (30°53´N, 131°46´E; water depth: 1540 m) and MV#14 (30°11´N, 131°23´E; water depth: 1700 m) based on the side scan sonar image. During the KH-15-2 cruise in 2015, we obtained two sediment cores from the summit of MV#1 (core length: 361 cm) and MV#14 (core length: 311 cm) using a Navigable Sampling System (NSS).
At the MV#1, the chloride (Cl^-) concentration linearly decreased from 550 mM near the sediment surface to 220 mM at 250 cmbsf. Below 248 cm to core bottom, the concentration was constant at ~220 mM. The stable isotopic compositions of pore waters exhibit ^{18}O-enriched and D-depleted isotopic values in proportion to the depletion of the Cl^- concentration, indicating the addition of water from the dehydration of clay minerals that typically occur in the temperature range from 60℃ to 160℃. Generally low concentration ratios of methane to ethane (C_1/C_2: ~ 30) and the stable carbon and hydrogen isotopic compositions of methane ($\delta^{13}C$: ~ −45‰; δD: ~ −120‰) consistently indicate that the hydrocarbon gases are derived from thermal decompositions of organic matter in deep sediments where the *in situ* temperature is >80℃. In contrast to the MV#1, at the MV#14, the Cl^- concentration only slightly decreased from 556 mM near the sediment surface to 490 mM at core bottom, indicating slow fluid advection. This sugggests that the activity of MV#14 is lower than the MV#1. The C_1/C_2 ratios were high as 700-4000, and $\delta^{13}C$ and δD values of methane were −75‰ and −150‰, respectively. These data strongly indicate that most methane is microbially produced via hydrogenotrophic methanogenesis.

Keywords: dehydration from clay mineral, methane, off Tanegashima

Investigation of distribution of mud volcanoes in East China Sea using distribution of methane concentrations in seawater

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Methane in the atmosphere is one of strong greenhouse gases with about 20 times of global warming coefficient of the carbon dioxide (IPCC, 2007). Methane in seawater of continental shelf and coastal area plays a role as a source of methane to the atmosphere (Bange et al., 1994; Bange, 2006; Holmes et al., 2000). In the East China Sea, methane in seawater of continental shelf area was accumulated in summer, and was released in winter to the atmosphere in association with development of mixed layers in the surface water (Tsurushima et al., 1996). In the continental shelf and the Okinawa Trough, mud volcanic geographical features were reported in the East China Sea (Yin et al., 2003), and the existence of chemosynthetic biological communities was observed in the continent slope area (Kuhara et al., 2014). The methane supply from seafloor in the shallow area of the sea can be a source of methane to the atmosphere, requiring a detail survey of distribution of the methane sources. In this study, we investigated methane distribution in the East China Sea, and clarified distribution of methane sources, including mud volcanoes, cold seeps, or hydrothermal systems.
Seawater samples were collected from several sites in the East China Sea during cruise training classes around May or June in 2011, 2012, and 2015. The seawaters were collected by Niskin sampler, and were distributed to 100-mL vials. These samples in vials were added with saturated $HgCl_2$ solution to stop microbial activities, and were capped with butyl rubber caps. They were stored in a refrigerator, and analyzed for methane concentration. During their samplings, CTD monitoring sensors were attached to the Niskin sampler, and they recorded conductivity, temperature, and pressure, etc.
The methane concentrations were measured by GC-FID (Shimadzu; GC-2014A) after gas extraction using extraction equipment. The concentration were determined by 10-ppm standard gas for a calibration, and the precision was within 8%.
Based on the CTD data, we classified the area into continental shelf area, continental slope area, and Kuroshio Current area. First, seawater in continental shelf area contained relatively much methane, suggesting the effects of continental water flows enriched in organic matter, or of seafloor sediments on the shelf. Next, in the continental slope area, seawater showed high methane concentrations around 100-200 m. On the other hand, in Kuroshio Current area, seawater showed the equilibrium concentration with the atmosphere at the surface water, 1-2 nmol/kg above 600 m, and <1 nmol/kg below 600 m. The methane anomaly around 100-200 m in the continental slope area was associated with low salinity, which would be derived from the continental shelf water.
The seawater at some sites in the continental slope area showed anomalous methane concentrations around several hundred meters. These sites include places that have never been reported as mud volcano area, cold seep area, nor hydrothermal area. We cannot identify phenomenon of the methane source, but hydrothermal systems are unlikely considering tectonic setting. Mud volcanoes and cold seeps are likely in this area. Below the seafloor, Shimajiri Group or Yaeyama Group may be distributed, which is rich in organic matter, and normal faults would be distributed associated with rifting activities of back-arc basin, which would play a role as a pathway of methane from deep layers to surface layers of sediments. In these areas, methane would be released from the seafloor as mud volcanoes, cold seeps, or pock marks. Depending on a scale or numbers, the methane sources can play a role a source of methane to the atmosphere. We will investigate methane

distribution in the seawater and observe the seafloor by submersibles, and clarify the details of methane releasing phenomenon.

Keywords: seawater, methane, East China Sea, mud volcano

The Ascension Process of the Fluid from the Mud Volcanoes along Anticline and Fault Zones

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We conducted geological surveys and geochemical analyses of the groundwater and the gas expelled from the mud volcanoes along the Chishan Fault (CMV) and along the Gutingkeng Anticline axis (KMV) in the southwest Taiwan to generalize the ascending process of highly saline groundwater erupted from the mud volcano. Also, we performed the geophysical exploration of the CSAMT method around the Wushanding mud volcano along the Chishan Fault.
Yanchao area in the southwest Taiwan is composed of Miocene Gutingkeng Mudstone, Wushan Sandstone and Pliocene Erchuangchi Shale. In addition, the reverse faults with NE-SW trend and SE dip (the Chishan Fault) and an anticline with NNW-SSE trending axis are distributed in the Yanchao area. Furthermore, we classified the mud volcanoes in the southwest Taiwan into 4 types based on the morphological feature. The Corn type is characterized by a conical high mound with the height of more than 1 m. The Pudding type is also characterized by a conical high mound with the height less than 1 m. The Crater type is characterized by an inside wall. The Pool type is characterized by a pool and without a mound. The Cone type is only observed in CMV. Along a fault, it is assumed that the fluid from the mud volcanoes with low water content ascends along the fault zone containing much clay like a fault gouge. The $\delta^{18}O$ of CMV is heavier than those of KMV. It is assumed that the $\delta^{18}O$ of groundwater from the mud volcano along a fault zone become heavy due to the water-rock interaction happened in deep underground. Gases of CMV are thermogenic. Those of KMV are characterized by the mixing of thermogenic one and microbial one. It is thought that the microbial gas is generated near the ground surface and mixed with the ascending thermogenic gas. Moreover, the erupted gases from the mud volcano distributed in the southwest Taiwan are biodegraded. The degree of biodegradation differs in each mud volcano in CMV. In contrast, the variation of biodegradation is small in the mud volcanoes in KMV. In addition, the maximum burial depth of the vitrinite of CMV is estimated to be about 3,500 m deep that is deeper than that of KMV (2,500 m) by the relationship between the vitrinite reflectance and geothermal temperature. Low electric resistivity zone obtained by the CSAMT exploration corresponds to the distribution of the Chishan Faults in the Yanchao area. Therefore, it is concluded that the fluid ascends through the Chishan Fault zone.
Based on the results obtained in the study and previous studies, we supposed the ascending process of the erupted fluid from the mud volcano as follows. At first, abnormal water pressure is formed in deeper at the fault zone than that at the anticline. The fluid from deep underground stay in the mud chamber once located shallow underground under the mud volcano along an anticline axis. Then, the fluid ascends with making cracks by the high gas pressure caused by de-gassing. Then, the fluid is erupted violently to the ground surface and forms the mud volcano with forming the morphological depression. On the other hand, the fluid ascends through the fault zone consisting clayey fault gouge under the mud volcano along the fault zone. The fluid involves clay and mud when it ascends through the fault zone. Then, the fluid ascends through various paths in the fault zone. Finally, most of the fluids erupt to the ground surface gently and form the Cone type mud volcano.

Keywords: mud volcano, Taiwan, fluid, anticline, fault zone, CSAMT method

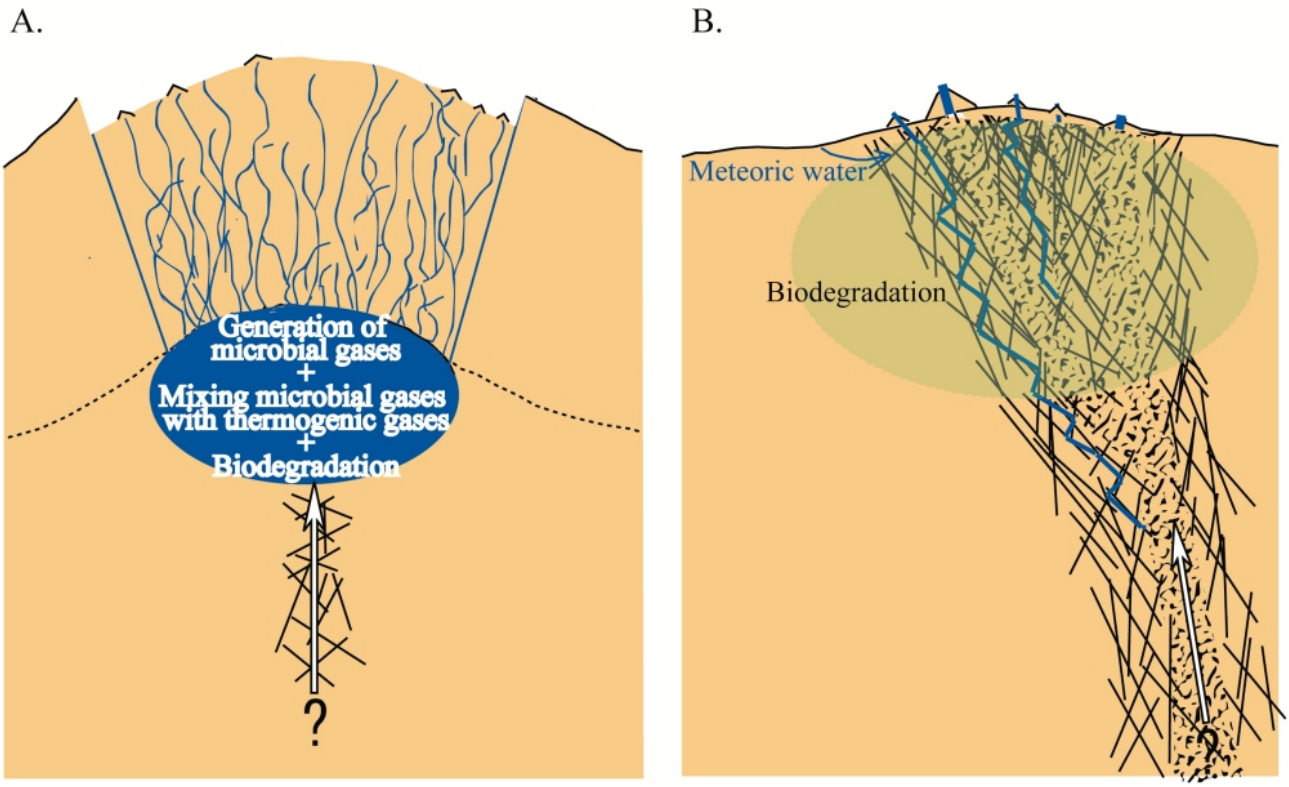

Fig. 1. The ascending model of the fluid erupted from the mud volcano in shallow underground. A: Anticline axis, B: Fault zone

Diapiric melange of the Shimanto belt in sowth Kii peninsula

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Pebbly mudstone melange, called "Sarashikubi beds", locally constitute the upper member of the Oligocene to Lower Miocene Shimanto belt in southern Kii peninsula. It is lithologically subdivided into three units, A, B and C in ascending order (Hisatomi et al. 1980). Unit A and C show of block-in-matrix texture in which clasts sandstone and conglomerate are in muddy matrix. Crusts size widely varies, and contains a large amount of mudstone fragments other than larger (~10m) the sandstone blocks, mud matrix is very few in amount. Although Unit A is a massive without any layering, while in Unit C shows stratification due to both size and amount of clasts. Unit B consists of layered sandstone and conglomerate beds with evidence of shallow-marine normal sediments. Conglomerates shows grain supported texture with sandy matrix. That melange has been interpreted as olistostrome formed by large-scale subaqueous slope failure. However, the involvement of mud diapirism is suggested by the following reasons, 1) Distribution of Unit A is discordant with the peripheral surrounding strata. 2) Preferred orientation of the blocks long axis in Unit A is predominant than in the debris flow deposits of the Unit C, which suggests the possibility of clast rotation due to shear at the time of intrusion. 3) Unit A and Unit C includes characteristic disaggregated sandstone block which characterize the Tako mud diapir (Lewis & Byrne, 1996). 4) The elastic-wave velocity and density of sandstone clasts included in melange is larger in sthan those surrounding strata. 5) Near the “Sarashikubi beds” there is often a clastics injections. In particular, the 30m scale mud diapir was found at the Tanosaki, 1km east from the “Sarashikubi beds”. 6) Carbonate nodule were found from the “Sarashikubi beds” as well as surrounding strata. They are several centimeters to 0.5m in diameter. In cross-section, they show concentric structure of dark gray calcite, with euhedral pyrite crystals (~1mm).

Keywords: mud diapir, melange, Shimanto Belt, Kii Pninsula, carbonate nodule

