Seafloor sedimentary processes on the western slope of Sagami Bay, Central Japan: deep tow observations

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Sedimentary processes related to active plate tectonics and the occurrence of a seep community was studied on the west slope of Sagami Bay. Five types of bottom sediments were identified on the basis of observations using a deep-towed camera imaging system and submersible. Very thin fine sedimentary layers were distributed on the slope. In the western, there occurred more slump sediment and rock outcrop, which was closely related to distribution of clams. At the base of the slope there occurred lots of small-scale debrites. The seafloor processes after earthquakes and during seismically quiescent times were compared. The turbidity currents with lots of mud were very strong after earthquake so that low-energy turbidity sediments can be deposited on the flat floor, which is interbedding with fine laminated hemipelagic sediments, whereas this turbidity current was very weak during seismically quiescent duration.

Keywords: Sedimentary processes, seep community, Sagami Bay, Deep Tow

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1. Introduction

Deep-water seep communities have been repeatedly discovered in the convergent margins (Barry et al., 1996; Fujioka et al., 1989; Greene et al., 1997; Hashimoto et al., 1989; Henry et al., 1989; Le Pichon et al., 1989; Okudani and Egawa, 1985; Suess et al., 1985; Suess et al., 1998; and so on). In accretion zone, the earliest report was from the Galapagos Ridge (Corliss et al., 1979; Suess et al., 1989). Similar communities have been widely reported from offshore Japan (Okutani and Egawa, 1985; Hashimoto et al., 1989; Fujioka et al., 1989). The cold community in the study area, also called Hatsushima community, is the one of largest one in Japan. It was discovered during a manned submersible dive in 1985 (Okutani and Egawa, 1985). This community is closely to its tectonic setting and the prevalent dynamic sedimentary dynamics. In the present study, factors that control the generation and sustenance of the Hatsushima community are investigated.

After the discovery of Hatsushima community, repeated observations using the ROV Dolphin 3K and the submersible Shinkai 2000 have been made to determine its distribution since 1980’s. These observations contributed to better understand of local geological setting and of bottom sediments. During Cruise KT88-1 the surficial sediments were sampled by grab sampler, piston corer (Fujioka et al., 1989). Measurements show that the heat flow here is high than other typical seepage areas (Fujioka et al., 1989). The Hatsushima community lies within an active earthquake zone. Lava flows were observed south of our study area during submersible dives where lava, volcanogenic sand and mud covered the seafloor (Naka et al., 1988). To monitor the seafloor geological processes and ecology of Hatsushima community, a deep-sea submarine observation station was installed in 1990 (Momma et al., 1997). Bottom currents, temperature and hydrochemistry of the near bottom waters have been collected since that time. Deep-towed, regional surveys conducted during Cruise KY99-02 and Cruise KY97-05 provided information on seafloor dynamic sedimentary processes.

2. Tectonic setting and bathymetry

Sagami Bay is located at the plate boundary between the Philippine Sea Plate and Northeast Japan plate which collided with each other during period 1-0.5 Ma (Fig. 1). These plates are also in collision with the Eurasian plate (central Honshu) to the west. Sagami Bay

![Regional tectonics and bathymetry. Box shows the study area](image-url)
is tectonically one of the most active area in the world (Ishibashi, 1985; Nakamura et al., 1984). It consists mainly of strongly folded and faulted Neogene to Quaternary strata, which characterize the subduction zone. The compressive deformation with significant uplift and a radial pattern of the maximum stress in the Izu region can be interpreted as a result of the collision of Izu-Bonin arc against central Honshu and the Northeast Japan plate (Nakamura et al., 1984). The central part of Sagami Bay is filled with more than 5 km of Late Cenozoic sediments (Kong et al., 1984).

Our study area is located west of Izu Peninsula (Fig. 2). The most prominent bathymetric feature in the western Sagami Bay are steep, north-south trending scars which can be followed unequivocally for about 40 km (Fig. 3). The relative height is 1000 m in the
north and over 500 m in the south. Small canyons or gullies exist on the slope, but they die out at the base of the slope, where the gradient changes abruptly, suggesting the existence of fault hinge (the West Sagami Bay Fault; Ishibashi, 1985; Kong et al., 1984). However, nature of the fault is still controversial. Ishibashi (1985) suggested that this fault may be an incipient subduction zone with a westward dip as a consequence of the collision of Izu-Bonin arc against central Honshu.

3. Methods and data

Deep Tow Camera with maximum depth 6,000m permits real time observations, measurements as well as sampling in the deep environment. It is towed at speeds of 0.5 to 1 knots and 3 or 4 meter above the seafloor. A 4,000m class Deep Tow camera was deployed in Cruise KY97-05 along nine tracks, while a 6,000 m class camera was used during Cruise KY99-02 (16-23 March, 1999) on 8 tracks (Fig. 2).

4. Bottom sediments observed by Video Camera imaging data

4.1. Upper slope thin bottom sediment (DT-2C, DT4K-9C, Fig. 4A)

Track DT-2C extends 500 m north-south and is situated on the gentle upper slope within water depth 321-340 m. The bottom sediments consist mostly of mud, while bedforms indicative of bottom currents are absent (Fig. 5C). Bottom organisms such as sea cucumber, starfish and shells have been observed. The long-range survey on the upper slope conducted in 1997, soon after the swarm earthquakes shows relatively flat seafloor with rock outcrops and small gullies formed by turbidity currents triggered by the earthquakes (Fig. 4A; Momma et al., 1997). Few turbidity currents, however, can be observed during periods of seismic quiescent.

4.2. Lower slope

Track DT-5C starts at 1165m depth and ends at

Fig. 4 Occurrence of turbidity current observed by deep towed camera during cruise KY97-05, whereas little turbidity current observed during earthquake quiescent (cruise KY99-02). 4A: the seabottom sedimentation of tracks DT4K-1C and DT4K-9C on the upper slope; 4B: seabottom sedimentation on the lower slope and comparison between after earthquake (DT4K-2C and DT4K-8C) and earthquake quiescent (DT-5C).
1169 m depth (Fig. 4B and 5A). It goes over a gently undulating seafloor with a maximum water depth of 1251 m and a minimum of 1165 m. Bottom sediments are characterized by fine grain size. The biota deposits are sea cucumber and starfish, but lack of clams represented the cold seep community. At the eastern-most end of the track are suspended particles characteristic of turbidity currents. Rock outcrops, boulders and gravel have been observed only at western part of the track, in particular from 10:09 to 10:12 (Fig. 5A). These boulder and gravel deposits are distributed discontinuously in a preferred direction. They probably represent breccia of the West Sagami Bay Fault zone.

Track DT-6C is located on rugged terrain with numerous scarps, some of which near the center of the track are over 50 m in height (Fig. 5B). With only a few exceptions, talus and rock outcrops occur over the entire track. The talus material is poor sorted and angular. Gravel, sand and silt deposits are observed within a small cannon (12:52 and 12:00h, Fig. 5B and 6d). Other features recorded include debris apron and numerous livings as well as dead clams.

Track DT-7C transits to the slope. It starts at a small gully with a steep scarp. Boulders, gravel and fine-grained size sediments are typical debris deposit. This kind deposit dominate along the entire track with only two exception: at 15:52:46h when rock outcrops along a steep scarp occur, and at 16:19h when bioclastic sediments succeeded by mud are observed (Fig. 5C). Current-induced bedforms are absent. From 16:14 to 16:18 h, shell beds are records. The shells are broken implying that they must have experienced reworking.
Track DT-8C begins at a small gully which is characterized by mud sedimentation on the flanks and erosion at the center. Northeast of the gully, the flank of a small canyon is encountered. Here, mud passes over to rock outcrop at a scarp. The canyon floor is covered by lots of boulders and gravel, as well as fine-grained sediments. Sea cucumber, shells and deed clams have been observed (Fig. 5D).

4.3. Sedimentary facies and Seep community

The biological characteristics of the cold seep community first discovered in 1985 have been studied in detail (Okutani and Agawa, 1985; Hashimoto et al., 1989; Greene et al., 1987). The prodigious numbers of dead and living giant clams *Clayptogena soyoeae* were scattered from place to place on the seafloor over roughly 7 km along the steep slope at depths between 900 and 1200 m (Fig. 6b). Living clams were distinguished by their closed shells and strikingly red-colored siphons. The living clams are concentrated in the north, while the deed clams are more abundant in the south. In contrast, neither living nor dead clams were found toward the flat basin, which is blanketed by fine sediments. As Hashimoto et al. (1989) reported, the living clams tended to occur in the northern part of our study area. Thus, no clams were reported from track DT-5C during KY99-02, but they are abundant along track DT-6C and 8C (Fig. 5B, 5D). There occur a few dead clams along track DT-7C (Fig. 5C).

4.4. Turbidity currents activity on the slope

The slope within our study area is characterized by a lack of channels and high the frequent occurrence of earthquake. In order to identify features associated with turbidity current, we compared the two repeated observations of Cruises KY99-02 and KY99-05 with each

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Fig. 6 Photographs made by the deep towed camera. a: rock outcrop on the northern part of lower slope. b: clams distributed in the lower slope from submersible Shinkai 2000 (Observer: Y. Ogawa, 1997). c: fine sediment on the flat base of the lower slope. d: debrites along track DT-7C on the slope foe.

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other. The survey of Cruise KY99-05 started soon after occurrence of an earthquake swarm (Iwase et al., 1998), while that of cruise KY99-02 took place during a seismically quiescent period.

The camera images along tracks DT4K-2C and DT4K-8C of cruise KY97-05 (after an earthquake swarm; Iwase et al., 1998), show lower visibility (lower transparency indices) than those in the images of the nearby track DT-5C of cruise KY99-02 (Fig. 4). Direct observations between DT-5C and DT4K-2C located at near same tracks showed a big difference. The mud turbidity current (black shadow) along DT4K-2C can be observed, whereas there was no mud turbidity current along track DT-5C. The mud turbidity currents were widely observed along track DT4K-8C after occurrence of earthquake swarm. Thus, this could imply that turbidity currents occur soon after earthquakes, but are absent or very few during quiescent times. That kind of mud turbidity current is triggered by earthquake. Real time observations at Hatsushima submarine station also support this view (Iwase et al., 1998). Turbidity currents are abundant and unconfined on the upper slope, but they are confined to gullies on the lower slope.

5. Sedimentary sequences and faces

5.1. Sedimentary facies

The sediment types and their distribution were mapped by deep-towed camera imaging, sidescan sonar imaging, direct observations as well as sampling using a submersible (Fig. 7). Five sedimentary processes could be distinguished on the slope. These are: (1) fine-grained sediments found as a very thin veneer on the upper slope (Fig. 6C and 7); (2) volcaniclastic outcrops occur on eroded gullies on the slope; (3) abundant, small-scale, sandy, sometimes gravel-bearing turbidites at the base of the slope; (4) thick, fine-grained sediments that occur in areas deeper than 1,100m; and (5)
debrites distributed over steep scarps in the western part of our study area (Fig. 7). The occurrence of clams is closely related to this debris flow deposits face.

5.2. The sedimentary types and distribution of the community
Several studies (Hashimoto, 1989, Greene et al., 1997) suggest that Hatsushima community is formed in association with active fault, namely the West Sagami Bay Fault first proposed by Ishibashi (1978). Although this fault is marked by steep scarps and is apparently recognizable in multi-channel reflection seismic data (Kong et al., 1984; Okimura et al., 1999), there exist two parallel faults, of which one is blind thrust, and disappear to the east. The geological model of the study area shows in Fig. 8A.

5.3. Geological setting and seep community
Previous geological studies of seep communities show that geologic complexity and tectonically dynamic nature of continental margins surrounding the Pacific Ocean basin favor cold seep formation in a variety of geological settings, which produce mud volcanic fault zones, channel and submarine artesian springs. Along the active boundaries, faults can interpret and focus fluid migration, enhancing the development and persistence of chemosynthetic communities. The often narrow continental shelf, steep slopes and common occurrence of submarine canons, faulted porous strata, or unconsolidated sediment promote localized upward or outward flow of sulfide and methane-rich pore water, thereby supporting chemosynthetic communities (Barry et al., 1996; Greene et al. 1997).

There are two factors benefiting to methane rich fluid migrated to the situ where clams discovered. First, West Sagami Bay Fault is active fault as above discussed. So it is considered the most important passage for the deep fluid migration to the seafloor along fault plane or its structural fractures. The west Sagami Bay Fault as syn-sedimentation fault cut into basement. The range of the fault limited the distribution of clams. That is why clams just found in westward of profile 08 (Fig. 5C). Second is sedimentary face. There are many debris lobes with high porosity and penetrability near the WSBF with gentle dip to trough. It naturally flows to place that clams occur at normal strata pressure.

6. Conclusion
1. The five sedimentary types have been mapped mainly by deep tow survey on the western slope of Sagami Bay, central Japan.
2. Turbidity currents have been observed at the base of the slope even during times when it was seismically quiescent. Immediately after earthquake, more significant turbidity currents occur both on the upper and lower slopes. Small-scale turbidites were found at the base of the slope.
3. Debrites was dominated near the western slope and is closely related to distribution of seep community.

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