Detailed Bathymetry and Submarine Terraces in the Coastal Area of the Dokdo Volcano in the Ulleung Basin, the East Sea (Sea of Japan)

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ABSTRACT

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In the northeastern part of the Ulleung Back-Arc Basin, the East Sea, the Dokdo volcano anomalously emerges, rising abruptly from the sea floor (~2,100 m below sea level). It is lying as a cluster of emerged small islets surmounting a larger submerged volcanic edifice. In order to investigate the detailed bathymetry and morphologic characteristics around the volcano's underwater guyot type summit, we carried out multi-beam surveys from 2006 to 2011 and analyzed the data. From the near islets to ~30 m depth, the flank slopes are very steep and irregular, overlain by sunken rocks, indicating partial erosion and talus formation due to waves, currents and weathering. The area from ~30 m to ~80 m depth shows gentle rises and falls, with a modest slope. Below ~80 m, the bathymetry gradually transitions to a relatively flat undulation with a smooth slope, extending to offshore areas. The bathymetry and the seafloor image from backscattering data show that there are small islets of the Dokdo volcano and a rocky sea bottom elongated from the islets, probably originating from residual parts of the eroded and collapsed main crater of the volcano. The seafloor images identify typical rocky bottoms, like rocky protrusions, and less sediment around the survey area, except for some areas with shallow sand sedimentary deposits. The stepped slopes of the study area are interpreted to be wave-cut submarine terraces rather than terraces from other origins, based on their relatively flat morphology and lack of sediments. The submarine terraces suggest a repetition of sea level changes (transgressions and regressions) in the Quaternary.

ADDITIONAL INDEX WORDS: *Dokdo volcano, detailed bathymetry, multi-beam survey, seafloor image, crater, submarine terraces, sea level changes.*

INTRODUCTION

The East Sea is located in a complex junction between the Eurasian, Pacific, and Philippine plates (Uyeda and Miyashiro 1974). While the Japan islands drifted apart from the Eurasian margin, the East Sea might have been formed in response to the subduction of the Pacific and Philippine plates (Hilde and Wageman, 1973; Uyeda and Miyashiro, 1974). Tectonically, the East Sea (Sea of Japan) is a back-arc basin, comprised of the Ulleung, Japan, and Yamato deep basins, and it is geographically surrounded by Korea, Russia, and Japan (Jolivet *et al.*, 1991). The Ulleung Basin is situated in the southwestern part of the East Sea and separated on the north from the Japan Basin by the Korean Plateau, and distinguished from the Yamato Basin northeastward by the Oki Bank. The basin has an uneven seabed morphology above 2,200 m b.s.l. (below sea level), but its floor is quite smooth and gently deepens northeastward from about 1,000 m b.s.l. at the basin margin, to about 2,500 m b.s.l. near the Korea Gap (Figure 1).

In the northeastern part of the Ulleung Basin, there are five pronounced volcanoes; Dokdo (Dok Island), Ulleungdo (Ulleung Island) and other three submerged seamounts (Figure 1) (KORDI, 2000). These linear volcanic chain is composed of Ulleungdo, Dokdo, the Anyongbok Seamount, the Simheungtaek and the Isabu Tablemounts (Figure 1). The NE–SW trending Korea Gap lies between the Anyongbok Seamount and Dokdo up to 2500 m b.s.l. Dokdo and the two tablemounts have submerged guyot summits, occurring at about 200 m b.s.l., which are gently sloping and flat but steep on their flanks (Figure 1).

Dokdo, our study area, is a volcanic island, which is located in the northeastern part of the Ulleung Basin and approximately 216.8 km away from the eastern part of the Korean peninsula. It is situated about 87.4km from Ulleungdo, the biggest volcanic island in the Ulleung Basin of the East Sea. Dokdo consists of two main islets and the associated submerged volcanic edifice. The height of the Dokdo volcano is about 2,100 m from the seafloor and the diameter of the submerged summit is more than 10 km. The subaerial part of the Dokdo volcano is composed of volcanic rocks such as alkali basalts, trachytes, and trachyandesites (Sohn and Park, 1994). Rock samples from its subaerial portion have been

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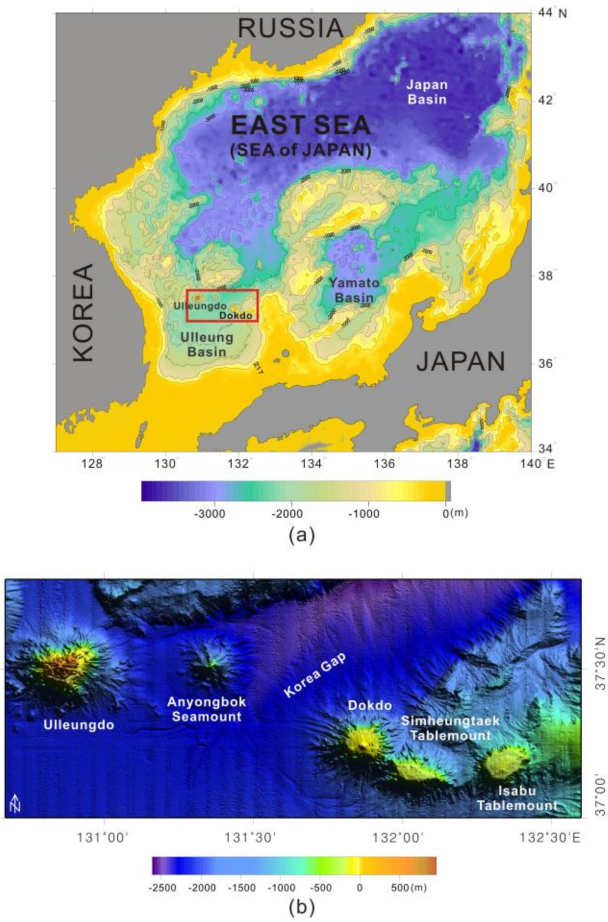

Figure 1. (a) Bathymetry of the East Sea (Sea of Japan). The East Sea is surrounded by Korea, Japan, and Russia. Depths are shown in meters with a color scale bar. The rectangular box outlined by red solid lines represents the index area of the lower figure. (b) 3D topographic map around Ulleungdo, Dokdo, and adjacent seamounts. Depths are shown in meters with a color scale bar.

dated at 4.6 ± 0.4 Ma in the early Pliocene to 2.7 ± 0.1 Ma in the late Pliocene to Quaternary (Sohn and Park, 1994). The submerged part of the volcano is less studied because of its difficult access.

Most studies about the Dokdo volcano have been conducted with regards to topography, geology, and geochemistry of the onland islets of the volcano (Hwang and Jeon, 2003; Hwang and Park, 2007; Kim *et al.*, 1987; Kim, 2000; Shim *et al.*, 2010; Sohn and Park, 1994; Song *et al.*, 2006). From the late 1990s, the development of research vessels and survey equipments have initiated some researches to be carried out to investigate sediments and regional structures around the submerged part of the volcano (Hyun *et al.*, 2010; Kang *et al.*, 2007; Kim *et al.*, 2009a, b; Kwon, 2005; Woo *et al.*, 2009).

The importance of the submerged summit area of the Dokdo volcano, including the coastal zone and terraces, has been increasing due to recent coastal development and conservation. Since Dokdo in the East Sea is isolated from main lands, Korea and Japan, its coastal area could serve as a good global environmental change indicator such as sea level changes (Abbey *et al.*, 2011; Coulbourn *et al.*, 1974; Emery, 1961; Wagle *et al.*, 1994). However, much of the coastal area and its surrounding area has been barely studied, compared with the onshore islets and the regional scale offshore area.

In order to address lack of geomorphologic and geologic knowledge about the submarine part of the Dokdo volcano, we have conducted geophysical surveys around the volcano's underwater guyot type summit from 2006. Based on the combined multi-beam survey data from 2006 to 2011, we present the detailed bathymetry, morphologic characteristics in the coastal area of the Dokdo volcano. Also the morphologic features of the submarine terraces are analyzed to infer its eustatic implication around the island.

DATA ACQUISITION AND PROCESSING

We conducted a bathymetry survey using the multi-beam echo-sounder system, loaded in multiple research vessels, such as R/V Eardo (KIOST, Korea Institute of Ocean Science & Technology) and two small vessels (Mulmaru-ho and Dokdo-ho). Each vessel was used depending upon its own proper functionality of depth coverage; in case of a water depth of less than 30 m, the EM 3001 multi-beam echosounder (Kongsberg), installed in Mulmaru-ho and Dokdo-ho vessels, was used. The EM 710 multi-beam echosounder (Kongsberg) was mounted on R/V Eardo for deeper water depth range.

Multi-beam echosounder system transmits a broad acoustic pulse and receives backscattered data to estimate water depth and seabed images. To acquire the high-resolution raw data of bathymetry, multi-beam sonar system is connected with DGPS (Differential Global Positioning System) and motion sensor. DGPS system measures the exact position of research ships and time. The motion sensor system detects the movement of the research ships such as roll, pitch, heave and heading, subsequently applied to adjust raw data. We also used SVP (Sound Velocity Profiler) and XBT (Expendable Bathythermograph) in order to obtain accurate sound velocity of sea water during the survey, which might fluctuate depending upon water temperature, pressure and salinity.

For processing bathymetry data, we used the Hips & Sips software (CARIS) that can fulfill post-processing. On data processing, we considered a variety of causes such as the motion of the ship (roll, pitch, yaw), the change of sound speed and tide variation. For tidal height correction in processing the multi-beam bathymetry data, the estimation was adjusted for tidal variation using tidal elevation data from KHOA (Korea Hydrographic and Oceanographic Administration). And on the processing works, noisy data was corrected and/or removed from the raw data. After completing these data processing workflow, we obtained the final detailed bathymetry of the survey area.

Besides the detailed bathymetry, the seafloor images were calculated based on the backscatter data from the multi-beam echosounder systems. The seafloor image is generated based on beam strength in the multi-beam system. For the post processing of the seafloor images, we used the Fledermaus software (IVS) that can process and adjust dB level of the images. Using the detailed bathymetry and the seafloor images, we could recognize the topographic features and the rough seabed environment around the study area, such as rock, reef, sand, mud and etc.

RESULTS AND DISCUSSIONS

Detailed Bathymetry

The precise topographical map of the shallow coastal area around the Dokdo volcano was made using the detailed bathymetry data around the two main islets, from multi-beam echosounder data of the volcano summit, and the airborne LIDAR (LIght Detection And Ranging) altitude data of the islets by National Geographic Institute of Korea (Figure 2). We could not obtain the bathymetry data in the areas very near to islets since it was difficult to navigate a small vessel due to very shallow water depths and strong currents. Except those areas, very detailed topographic features are well delineated in the bathymetry data. The two main islets have been called as the East islet (east side) and the West islet (west side), respectively (Figure 2).

The bathymetry data show that the underwater reefs are irregularly scattered, with shallow water depth (within about 10 m), in the seabed close to the East islet and the West islet (Figure 2). The area near the pier of the East islet is very shallow (< 5 m). The southeastern part near the West islet has a narrow deep pathway (>10 m) compared to other seabed areas. The waterway between the two islets is very shallow (from about 5 m to about 1.5 m). The water depth of the way deepens southwestward and northeastward from the central area, connecting to offshore areas.

Figure 3 represents the detailed bathymetry in the coastal survey area of the volcano summit, calculated from the obtained multi-beam data and the airborne LIDAR altitude data. In the figure, from the near islets to ~30 m depth, the flank slopes are very steep and irregular, overlain by many submerged rocks, indicating partial erosion and talus formation due to waves, strong currents and weathering. The seabed area from ~30 m to ~80 m depth shows gentle rises and falls, with a modest slope. And below ~80 m, the bathymetry gradually transitions to a relatively even undulation with a smooth slope, extending to offshore areas. The bathymetry shows northeastward and northwestward rocky sea bottoms elongated from the main islets. Those elongated rocky sea bottoms might be residual parts of the eroded and collapsed main crater of the volcano or the topographic features related to the eruptions along the fractures around the main crater. Therefore, we suggest that the main islets of the Dokdo volcano and rocky sea bottoms elongated from the islets correlate with residual parts of the main crater.

Some other small craters are observed at depths of about 70, 100, and 110 m in the western and northern parts of the submerged summit of the volcano, implying later volcanic eruptions (Figure 3). Based on the proximity of these small craters to the possible main crater, we speculate that they might have originated from the volcanic activities related to the main crater.

Seafloor Images

The seafloor images of the survey area were obtained by the backscatter data of the multi-beam echosounder systems (EM 710). After the post processing, the images were merged into one seafloor image, overlapped on the detailed 3D bathymetry, for the integrated analysis of the sea bed (Figure 4). Figure 4 shows the distribution of the rocky sea bottoms and the sediments in the submerged summit of the volcano. Based on the seafloor image, we identified typical rocky bottoms around the sea bed of the survey area, underlain by rocky protrusions and less sediment except for some areas with shallow sand sedimentary deposits. The highlighted area in the south eastern part of the image (Figure 4) suggests the lower flat terrain area with sand sediment than other areas.

The result of sub-bottom profiling survey and the seafloor image show that some areas might be covered by sand sediments of about 2-3 m thickness, especially around the western part of the West islet and the southern and eastern parts of the East islet (Figures 4 and 5). However, the seafloor image shows that the main feature of the sea bed is rocky rather than covered by

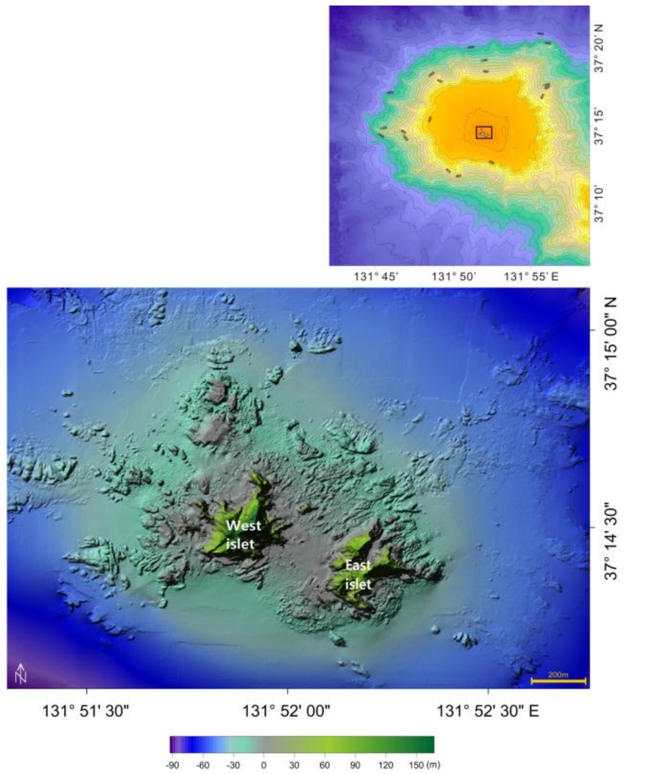

Figure 2. Detailed 3D bathymetry around the coastal area of the Dokdo volcano (vertical view). Depths are shown in meters with a color scale bar. The small rectangle outlined by black solid lines in the upper right figure represents the location of the coastal area.

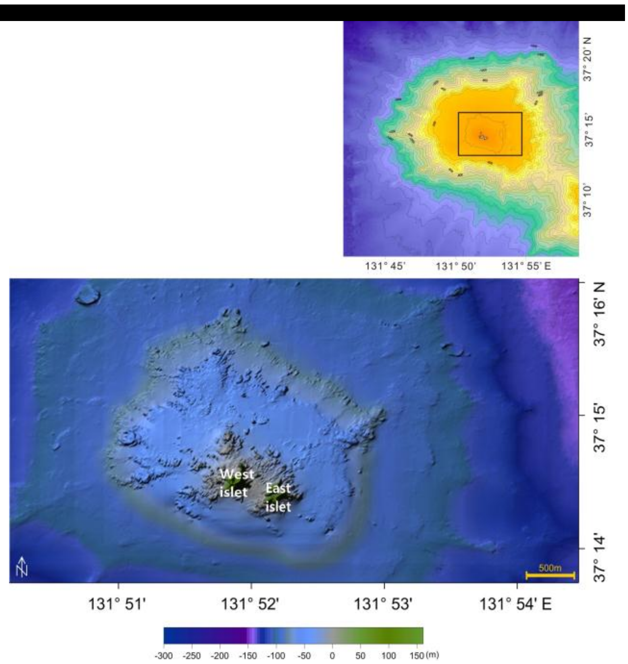

Figure 3. Detailed 3D bathymetry around the summit area of the Dokdo volcano (vertical view). Depths are shown in meters with a color scale bar. The small rectangle outlined by black solid lines in the upper right figure represents the location of the survey area.

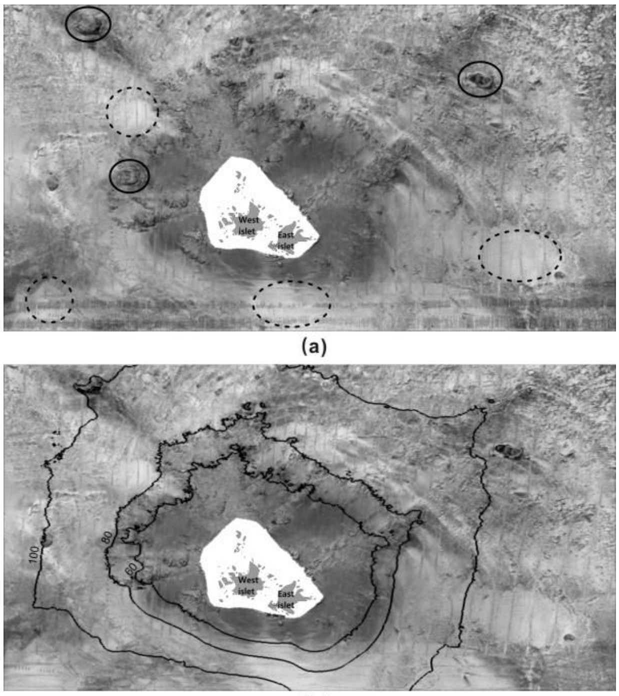

Figure 4. (a) Seafloor backscatter image draped on 3D bathymetry. Black line circles represent the topographic features of small craters. The areas within the black dashed line circles are interpreted to be sand sediments. (b) Seafloor backscatter image draped on 3D bathymetry with water depth contour lines (60, 80, and 100 m).

sedimentary deposits. Since islands in oceans constitute a much poorer source of sediment than mainland areas and the islets are much smaller than the submerged summit of the volcano, less sediments from the small islets might have influxed into the coastal area. We also observed the small craters and the elongated rocky sea bottoms from the islets, related to residual parts from the eroded and collapsed main crater, in the overlapped image as well as the bathymetry (Figure 4).

Submarine Terraces

Coastal morphology of marine or submarine terraces has been actively studied since because they might provide a key geological

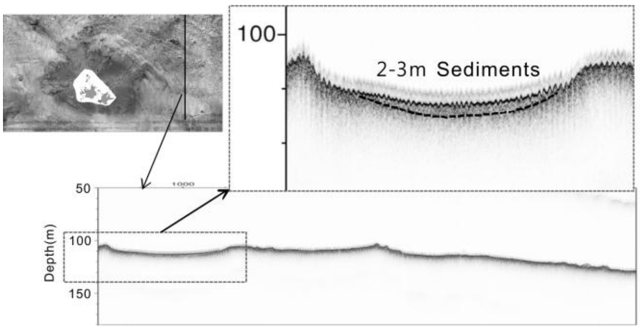

Figure 5. Section of sub-bottom profiling survey. The location of the profile is shown in the upper left corner of this figure.

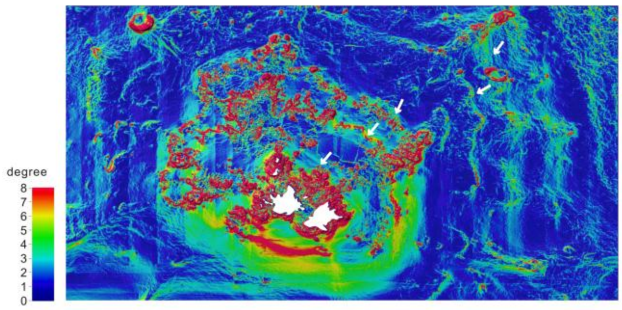

Figure 6. Slope analysis of the study area. White arrows represent the inner edges of submarine terraces.

information regarding Quaternary stratigraphy and eustatic changes (Passaro et al., 2011). Morphologically, marine or submarine terraces are relatively flat, gently inclined surfaces with prominent scarps at the shoreward end (Pirazzoli, 2005; Wagle et al., 1994). These characteristic features have been reported around continental margins and islands throughout the world (Abbey *et al.*, 2011; Chatterjee, 1961; Coulbourn *et al.*, 1974; Emery, 1961; Passaro *et al.*, 2011; Stearns, 1961; Wagle *et al.*, 1994). Carter and Johnson (1986) surmised that terraces were formed during sea level stillstands and cut by erosive wave action. Harris and Davies (1989) proposed two additional mechanisms for terrace formation, including lagoonal backfilling behind a barrier reef to create a terrace, and faulting. Wagle *et al.* (1994) suggested that the submarine terrace could be broadly categorized based on their geomorphic features, lithological characteristics and locations: (1) wave-cut terraces, (2) coral/algal reef-induced terraces, and (3) palaeo-beach/barrier terraces. Around the Dokdo volcano, we found some stepped slopes, morphologically similar to the ones in the Hawaii Islands and the continental shelf of India, probably affected by the eustatic changes of sea level (Coulbourn *et al.*, 1974; Wagle *et al.*, 1994). Interestingly, the seabed is found to have the stepped slopes in the bathymetry and the seafloor image (Figures 3, 4 and 6). The slopes might be deformed by wave activity and erosion. Seabed images of figure 7 show rocky sea bottom covered with few sediments and no hard corals in the coastal area of the Dokdo volcano. These topographic features (stepped slopes) are interpreted to be wave-cut submarine terraces rather than terraces from other origins, based on their relatively flat morphology, lack of sediment deposit, and no hard corals (Figures 3, 4, 5 and 7). Figure 6 shows the slope analysis map of the bathymetry in the study area. The white arrows indicate the inner edges (nicks) of the submarine terraces. The bathymetry and the seafloor backscatter image are easier to distinguish the inner edges of the terraces for a depth range under about 100 m than over about 100 m. But the slope map represents the inner edges for over 100 m as well as under 100 m depth. The terraces are noticeable between water depths of 30 and 125 m and occur at about 30-50 m, about 60-80 m, about 85-95 m, about 100-105 m, and about 110-125 m in the northeastern part of the study area rather than the southwestern part. Figure 8 represents the comparison of submarine terraces in various parts of the world (Emery, 1961), including the Dokdo volcano in the East Sea. Several prominent submarine terraces of the volcano's submerged summit might propose the repetition of sea level changes (transgressions and regressions) in the Quaternary.

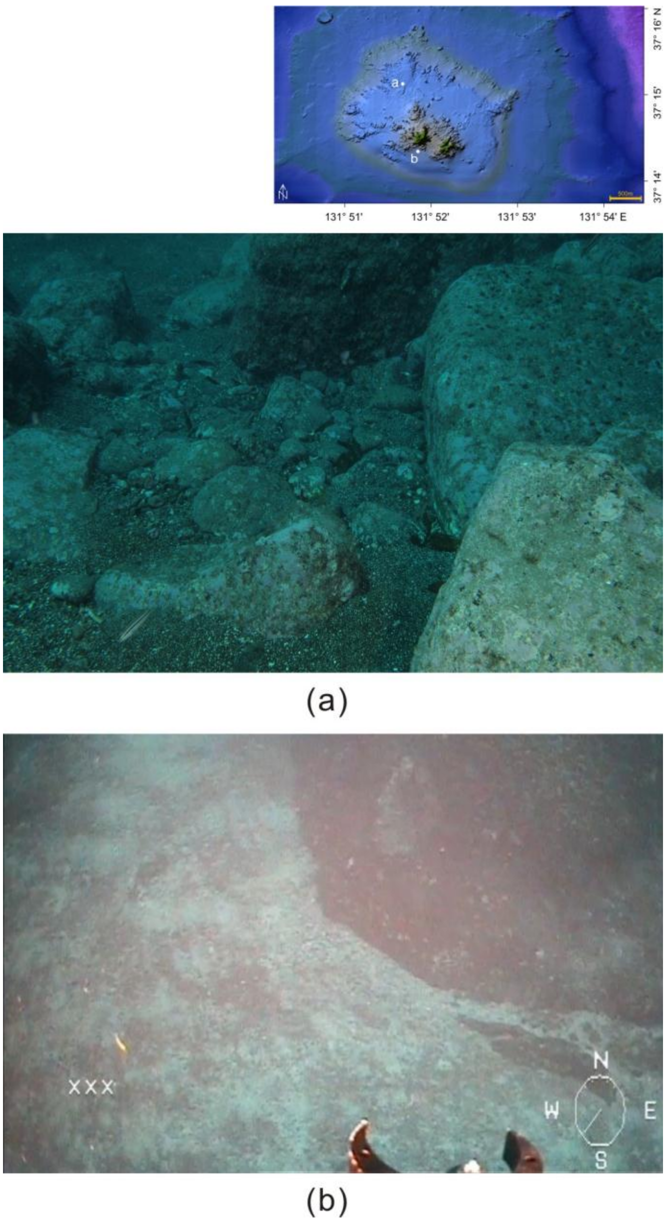

Figure 7. (a) Seabed image by a diver underwater camera at ~ 20 m b.s.l., (b) Seabed image by ROV video camera at ~ 50 m b.s.l. in the survey area. The locations of the images are shown in the upper right figure.

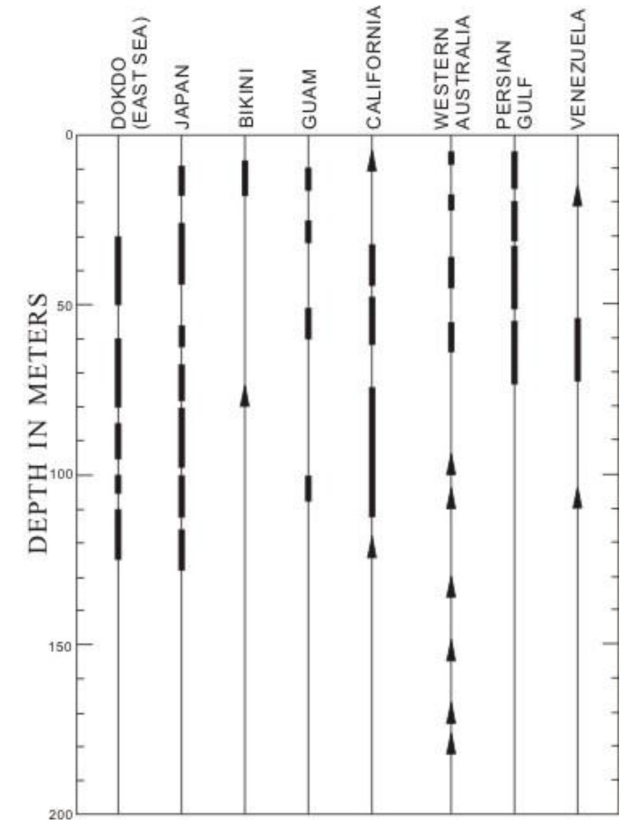

Figure 8. Depth of submarine terraces in various parts of the world, including the Dokdo volcano in the East Sea. This figure is modified from Emery (1961). Tapering triangles show the depth of the outer edges of terraces for which the depth of the inner edge is unknown.

CONCLUSION

The bathymetry around the main East and West islets of the Dokdo volcano is very shallow (less than ~10 m b.s.l.), with submerged rocks interspersed around the irregularly undulated seafloor. From the near islets to ~30 m depth, the flank slopes are very steep and irregular, overlain by sunken rocks, indicating partial erosion and talus formation due to waves, currents, and weathering. The area from ~30 m to ~80 m depth shows gentle rises and falls, with a modest slope. Below ~80 m, the bathymetry gradually transitions to a relatively flat undulation with a smooth slope, extending to offshore areas. The bathymetry and the seafloor image from backscattering data show that there are small islets of the Dokdo volcano and a rocky sea bottom elongated from the islets, probably originating from residual parts of the eroded and collapsed main crater of the volcano. Some other small craters are also observed at depths of about 70, 100, and 110 m in the western and northern parts of the volcano, implying later volcanic eruptions. The sub-bottom profiles and the seafloor images identify typical rocky bottoms, like rocky protrusions, and less sediment around the survey area, except for some areas with shallow sand sedimentary deposits. Interestingly, the stepped slopes features are found, interpreted to be wave-cut submarine terraces rather than terraces from other origins, based on their relatively flat morphology and lack of sediment deposit. Several prominent submarine terraces are observed in the survey area around the volcano's submerged summit, suggesting the eustatic changes of sea level in the Quaternary.

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LITERATURE CITED

Abbey, E., Webster, J. and Beaman, R., 2011. Geomorphology of submerged reefs on the shelf edge of the Great Barrier Reef: The influence of oscillating Pleistocene sea-levels. *Marine Geology*. 288, 61–78.

Carter, R.M. and Johnson, D.P., 1986. Sea-level controls on the post-glacial development of the Great Barrier Reef, Queensland. *Marine Geology*. 71, 137–164.

Chatterjee, S.P., 1961. Fluctuations of Sea level around the coasts of India during the Quaternary Period. *In:* Russell, R.J. and Rouge, B. (eds.), *Symposium of Pacific Island Terraces: Eustatic?* (Berlin, Germany), pp. 48-56.

Coulbourn, W.T., Campbell, J.F. and Moberly, R., 1974. Hawaiian submarine terraces, canyons, and Quaternary history evaluated by seismic- reflection profiling. *Marine Geology*. 17, 215-234.

Emery, K.O., 1961. Submerged Marine Terraces and their Sediments. *In:* Russell, R.J. and Rouge, B. (eds.), *Symposium of Pacific Island Terraces: Eustatic?* (Berlin, Germany), pp. 17-29.

Harris, P.T. and Davies, P.J., 1989. Submerged reefs and terraces on the shelf edge of the Great Barrier Reef, Australia—morphology, occurrence and implications for reef evolution. *Coral Reefs*. 8, 87–98.

Hilde, T.W.C. and Wageman, J.M., 1973. Structure and origin of the Japan Sea. *In:* Coleman, P.J. (ed.), *The western Pacific: island arcs, marginal seas, geochemistry*. Perth, Australia: University of Western Australia Press, pp. 415–434.

Hwang, S.I. and Park, K.G., 2007. Tafoni Geomorphic Developmnet in the Western Coast of Dongdo of Dokdo, Korea (in Korean with English abstract). *Journal of the Korean Association of Regional Geography*, 13, 422-437.

Hwang, S.K. and Jeon, Y.G., 2003. Eruption Cycles and Volcanic Form of the Dokdo Volcano (in Korean with English abstract). *The Korean Society of Economic and Environmental Geology*, 36, 527-536.

Hyun, S.M., Kim, C.H., Jou, H.T., Kim, J.K. and Park, C.H., 2010. Characteristics of surface sediments distribution and sub marine topography around Dokdo Island, Korea (in Korean with English abstract). *Journal of the Geological Society of Korea*, 46, 647-660.

Jolivet, L., Huchon, P., Lepichon, X., Chamot-Rooke, N. and Thomas, J.C., 1991. Arc deformation and marginal basin opening: Japan Sea as a case study. *Journal of Geophysical Research*, 96, 4367–4384.

Kang, M.H., Han, H.C., Yun, H.S., Kong, G.S., Kim, K.O. and Lee, Y.S., 2007. 3D gravity modelling for Anyongbok Seamount in the East Sea. *Marine Geophysical Research*, 28, 257–269.

Kim, C.H., Park, C.H., Jeong, E.Y., Hwang, J.S. and Ko, Y.T., 2009. Evolution of the Dok Do seamounts, Ulleung Basin, East Sea: constraints based on the reconstruction of virtual geomagnetic poles using paleomagnetic data. *Geo-Marine Letters*, 29, 161–169.

Kim, C.H., Park, C.H., Jeong, E.Y., Ko, Y.T., Hwang, J.S. and Shim, T.M., 2009. Flexural isostasy and loading sequence of the Dokdo seamounts on the Ulleung Basin in the East Sea (Sea of Japan). *Journal of Asian Earth Sciences*, 35, 459–468.

Kim, K.H., 2000. K-Ar ages and Nd-Sr isotopes of Dokdo alkali volcanic rocks in the East Sea, South Korea (in Korean with English abstract). *Journal of the Geological Society of Korea*, 36, 313–324.

Kim, Y.K., Lee, D.S. and Lee, K.H., 1987. Fractional Crystallization of the Volcanic Rocks From Dog Island , Korea (in Korean with English abstract). *Journal of the Geological Society of Korea*, 23, 67-82.

KORDI (Korea Ocean Research and Development Institute) Staff, 2000. The study of on land and marine environments and ecosystems of Dokdo (in Korean with English abstract). Korea Ocean Research and Development Institute Publication, 600p.

Kwon, I.K., 2005. *I. Sequence stratigraphy of the Taebaek Group (Cambrian-Ordovician), mideast Korea. II. Seismic stratigraphy of the western South Korea Plateau, East Sea*. Seoul National University , Ph.D. thesis, 205p.

Passaro, S., Ferranti, L. and Alteriis, G., 2011. The use of high-resolution elevation histograms for mapping submerged terraces: Tests from the Eastern Tyrrhenian Sea and the Eastern Atlantic Ocean. *Quaternary International*. 232, 238-249.

Pirazzoli, P.A., 2005. Marine Terraces. *In:* Schwartz, M. (ed.), *Encyclopedia of Coastal Science*. Dordrecht, Netherland: Springer, pp. 632-633.

Shim, S.H., Im, J.H., Jang, Y.D., Choo, C.O., Park, B.J. and Kim, J.H., 2010. Petrological Characteristics and Origin of Volcaniclasts within the Massive Tuff Breccia Formation from Dokdo Island, Korea (in Korean with English abstract). *Journal of the Petrological Society of Korea*, 19, 141-156.

Sohn, Y.K. and Park, K.H., 1994. Geology and evolution of Tok Island, Korea. *Journal of the Geological Society of Korea*, 30, 242-261.

Song, Y.S., Park, M.E. and Park, K.H., 2006. Ages and evolutions of the volcanic rocks from Ulleung-do and Dok-do (in Korean with English abstract). *Journal of the Petrological Society of Korea*, 15, 72–80.

Stearns, H.T., 1961. Eustatic shorelines on Pacific Islands. *In:* Russell, R.J. and Rouge, B. (eds.), *Symposium of Pacific Island Terraces: Eustatic?* (Berlin, Germany), pp. 3-16.

Uyeda, S. and Miyashiro, A., 1974. Plate tectonics and the Japanese island: a synthesis. *Geological Society of America Bulletin*, 85, 1159-1170.

Wagle, B.G., Vora, K.H., Karisiddaiah, S.M., Veerayya, M. and Almeida, F., 1994. Holocene submarine terraces on the western continental shelf of India; Implication for sea-level changes. *Marine Geology*, 117, 207-225.

Woo, K.S., Ji, H.S., Kim, L., Jeon, J.A., Park, J.S., Park, H.S., Kim, D.S. and Park, C.H., 2009. Distribution and Origin of Carbonate Sediments near Dok Island: Preliminary Study (in Korean with English abstract). *Journal of the Korean Society of Oceanography*. 14, 171-180.