State of the Nankai Trough seismogenic zone inferred from thermal and hydrological regime of the mud volcanoes

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Mud volcano is a conical-shape mound with its diameter ranging from several hundred meters to several kilometers. It is characterized by a sub-seafloor seismically-transparent diapir underlying the cone. Intensive surveys of mud volcanoes have been carried out in many areas; Mediterranean accretionary complex, North Sea (Stregga landslide, etc.), Black Sea, Lake Baikal, Taiwan, East China Sea, Nankai Trough, Cascadia, Costa Rica margin, and Barbados. A driving mechanism for the mud diapirism is the buoyance by a negative density of the diaper and the triggering by the tectonic compression due to plate convergence. Depending on the hydrological property of the sediment, pore fluid cannot drain out from the sediment generating overpressures that also promotes the fluid seepage to the seafloor.
In the Kumano forearc basin there are some mud volcanoes. The Li-isotope analysis of pore water in the core samples obtained from the mud volcano revealed that the origin of the fluid is at depth where formation temperature reaches ~300 degC (Nishio et al., 2015EPSL). A simple extrapolation of surface thermal gradient ~40 mK/m gives the depth of 7-8 km for 300 degC. However, the actual depth is deeper because the thermal gradient should decrease with increasing depth. More importantly, the thermal regime is neither one-dimensional nor in steady state. You need 2D or even 3D numerical simulation, taking into consideration of the advective effect of plate subduction, sediment compaction, geological-scale sediment deformation (fold and thrust), frictional heating due to coseismic fault slip, etc. Through matching the surface heat flow data to the model, Harris et al. (2011 G-cubed) inferred the 300degC depth at ~20 km.
An important factor affecting the evolution of mud volcano is the fluid expulsion rate. Since it is important to directly measure the rate, some proxies are used such as nonlinear profile in pore fluid chemistry (Cl, SO4, etc.) and geotherm, or BSR depth anomaly as indicating the base of methane hydrate stability. Goto et al. (2007AGU) reported the heat flow distribution across the Kumano Knoll No. 4 (KK4); the heat flow higher than 70 mW/m2 in the base of the mud volcano, low heat flow (20-30 mW/m2) in the western slope, and heat flow of ~60 mW/m2 in the summit area. Through numerical calculation considering the topographic effect (thermal refraction), they suggest an upward fluid flow rate of ~1mm/year. The driving force of the flow can be the overpressure at ~20km, which is about the depth of plate boundary fault zone causing M8 great earthquakes. The overpressure may be generated along the fault zone due to the dehydration of clay minerals or coseismic dynamic thermal pressurization if combined with the hydrologically undrained condition. As such, we expect that the mud volcano activity can be an important proxy (or window to the seismogenic zone activity) for the assessment of seismic urgency.
Recently, Asada et al. (2016, this meeting) discovered a giant mound and mud flow activity at the seaward edge of the Kumano basin, where a previous 3D seismic survey revealed a distinctive diaper structure. The depth to the mega-splay fault (seismogenic fault) is only 3 km and the inferred temperature is only 100 degC. A further in-depth research should reveal the state of the fault zone, improving our understanding on the Nankai seismogenesis.

Keywords: Nankai Trough seismogenic zone, mud volcano, heat flow anomaly

Dispersal of deep-biosphere communities from submarine mud volcanoes to the overlying hydrosphere

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Submarine mud volcanoes along the plate convergent margins represent "natural pipelines" that vertically transport low density, deformable sediments and gaseous compounds from several kilometers below the seafloor to the overlying hydrosphere. For example, methane is supplied through upward fluid advection via the mud volcanism from the deeper hydrocarbon reservoir and microbial communities near the seafloor consume a large fraction of methane through their aerobic and anaerobic oxidation activities on the seafloor. However, the vertical dispersal of microbial components from the subseafloor habitat to the overlying seawater remains unknown.
Since 2012, using the AUV "Urashima" and ROV "Hyper-Dolphin", we performed an intensive seafloor survey of the submarine mud-volcanic structures off Tanegashima Island, showing well-preserved mud-flow channels suggestive of the recent mud-volcanic activities. During the KH-15-2 cruise in 2015, we obtained sediment core and water samples from the summit of MV#1 and MV#14 using a Navigable Sampling System (NSS). The profiles of methane concentrations in the water column showed a small peak (1-2 nM) at about 40 m and 60 m above the top of MV#1 and MV#14, respectively, indicating the existence of methane plume discharged from the submarine mud volcano. To study taxonomic composition of microbial communities in sediment and water-column habitats, we extracted DNA and then sequenced 16S rRNA genes using a next generation sequencer. The sequence analysis demonstrated that microbial community structures are overall very different above and below the seafloor. However, interestingly, we found some common species, such as "*Atribacteria*"-relatives, which are widely distributed in anaerobic subseafloor sedimentary habitats. Moreover, the distribution patterns of those common species correlate with the peaked methane profiles. Our geochemical and microbiological observations suggest that a small fraction of deep-biosphere microbial communities are geomechanically dispersed with methane from submarine mud volcanoes to the overlying hydrosphere.

Keywords: Mud Volcano, Microbial community structure

Shallow marine mud volcanoes in the Miocene Tanabe group, Kii Peninsula

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The component material and intrusive structures of several mud diapirs in the Miocene Tanabe Group, southwest of the Kii peninsula were examined to reveal the fluid intrusion style and processes. To examine factors controlling the intrusive styles, tank experiments were also performed. Three types of intrusive structures such as cylinder, dome, and sill types were observed in ascending order in the Shirahama Formation overlying the muddy Asso Formation of the Tanabe Group. (1) Cylinder type: The Ichieminami mud diapir, the about 20m in diameter, intruded into bedded sand and siltstones almost vertically. The majority matrix is siltstone, with subordinate sand and quartzose sand in inner part. (2) Dome type: Ichiezaki mud diapir has a dome shape of about 150m in diameter including blocks and sand grains of host sediments by stoping. Many mud dykes radially intruding into hostrocks are clayey in the early stage and sandy in the later stage. (3) Sill type: The mud diapir of the Migusa represents the lens shaped lacolith with at least 200m in diameter, mainly consists of pebbly mudstone involving blocks of surrounding strata. There are small-scale mudstone sills and dykes around the diapir. As a result of tank experiments, it was observed that a series of lenticular intrusive slurry body with dome like upheaval, transforming into the mud chamber expanded involving blocks and particles of the host sediments. As it collapsed, a conduit of upward escaping muddy fluids, sill and dyke structures are formed above the chamber. Based on the correlation between the diapiric structures in the Tanabe Group and intrusive features in the tank, (1) Cylinder type intrusion is indicative of conduit of the fluid to the chamber. Such a vertical path shows a concentrated fluid flow cut through permeable sedimentary strata without any muddy impermeable intercalation. (2) Dome type diapir corresponds to a mud chamber or the upper most part of a cylinder type intrusive body where the stoping process is most predominant. (3) Sill type intrusive body is thought to represent the mud chamber intruded into layered sedimentary sequence with remarkable permeability contrast. These diapirs of the Tanabe Group show a variety of intrusion by a single event that a high-pressured fluid with small amount of mud injected through a narrow conduit to the level where a large mud chamber expands one after another, by which different types of intrusive structures are formed in accordance with permeability contrast and the degree of solidification of the host sediments. Subaqueous debris flow depsits erupted from a mud volcano (Nakaya and Hamada, 2009) more than 100m in thickness have been reported from middle to upper member of the Shirahama Formation. Small scale (less than 20m) fluid intrusion structures were also found in several horizons of the upper member of the Shirahama Formation. At least, some of those structures display characteristic deformation style suggesting the fluid as gas phase. Carbonate nodules and chimneys were found in from the uppermost Asso Formation. The carbon stable isotope ratios of calcite and dolomite in nodules and chimneys ranges from -22 to 7 permil. (PDB), and the oxygen stable isotope ratios ranges from -20 to 0 permil. (PDB). Pyrite nodules less than 10 cm in diameter are formed in the fluid intrusion structures in several horizons of the upper member of the Shirahama Formation. The sulfur stable isotope ratios of the pyrite nodules are ranging from -4.3 to +l.4 permil. (CDT), which are similar of those in carbonate nodules and chimneys. Thermal or deep-seated fluid with CH4/CO2/H2S gases might have been erupted to the shallow water area at the time of regression stage of the Tanabe Group.

Keywords: mud volcano, mud diapirism

Ground deformation of mud volcanoes in Azerbaidzhan detected by InSAR and estimation of the pressure source

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Interferometric synthetic aperture radar (InSAR) allows us to observe a wide area and two-dimensional information of Earth's surface without the need for ground-based measurement tools with a precision on the order of a few centimeters. The purpose of this study is to detect ground deformation of mud volcanoes in Azerbaijan by InSAR and to estimate the depth and volume change of the pressure source using a Mogi model (Mogi, 1958).
Azerbaidzhan, located on the western edge of the Caspian Sea in Central Asia, is one of the most abundant countries in term of the population of mud volcanoes over the land. We use the SAR images derived from ALOS/PALSAR and ALOS-2/PALSAR-2 launched by JAXA in 2006 and respectively. As a result, we could detect surface deformation mostly uplifting signals at more than 10 mud volcanoes. These observations indicate that the mud volcanoes around the studied areas are active. We noticed two mud especially large volcanoes in Azerbaidzhan, Ayaz-Akhtarma mud volcano and Akhtarma-Pashali mud volcano. Benedetta et al. (2014) also detected the pre-eruptive ground deformation of these mud volcanoes, using ENVISAT/ASAR C-band SAR data for descending pairs that, span from 2003 to 2005. Although the ground displacement at both volcanoes were 20 cm and 4.5 cm for the two years, subsequent movement was not clear. We report the ground displacements both mud volcanoes, using ALOS data for ascending and ALOS-2 data for ascending and descending tracks, respectively. The detected interferograms indicated that the maximum line of sight (LOS) changes were -13cm/yr. Based on the Mogi model, our preliminary estimate of the depth and volume changes are 400 m and 1.0×10^5 m^3, respectively.

Keywords: InSAR, Mogi model, Azerbaidzhan

Distribution and geomorphology of well-preserved pitted mounds in Terra Sirenum, Mars: Implications for possible mud volcanism

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On early Mars (Noachian to Hesperian Periods with approximate absolute age ranging from 4.1 to 3.1 Gyr [1]), groundwater/hydrothermal systems, estimated from the presence of clay minerals on a global scale [e.g., 2], may have occurred, with diverse evidence including a number of putative mud volcanoes being reported in both the northern lowlands [e.g., 3] and relatively old, southern highlands [e.g., 4, 5]. However, the spatial extent of potential mud volcanism on Mars has yet to be fully understood. Moreover, criteria for distinguishing between mud volcanoes and other analogs (e.g., cinder cones, tuff cones, rootless cones, pingos) has yet to be established.
Here we focus on clusters of mounds within an elongated basin floor (~181 km x <~47 km, centered at 203.4°E, 27°S) in the northern Terra Sirenum region (mapped as early to middle Noachian terrain [1]) of the southern highlands, and analyze their spatial distribution, morphological characteristics, and morphometric parameters using high-resolution images recently acquired by NASA's High Resolution Imaging Science Experiment (HiRISE; 25 or 50 cm/pixel spatial scale [7]) and Context (CTX; ~5 to 6 m/pixel [8]) cameras onboard the Mars Reconnaissance Orbiter (MRO), and high-resolution (2 m/post) digital elevation models (DEMs) created from HiRISE stereo pairs.
Mapping of more than 600 mounds, based on a mosaic of CTX images, reveals the alignment of mounds along regional structures, and spatial concentration of ~150/1000 km^2. Using HiRISE images, geomorphological characteristics, such as summit pits, meter-size boulders and dune deposits on their flanks, and smoother surface textures relative to the surrounding terrains, can be commonly observed from most of the mounds. Preliminary morphometric analysis of four mounds, calculated from our DEM, show that they have basal widths ranging from~300 m to 800 m, heights of up to ~40 m, height-to-width ratios of 0.04 to 0.07, and cross-sectional topographic profiles exhibiting convex-upward slopes.
The resultant values are comparable to those of some mud volcanoes on Earth [9], and the slope geometry is highly consistent with the emplacement of yield-strength fluids [10] (e.g., slurries of water and mud or lava flows) rather than deposition of pyroclastic fragments. Though a volcanic origin cannot be ruled out, the combination of their distribution and meter-scale morphology with their morphometry favor a mud volcano origin. If the mud volcano hypothesis is true, their relatively young surfaces suggest that the formation of source reservoirs and conduit openings along regional fissures for erupting mud and water might have occurred during more recent times than Noachian age. This is consistent with other post-Noachian features in the region such as valley networks and collapse depressions which are linked to faults [11]. Additional high-resolution spectral data coverage obtained by the MRO spacecraft in the future will improve mineralogical characterization of the mounds and further discussions of possible diagenetic processes and/or hydrothermal alteration.
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Keywords: mud volcanism, Mars, remote sensing

Mud Volcano Activity Confirmed at the Kumano Basin Edge Fault Zone

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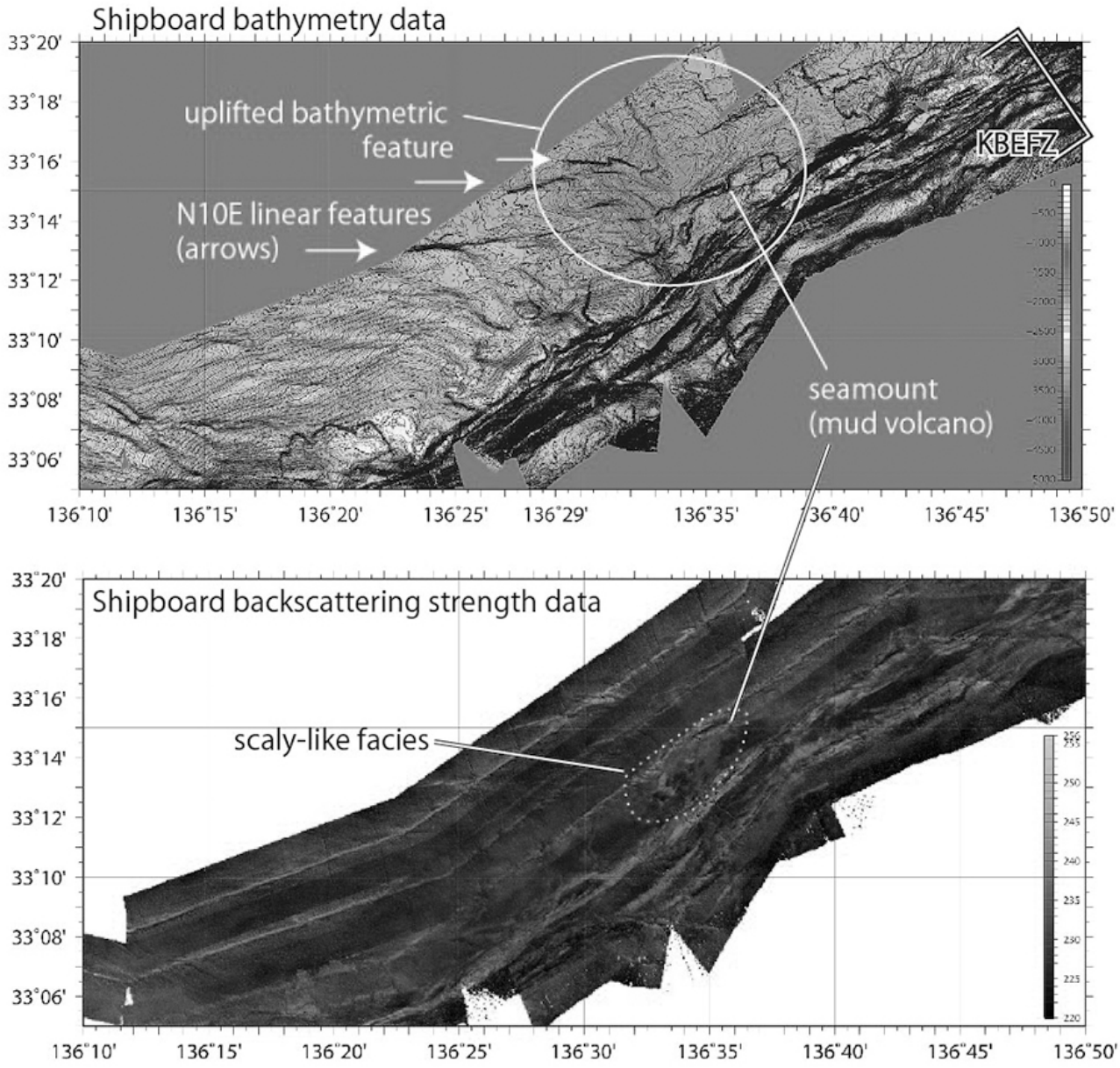
[Introduction]
Mud volcano activity at the Kumano Basin Edge Fault Zone (KBEFZ) was suggested almost 10 years ago, based on the 3D seismic observation of the Nankai Trough seismogenic zone experiment (NanTroSEIZE). The KBEFZ is a tectonic feature along the seaward edge of the Kumano forearc basin (Moore 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

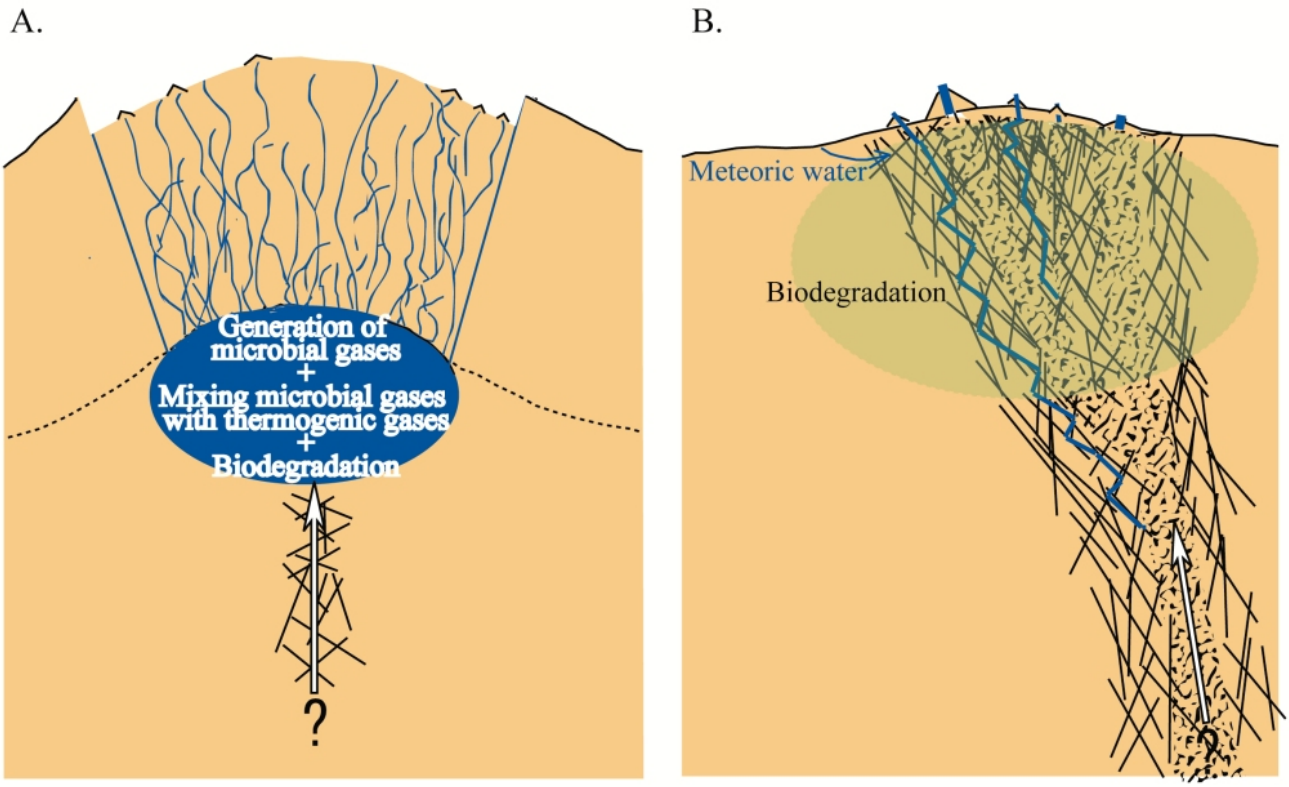

Fig. 1. The ascending model of the fluid erupted from the mud volcano in shallow underground. A: Anticline axis, B: Fault zone

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).

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