Morphological evolution of five seamounts near the Ogasawara Fracture Zone in thePacific using chirp (3-7 kHz) subbottom profile data

T.G. Lee*,S.M. Lee**,J.W. Moon*,K. Lee**

* Marine Geoenvironment and Resources Research Division, Korea Ocean Research, tglee@kordi.re.kr

** School of Earth and Environmental Sciences, Seoul National University, Seoul 151-742, Korea

1. Introduction

Past observations have shown that submarine volcanoes tend to evolve morphologically from simple circular cones to complex shapes by a combination of extrusive and intrusive volcanisms, sediment deposition, erosion, and slope failure along the flank (Vogt and Smoot, 1984; Mitchell, 2001). This morphological evolution is distinct in large volcanoes of the western Pacific. Canary Islands and Hawaiian Islands which were studied recently are good examples of the transition from conical shape into stellate form by flank eruption and mass-wasting (Gee et al., 2001; Mitchell et al., 2002). Flank eruption and mass-wasting on large volcanoes are probably one of the most important and effective processes involved in their destruction and construction (Mitchell et al., 2002). Therefore, a better understanding of mass-wasting and flank eruption processes may provide us the key to decipher morphological evolution of seamounts.

The multibeam bathymetric and chirp (3-7 kHz) subbottom data used in this study were obtained during a reconnaissance survey of seamounts in the west Pacific for ferromanganese crusts by KORDI onboard R/V Onnuri during 2000 and 2003. In this study, we construct detailed echo-type maps based on chirp subbottom profile. These map show extensive mass-wasting processes and features related with flank evolution of seamounts in the Ogasawara Fracture Zone (OFZ) of the west Pacific.

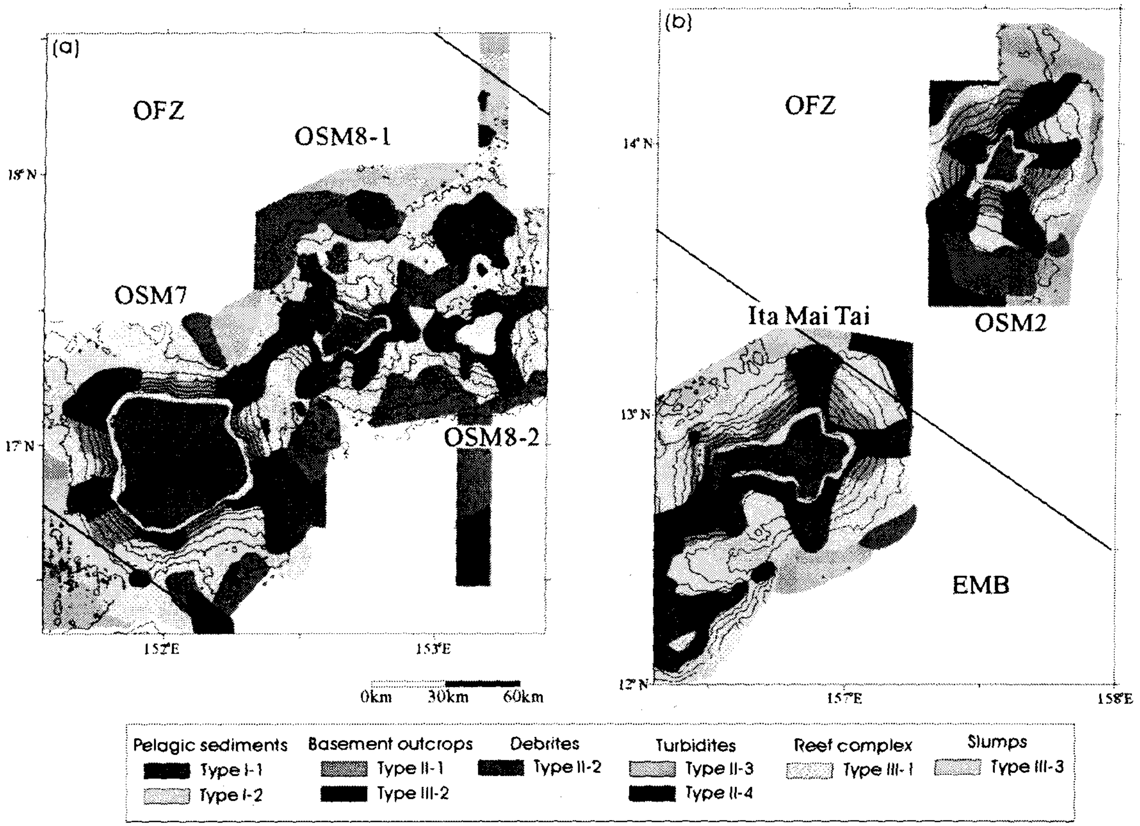

Fig. 1. Distribution of echo types on (a) OSM7, OSM8-1, and OSM8-2, and (b) Ita Mai Tai and OSM2. OFZ and EMB denote Ogasawara Fracture Zone and East Mariana Basin, respectively. Bathymetry contours are shown at 500-m interval

2. Geological settings

Our study area is located in the western Pacificnear the OFZ which divides the East Mariana Basin (EMB) from the Pigafetta Basin (PB). According to Nakanishi et al. (1989), OFZ acted as the boundary between the Izanagi and Pacific plates during the Middle to Late Jurassic. It extends northwest to the Mariana Trench, while the southeast end is not well-defined. On the basis of multi-channel seismic profiles (Abrams et al., 1992), the OFZ represents a 150 km-wide rift zone with sharp bounding walls which are perpendicular to the surrounding magnetic lineations. From the magnetic anomaly lineation M35 between the PB and EMB, there has been about 600-km-long movement between them (Nakanishi et al., 1989). The OFZ is somewhat unique among other western Pacific fracture zones in that it includes many seamounts (e.g., Magellan Seamounts and seamounts on the Dutton Ridge).

Three seamounts in the west study area have not been mapped before using modern multi-beam echosounder and have been not named. The newly surveyed seamounts in 2003 are denoted sequentially as open-sea seamount (OSM) and numbered as 7, 8-1, and 8-2. The depth to the base of slope ranges from 5,300 to 5,900 m below sea level (mbsl). The summit depth ranges from 1,190 to 1,350 mbsl. The diameter at the base of OSM7 and Ita Mai Tai is over 80 km, and their flat-summit surface area 2,395 and 650 km2, respectively. The rest seamounts have diameters less than 300 km2. Average slope gradient of seamounts is from 8.3o to 10.1o and that measured without the flat part of the summit from 8.7o to 11.9o.

3. Classification and distribution of echo types

A total of nine different echo types were identified based on the clarity of echo, subbottom structure and morphology of the seafloor. The echo types can be grouped into three major classes: (1) distinct echoes (types I-1 (a distinct, weakly convex-upward bottom echo and continuous, parallel internal reflectors which conform to the surface reflector) and I-2 (an internally transparent characteristics with a distinct bottom reflector)), (2) indistinct echoes (types II-1 (indistinct bottom echo with no subbottom echoes or weakly prolonged subbottom echoes along steeply inclined topography), II-2 (lens-shaped or laterally wedged form with internally transparent characteristics), II-3 (an indistinct bottom echo and parallel internal reflectors which are nearly flat), and II-4 (prolonged bottom echoes with diffuse subbottom echoes)), and (3) hyperbolic echoes (types III-1 (numerous, strong, and small hyperbolic bottom echoes with very prolonged or irregularly hyperbolic subbottom echoes), III-2 (large irregular overlapping hyperbolae with varying vertex elevations), and III-3 (irregular, hyperbolic, blocky or hummocky layers with main occurrence at places where there is a substantial change in slope and bounded by a scar upslope)).

The distribution of different echo type are shown in Fig. 1. In mapping the echo type distribution, we also took into account the contour lines and morphology. The different echo types appear in different regions of the seamounts. For example, pelagic sediment of types I-1, I-2 and type III-1 reef build-up complex are found on the flat summits; basement outcrop of types II-1 and III-2 on the flank rift zones, slopes and hills; type III-3 slump on the lower slope and the embayment between the flank rift zones; type II-2 debrite on the base of slope; and turbidite of types II-3 and II-4 on the basin floor.

4. Discussion and summary

Chirp subbottom profiles across the margin of summit on OSM2 and OSM8-2 show large fault blocksdowndropped relative to the summit plateau. The fault scarps were not swept down and shows only vertical displacement. The pelagic sediment is discontinuous by the fault scarps. The scarps adjacent to the fault blocks range from 50 to 80 m high. The slope extended from the fault blocks shows the shape of embayment surrounded by the flank rift zones. Types III-3 slump and II-2 debrite continue from the middle slope to basin floor. Particularly, II-2 debrite is 50 km long and 30 m thick at the south of OSM8-2. The debris avalanches of the Hawaiian ridge are long (up to 230 km) and thin (0.05-2 km) comparing to the slump (Mooer et al., 1989). Those of the Canary Islands have runout distances of up to 130 km from the source (Masson et al., 2002). They are different from those of the study area in that Hawaiian ridge and Canary Islands are young and more volcanically active near the hotspot swell. The mass-wasting continues to affect submarine volcanoes after they have moved away from the hotspot swell.

Large mass-wasting may be triggered by earthquakes, dike intrusion, caldera collapse, weakening of volcanic rocks by hydrothermal fluids, reactivation of basement faults, etc. (Lipman et al., 1988; Lopez and Williams, 1993; Elsworth and Voight, 1995; Marti et al., 1997; Vidal and Merle, 2000). The seamounts in the study area formed at the hotspot swell in Cretaceous (Sager, 1992; Lee et al., 2003) and moved away from the hotspot swell. The mass-wasting shown in chirp subbottom profile recently occurred in the geologic time scale. Therefore the intraplate volcanism is not the cause of mass-wasting in the study area. There are two possibilities that the mass-wasting of the west study is well-developed. The first is that the strong tensional stress in theOFZ makes some fissures or basement faults in the fracture zone and intrusions occur. The magnetic anomaly lineation M35 between the PB and EMB suggests that there has been about 600-km-long movement between them (Cande and Kent, 1992; Nakanishi et al., 1992). The OFZ, seamounts, and associated flexural moat separate the PB and EMB (Abrams et al., 1992). These strong stresses may make basement faults and/or fissures. Another cause may be the complex of the faults on the summit, steep upper slope, and closeness to the Mariana Trench. The slope failure in the study area started on the margin of summit and upper slope. The steep upper slope and faults on the summit in the west study area are easy to cause the mass-wasting by shear stresses above critical shear strength of sediments. The Mariana Trench, which is 500600 km distant from the west study area, is the origin of strong and deep earthquakes. The earthquakes, which occurred when the Pacific plate subducts under the Philippine Sea plate, may trigger the shaking or activation of other faults in the OFZ.

References

Abrams, L.J., Larson, R.L., Shiply, T.H., Lancelot, Y., 1992, The seismic stratigraphy and sedimentary history of the East Mariana and Pigafetta basins of the western Pacific: in Larson, R.L., Lancelot, Y., Fisher, A., Winterer, E.L., Eds., Pro. ODP Sci. Results, 129. College Station, TX (Ocean Drilling Program), 551-569.

Cande, S.C. and Kent, D.V., 1992,A new geomagnetic polarity time scale for the Late Cretaceous and Cenozoic, J. Geophys. Res., 97, 13917-13951.

Elsworth, D., Voight, B., 1995,Dike intrusion as a trigger for large earthquakes and the failure of volcano flanks,J. Geophys. Res., 100, 6005-6024.

Gee, M.J.R., Watts, A.B., Masson, D.G., Mitchell, N.C., 2001, Landslides and the evolution of El Hierro in the Canary Islands, Mar. Geol., 177, 271-293.

Lee, T.G., Lee, S.M., Moon, J.W., Lee, K., 2003, Paleomagnetic investigation of seamounts in the vicinity of Ogasawara Fracture Zone northwest of the Marshall Islands, western Pacific, EPS, 55, 355-360.

Lipman, P.W., Normark, W.R., Moore, J.G., Wilson, J.B., Gutmacher, C.E., 1988, The giant submarine Alika debris slide, Mauna Loa, Hawai'I, J. Geophy. Res., 93, 4279-4299.

Lopez, D.L., Williams, S.N., 1993, Catastrophic volcano collapse: Relation to hydrothermal alteration, Science, 260, 1794-1796.

Masson, D.G., Watts, A.B., Gee, M.J.R., Urgeles, R., Mitchell, N.C., Le Bas, T.P. and Canals, M., 2002, Slope failures on the flanks of the western Canary Islands, Earth-Sci. Rev., 57, 1-35.

Marti, J., Hurlimann, M. and Ablay, G.J., 1997, Vertical and lateral collapses on Tenerife (Canary Islands) and other volcanic ocean islands, Geology, 25, 879-882.

Mitchell, N.C., 2001,Transition from circular to stellate forms of submarine volcanoes, J.Geophys. Res., 106, 1987-2003.

Mitchell, N.C., Masson, D.G., Watts, A.B., Gee, M.J.R., Urgeles, R., 2002,The morphology of the submarine flanks of volcanic ocean islands: A comparative study of the Canary and Hawaiian hotspot islands, J. Volcanol. Geotherm. Res., 115, 83-107.

Moore, J.G., Clague, D.A., Holcomb, R.T., Lipman, P.W., Normark, W.R. and Torresan, M.E., 1989, Prodigious submarine landslides on the Hawaiian ridge, J. Geophy. Res., 94, 17465-17484.

Nakanishi, M., K. Tamaki, Kobayashi, K., 1989, Mesozoic magnetic anomaly lineations and seafloor spreading history of the northwestern Pacific, J. Geophys. Res., 94, 15437-15462.

Nakanishi, M., Tamaki, K. and Kobayahsi, K., 1992, Magnetic anomaly lineations from late Jurassic to Early Cretaceous in the west-central Pacific Ocean, Geophy. J. Int., 144, 535-545.

Sager, W.W., 1992, Seamount age estimates from Paleomagnetism and their implications for the history of volcanism on the Pacific plate: In Keating, B.H. and Bolton, B.R., Eds., Geology and OffshoreMineral Resources of the Central Pacific Basin, Circum-Pacific Council for Energy and Mineral Resources Earth Science Series, vol. 14. Springer-Verlag, New York, 21-37.

Vidal, N., Merle, O., 2000,Reactivation of basement faults beneath volcanoes: A new model of flank collapse,J. Volcanol. Geotherm. Res., 99, 9-26.

Vogt, P.R., Smoot, N.C., 1984,The Geisha guyots: multibeam bathymetry and morphometric interpretation, J. Geophys. Res., 89, 11085-11107.