Geomorphic Analysis of Seamounts Adjacent to the Mendocino Fracture Zone

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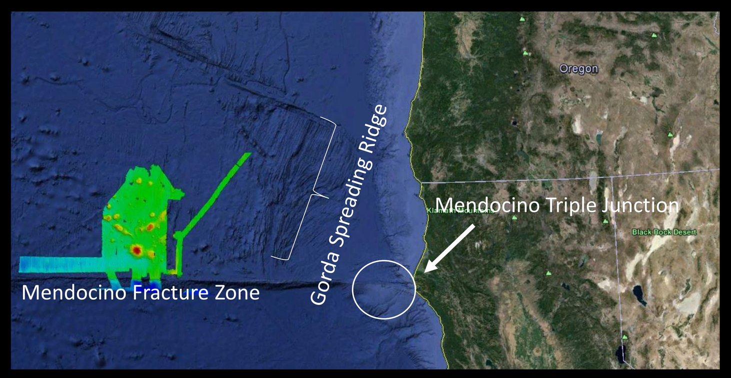
ABSTRACT

Multibeam sonar data acquired during the September 2014 R/V Atlantis cruise-AT26-21 were used to characterize the geomorphology of seamounts adjacent to and north of the Mendocino Fracture Zone, approximately 400 km off the northern California margin, 250 km west of the Gorda Spreading Ridge. The eleven seamounts studied are located on the plateau of the Gorda Escarpment. Using CARIS HIPS and SIPS 9.0 software, seamount geomorphologies including their associated calderas were characterized by measuring slope, height, relief, width, shape, and index values for each characteristic were generated. Seamount base depths range from 3,000 to 3,500 m with the largest peak's depth at 923 m. Characterization of these seamounts may serve as an indicator of nearby fracture zone strength, as weak fracture zones that are formed at fast-slipping transform boundaries provide preferential conduits for volcanism. This geomorphic analysis of seamounts aims to provide further insight into oceanic fracture zone geomorphology.

BACKGROUND

The seamounts examined in this study are located adjacent to the Mendocino Fracture Zone off the northern coast of California along the Gorda Escarpment. The eleven seamounts exhibit flat top features with nearly circular depressions formed by magma chamber collapse. The formation of flat top seamounts occurs as submarine lava ponds overflow and require effusive eruptions with low volatile content in addition to pressure constraints from depth (Clague et al., 2000). The nearly circular nature of many of the seamounts indicates symmetrical eruption sequences. The seafloor crustal age for the study area ranges from 8.0 to 5.0 mya (Muller et al., 2008). The depth of the seamounts indicates caldera collapse as the mechanism for flat top formation as opposed to erosional influence (Kopp et al., 2003). Flat top seamount formation and the processes that shape oceanic volcanism can be better understood through the characterization of seamounts along the Gorda Escarpment. The information gained from mapping the study area provides a detailed window into the formation of flat top seamounts and their geomorphologies.

FIGURE 1: Seamounts adjacent to the Mendocino Fracture Zone.



- Seamounts labeled 1-11 as seen on the CUBE BASE surface.
- Seamounts 2,9, and 10 lack calderas with 10 being the largest of the seamounts.

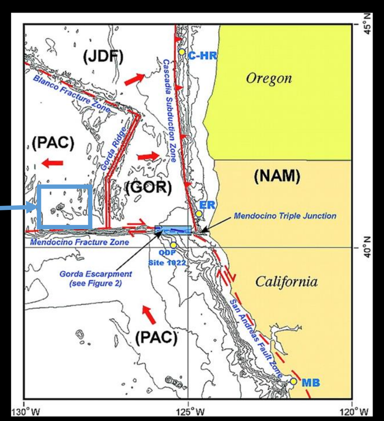
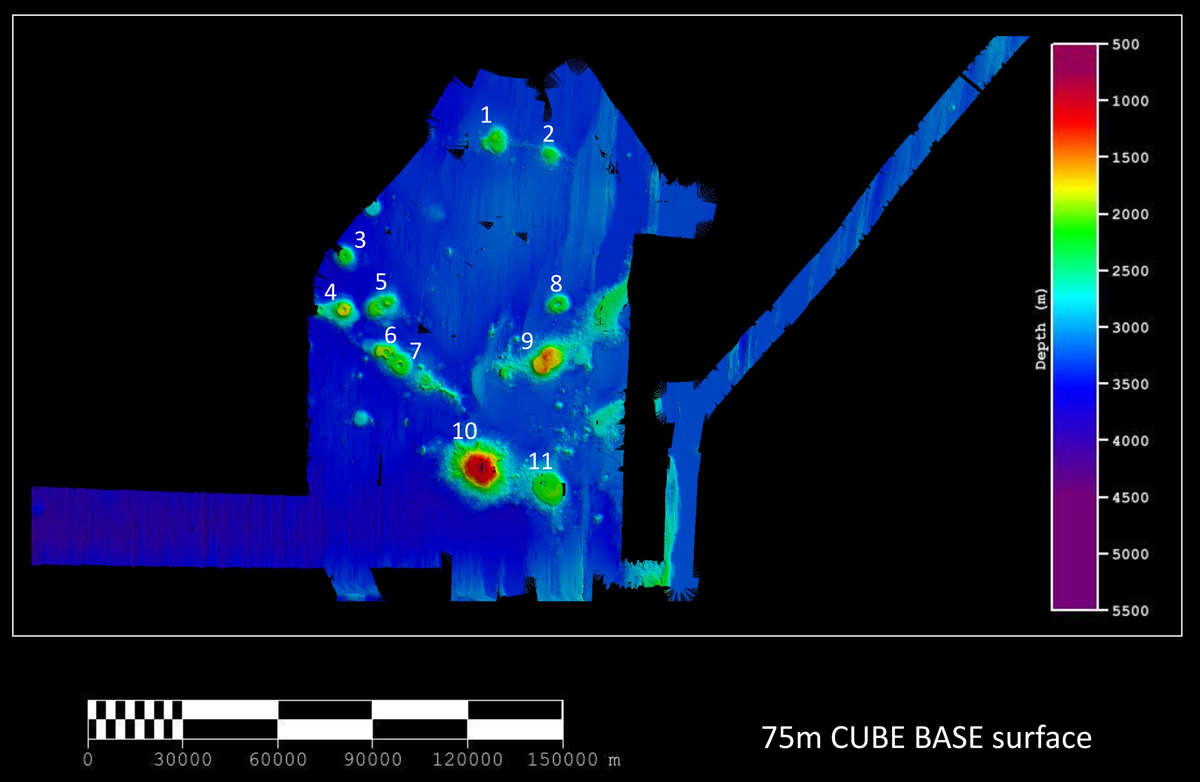
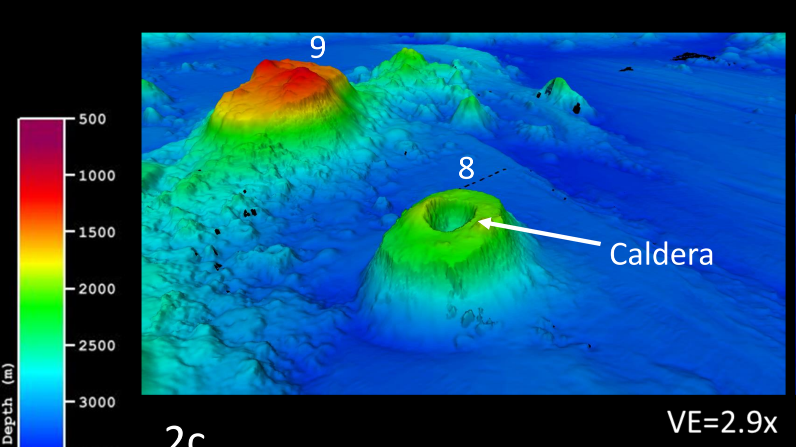


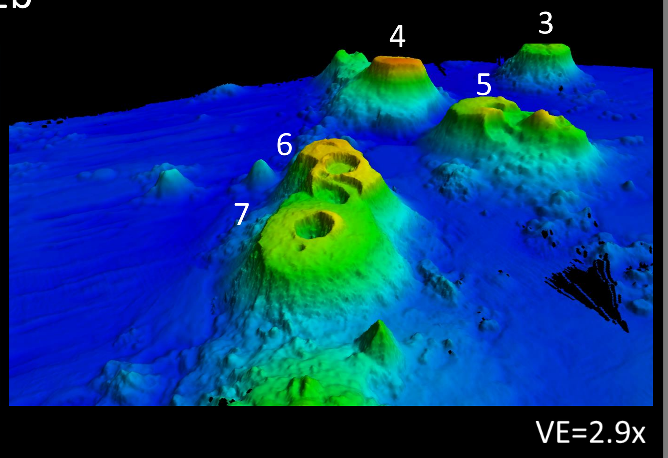
Image from Stakes et al., 2002.



METHODS

Multibeam survey data of the eleven seamounts adjacent to the Mendocino Fracture Zone from the 2014 R/V *Atlantis* cruise-AT26-21 were acquired using a Kongsberg EM122 and post processed using CARIS HIPS and SIPS 9.0 software. A CUBE BASE surface was created to observe local bathymetry and the geomorphologic characteristics of the eleven seamounts. Profiles were taken across the long and short base lengths of each seamount in order to create an index for the degree of circularity with values closer to 1 indicating a more circular seamount. The short and long base lengths derived from the profiles were compared to the seamount height providing a relief index for each length. Google Earth Pro was used to calculate the base, flat top, and caldera areas for each seamount. Relationships between these geomorphologic variables were analyzed through regression tools for statistical significance in order to characterize the seamounts. 3D views were used to observe specific areas in the study site in order to observe changes in bathymetry at a more local scale.





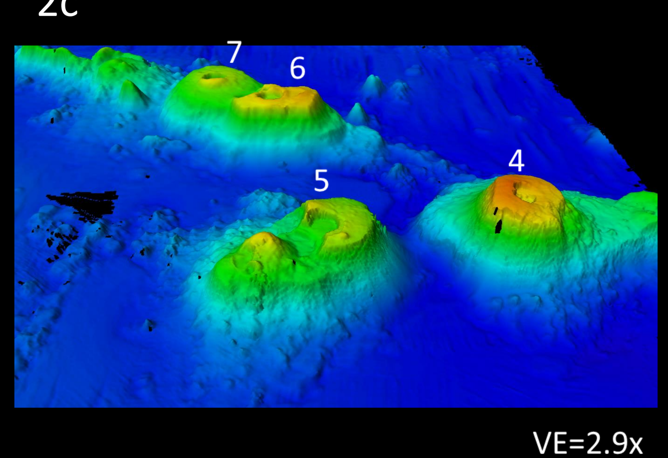


FIGURE 2

a) Seamounts 8 and 9 both have flat top features; however 8 is characterized by a crater formed by caldera collapse.
b) View of seamounts 3-7 from the southeast illustrating multiple calderas on 6 and 7 and nearly cylindrical shapes for 3 and 4.
c) View from the north of seamounts 4-7 showing the flat top nature and the calderas of the seamounts.

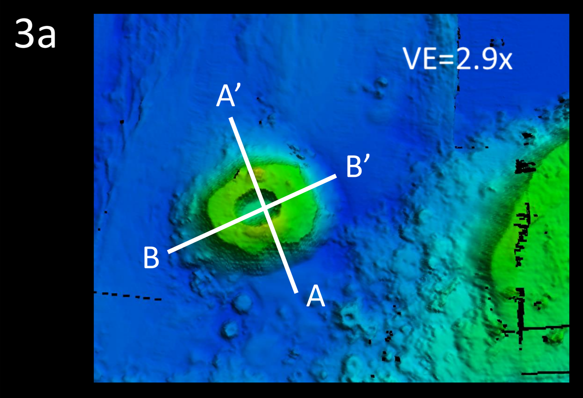


FIGURE 3

a) 3D view of example seamount 8 with profiles A-A' (long base) and B-B' (short base). The profiles were used to derive indices for the degree of circularity and the relief for each profile.
b) Profiles A-A' and B-B' for seamount 8 with base length and seamount height. Base length was measured at the depth of the seamount flank's slope change, and the seamount height was determined from the depth of the base length to the flat top.

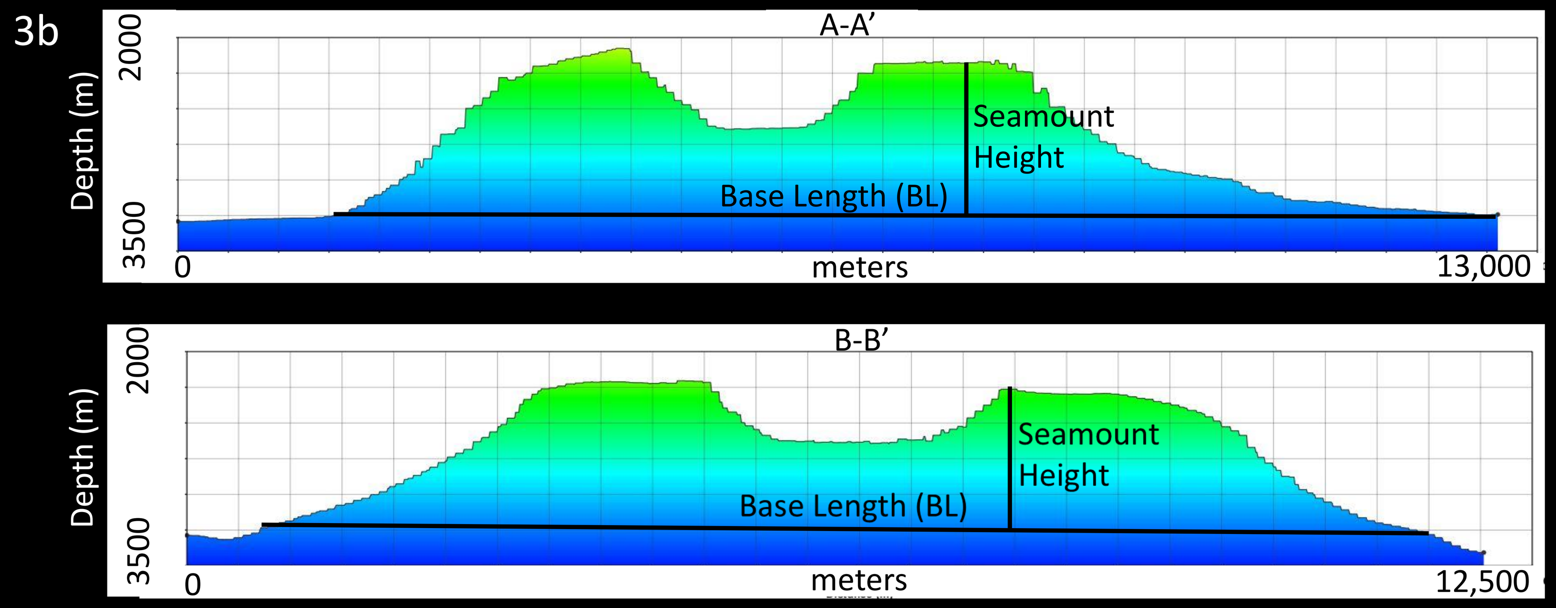
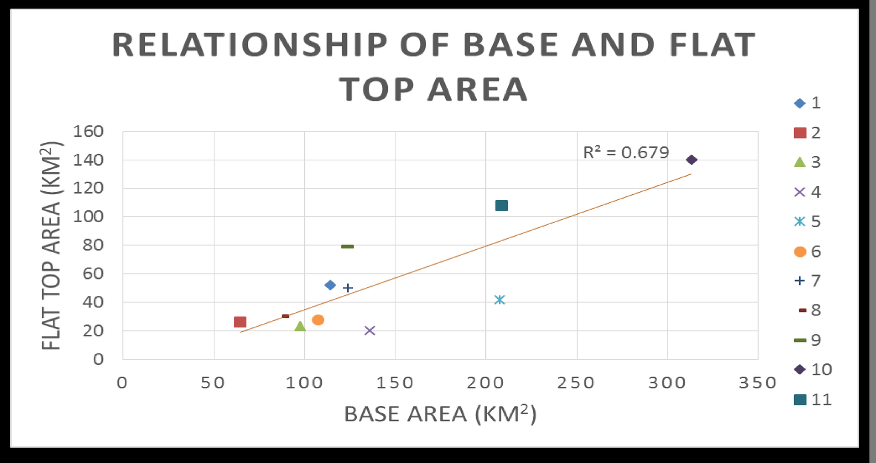
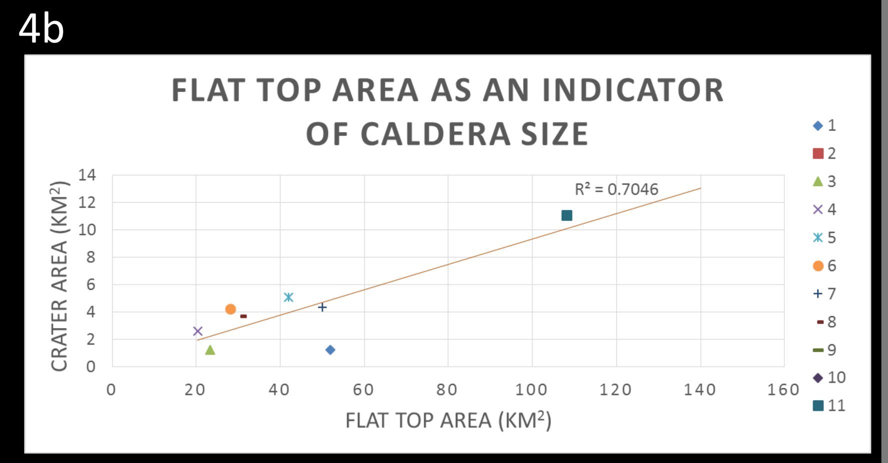


FIGURE 4

a) Comparison of the base area of each seamount to the area of the flat top. Seamount 10 has the largest base area as well as flat top area.



b) Relationship between the flat top area of each seamount and the area of the caldera. Seamounts 2, 9, and 10 do not have plotted points due to their lack of calderas.



RESULTS

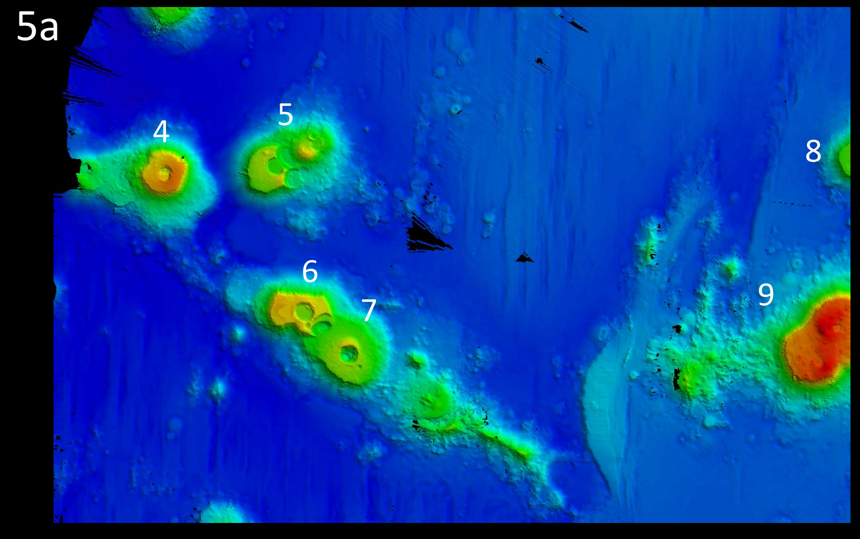
- The study area is characterized by eleven seamounts that are located on the elevated portion of the Gorda Escarpment north of the Mendocino Fracture Zone.
- The presence of seamounts on this portion of the Gorda Escarpment indicates eruptive sequences in proximity to the Mendocino Fracture Zone west of the Gorda Spreading Ridge.
- The geomorphology of the eleven seamounts (Figure 1) is characterized by the presence of calderas, circular flat tops, and varying relief.
- The degree of circularity for each seamount is indicated by the proportion of base lengths for each seamount.
- Seamounts plotted on the circularity index (Table 1, Figure 5b) with values closer to the trend line indicate greater circularity.
- A good correlation exists between seamount base lengths (long vs. short) with an R^2=0.7769 (Figure 5c).
- In addition to circularity there is a moderate correlation R^2=0.679 between base area and flat top area for each seamount (Figure 4).
- Base area is correlated to the area of the flat top for each seamount (Figure 4a).
- Flat top area can also be used as an indicator of caldera size shown by the correlation between flat top area and caldera area with an R^2=0.7046.
- These results indicate that the size of the flat top of a seamount can be used as a measure for the size of the caldera associated with magma chamber collapse.

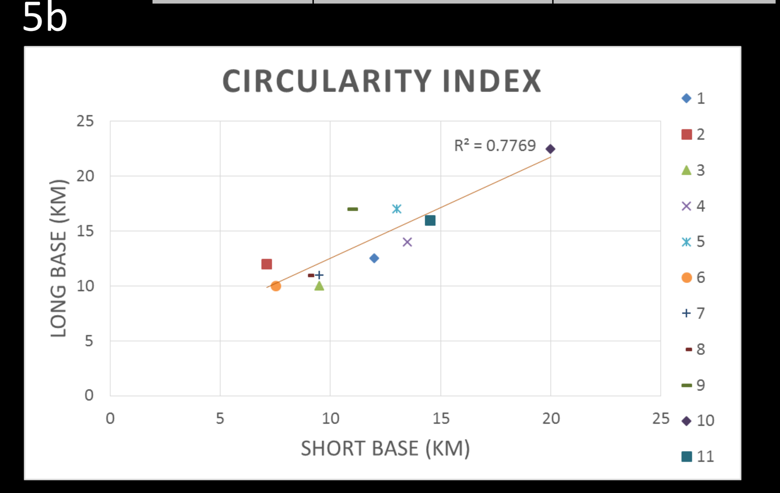
FIGURE 5

a) Seamounts 4-9 illustrate the circular nature of the calderas and the seamount bases. For instance, seamount 4 falls closer to the trend line indicating greater circularity while seamount 9 is found further from the trend line and is less circular.
b) Circularity index shown with a trend line and R^2=0.7769 indicating a correlation between base lengths and the degree of circularity of each seamount.

Table 1. Base lengths in km.

Seamount	Base Short (KM)	Base Long (KM)
1	12	12.5
2	7.1	12
3	9.5	10
4	13.5	14
5	13	17
6	7.5	10
7	9.5	11
8	9	11
9	11	17
10	20	22.5
11	14.5	16





DISCUSSION

The seamounts along this portion of the Gorda Escarpment adjacent to the Mendocino Fracture Zone are characterized by circular calderas, relatively high relief, and flat top features. The formation of the seamounts may be related to the proximity of the Gorda Spreading Ridge to the east. Ridge-transform intersections (RTIs), like that of the Mendocino Fracture Zone and Gorda Ridge intersection, lead to hotspot volcanism. Increased extensional stress at RTIs promotes adiabatic melting, thinner lithosphere, and a shift in the thermal gradient (Beutel, 2005). The eleven seamounts are characterized by a correlation between the shortest and longest base lengths relating to the degree of circularity for each seamount (Figure 5). The most circular seamounts lie closest to the trend line with those irregularly shaped seamounts falling further from the plotted trend. In addition to the circular nature of the seamounts, the area measurements for the base, flat top, and caldera are used to further characterize the geomorphologies of the seamounts. The area of the base correlates to the area of the flat top, and the area of the flat top can be correlated to the size of the caldera, when present. The correlated areas can be attributed to the relationship between lava pond formation and levee size for each seamount. Flat top seamounts of this kind are formed as lava ponds forming near RTIs and are constrained by a levee. The size of the levee can be seen in the relationship between flat top area and the caldera area. As lava accumulates in the pond and overflows the lowest part of the levee, the seamount begins to take shape. Subsequent effusive eruptions occur leading to the seamount geomorphology seen at this location (Clague et al., 2000).

The characterization of the eleven seamounts on this portion of the Gorda Escarpment leads to further questions on flat top seamount formation. Do flat top seamounts of this nature typically form near RTIs? Are such seamounts related to weakened fracture zones? What other controls effect the formation of flat top calderas? Can the geomorphology of such seamounts indicate eruption volume and seamount size?

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