Characterization of Five Geologic Zones Within the Northern Mariana Subduction Region

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ABSTRACT

Between 2003 and 2016 scientists from the NOAA Office of Ocean Exploration and Research, the University of New Hampshire's Center for Coastal and Ocean Mapping, and the University of Washington collected multibeam sonar data approximately 2,330 km off Taiwan along the Northern Mariana Trench. Sonar data were post-processed with CARIS HIPS 10.4 software to create 2D and 3D bathymetric surfaces, and the area's geomorphology was examined focusing on differences between five zones identified which are characteristic for subduction regions: remnant arc; back-arc basin; volcanic arc; fore-arc; and trench. Typical features found within these zones were observed, including back-arc basin rifting, seamounts along the volcanic arc, and mud mounds within the fore-arc. Overall, this portion of the Mariana Trench was determined to include the classic geologic zones associated with subduction regions, however an unusual rifting area was identified, oriented perpendicular to the trench within the volcanic arc zone.

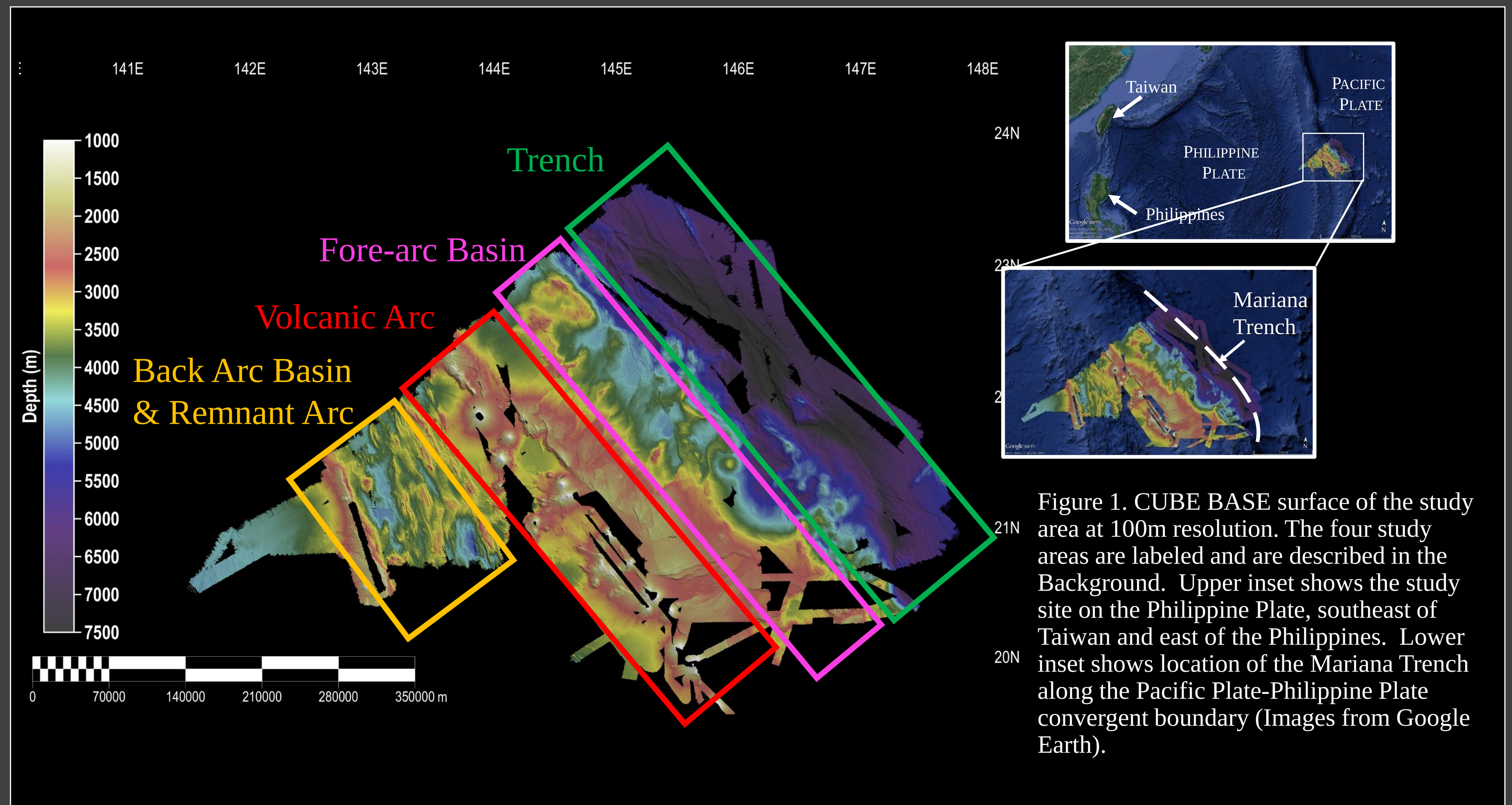


Figure 1. CUBE BASE surface of the study area at 100m resolution. The four study areas are labeled and are described in the Background. Upper inset shows the study site on the Philippine Plate, southeast of Taiwan and east of the Philippines. Lower inset shows location of the Mariana Trench along the Pacific Plate-Philippine Plate convergent boundary (Images from Google Earth).

BACKGROUND

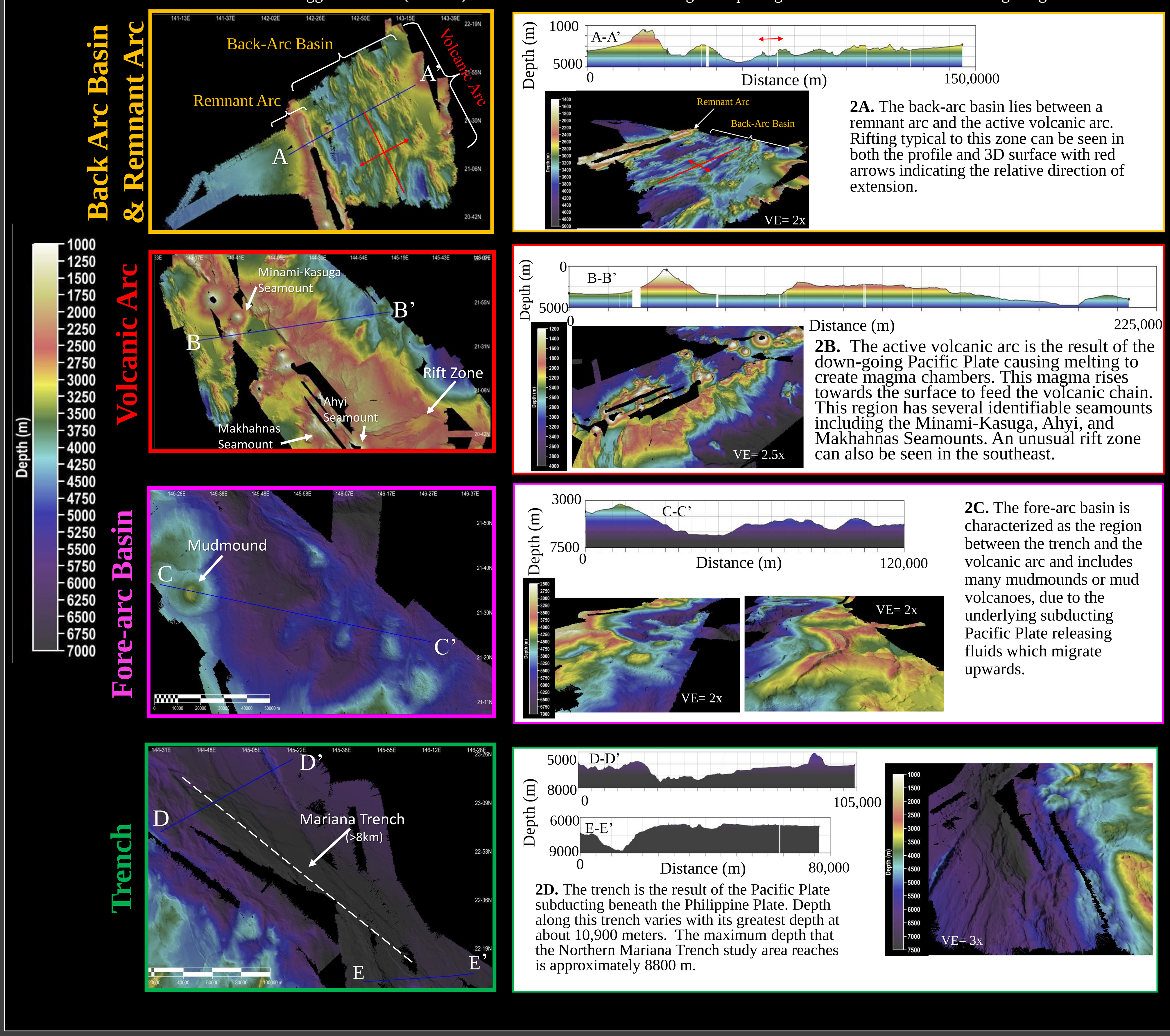
The study area lies within the western Pacific Ocean approximately 1,300 miles east of the Taiwan (Figure 1A). The Mariana convergent margin is between the Philippine and Pacific Plates and is a highly faulted nonaccretionary system. The Mariana Trench is the result of the subduction of the Pacific Plate beneath the Philippine Plate. The trench marks the deepest point on the planet at 10,916 meters and measures about 2,550 km in length with a width of 69 km (Chadwick and Fryer, 2016). The direction of stress acting on the trench is variable due to broad regional plate tectonics. Tectonically derived structures form both as escarpments from thrust-faulting and as mounds from extrusions of mud rising through fractures, whereas the volcanically-originated features form as seamounts and serpentine mud volcanoes (Fryer, 2016). The Mariana Subduction Zone is typical of most subduction zones consisting of a trench, fore-arc basin, volcanic arc, back-arc basin, and a remnant arc (Fig. 1). The fore-arc basin is the region between the trench and the volcanic arc. The volcanic arc is the chain of seamounts and sometimes islands that occur as a result of volcanic activity beneath the subduction zone. The back-arc basin lies between the active volcanic arc on the east and an inactive remnant arc on the west.

Only nine of the active volcanoes/seamounts along the entire Mariana arc are tall enough to form volcanic islands, while the rest of the seamounts are completely below the sea surface (Chadwick and Fryer, 2016). The volcanic arc is the weakest zone within the subduction region because it is both warm and brittle. These characteristics typically cause the arc to begin to break up, causing the crust and upper mantle to fault, become stretched, and begin to subside, creating the back-arc basin.

The tectonic plates are spreading apart in some areas as well as the subduction from collision, creating a diverse group of features in the area (Chadwick and Fryer, 2016). The purpose of this study is to characterize each of the typical geologic zones of the northern portion of the Mariana Subduction Zone.

Five Geologic Zones

Figure 2. Comparison of 2D BASE Surfaces of A) the back-arc basin and remnant arc with a 50 m resolution, B) the active volcanic arc (50 m resolution), C) the fore-arc basin (75 m resolution), and D) the trench (100 m resolution). Profiles with a vertical exaggeration of 2 (VE= 2x) were created to demonstrate the geomorphological differences between the five geological zones.



2A. The back-arc basin lies between a remnant arc and the active volcanic arc. Rifting typical to this zone can be seen in both the profile and 3D surface with red arrows indicating the relative direction of extension.

2B. The active volcanic arc is the result of the down-going Pacific Plate causing melting to create magma chambers. This magma rises towards the surface to feed the volcanic chain. This region has several identifiable seamounts including the Minami-Kasuga, Ahyi, and Makhahnas Seamounts. An unusual rift zone can also be seen in the southeast.

2C. The fore-arc basin is characterized as the region between the trench and the volcanic arc and includes many mudmounds or mud volcanoes, due to the underlying subducting Pacific Plate releasing fluids which migrate upwards.

2D. The trench is the result of the Pacific Plate subducting beneath the Philippine Plate. Depth along this trench varies with its greatest depth at about 10,900 meters. The maximum depth that the Northern Mariana Trench study area reaches is approximately 8800 m.

METHODS

- Data were processed using CARIS HIPS 10.4 to create 2D and 3D bathymetric surfaces ranging from resolutions of 50-100 m. Slope and aspect surfaces, as well as cross-sectional profiles were also generated.
- Data were collected by the University of New Hampshire, Center for Coastal and Ocean Mapping using a Kongsberg EM122 Transducer aboard the R/V *Fugro Supporter*. The NOAA Office of Ocean Exploration and Research worked aboard the NOAA Ship *Okeanos Explorer* using a Kongsberg EM302 transducer, and the University of Washington surveys were conducted onboard the R/V *Thomas G. Thompson* using a Kongsberg EM300 transducer.
- Data collected and processed were used to characterize each section of the subduction zone

RESULTS

- Five geologic zones were identified within the Northern Mariana Trench subduction region including a remnant arc, back-arc basin, volcanic arc, fore-arc basin, and trench (Fig 2).
- The deepest point of this region was found to be approximately 8,800 meters (Fig. 4).
- Rifting was determined to be taking place within the back-arc basin between a remnant arc and the active volcanic arc (Fig. 2A).
- Although none of the active seamounts in the study area were determined to be volcanic islands, their summits ranged between depths of approximately 330 m and 590 m (Fig. 2A, 5).
- An unusual feature was found within the volcanic arc zone. This area appears to be rifting perpendicular to the plate's compressional movement (Fig. 3). The small area of extension within this compressional zone is atypical. This rifting occurs at the base of two seamounts and has tilted, terraced rocks on the seabed characteristic of horst and graben features.
- The geomorphology of mud mounds and seamounts were compared, revealing that seamounts are significantly larger, rounder, more symmetric, and more conical in shape while mud mounds typically result in a low, flattened and tilted seabed, likely the result of mud flow characteristics (Fig. 5).

Rifting in the Volcanic Arc

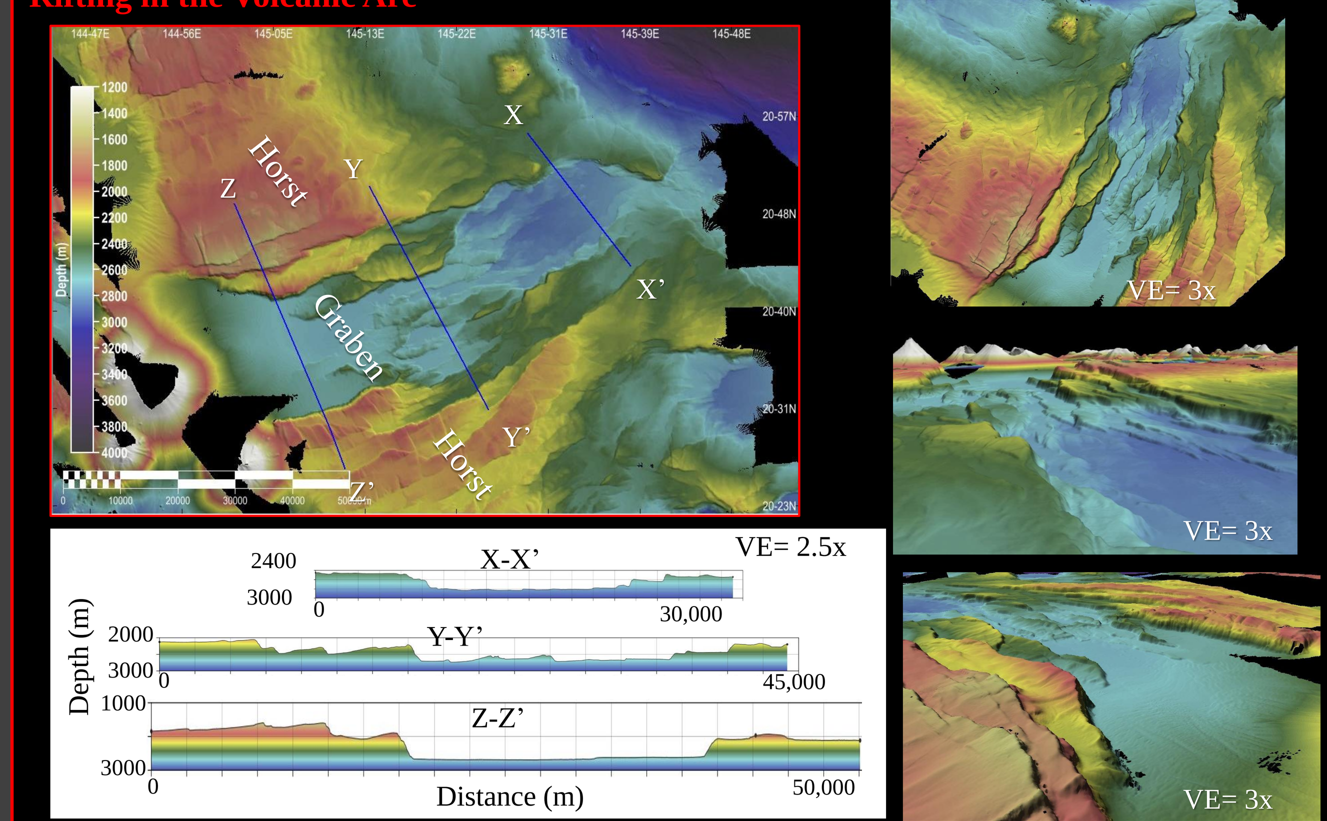


Figure 3. Profiles of irregular rifting area within the volcanic arc zone, oriented perpendicular to the volcanic chain. This area is located at the base of the Ahyi and Makhahnas Seamounts. This rifting is most likely due to normal faulting within the volcanic arc zone. The tilted seabed as seen on the edges of the horsts show a terrace effect within the rift zone. The horsts are tilting away from the graben indicating that there is most likely rotational block faulting occurring here.

DISCUSSION and CONCLUSIONS

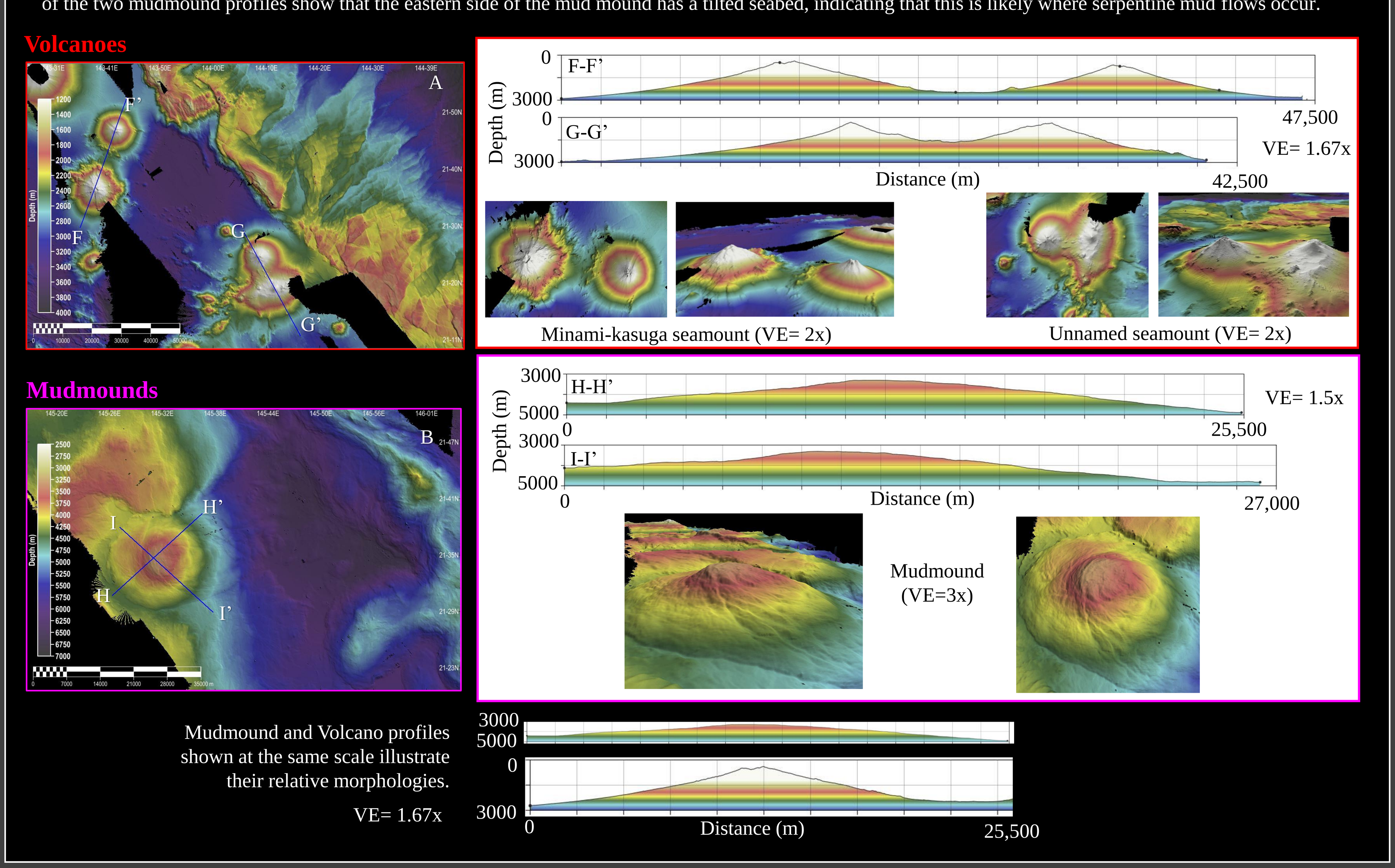
The **back-arc basin** lies between the active volcanic arc to the east and inactive **remnant arc** westward. At the back-arc basin, the Philippine Plate, which overrides the Pacific Plate, is under tremendous tension.

The **active volcanic arc** is exposed to extreme heat, making it more brittle, and may cause a volcanic arc to begin to break up. As a result, the lithosphere becomes faulted as it is stretched thinner, and begins to subside, creating the back-arc basin (Chadwick and Fryer, 2016). The volcanic arc in the study area is typical for a subduction region, with one notable anomalous feature of a rifting region perpendicular to the compressional trend (Fig. 3). There are regional and local fracture patterns on the Mariana fore-arc as well as within the volcanic arc. Fryer and Hussong (1985) suggested that these weak zones are the result of the seabed adjusting to the increasing curve of the Mariana arc. These fracture zones are creating planes of weakness, and this unusual feature is likely the result of a normal fault that created the horsts and graben (Fryer and Hussong, 1985). The horsts are tilting away from the graben, indicating rotational block faulting. It is also possible that this is an area of extension, rather than of faulting, where the volcanic arc is changing orientations from northwest-southeast to a more north-south orientation. Further research on a larger study area would need to be conducted to confirm these hypotheses.

While the **fore-arc basin** is located between the active volcanic arc and the volcanically inactive trench, it is still a volcanically dynamic zone (Fryer, 1996). Mud mounds, or mud volcanoes, are found on the fore-arc of the Northern Mariana subduction region (Fig. 2C, 5). These mud mounds are formed by the releasing of fluids from the Pacific Plate as it is subducted beneath the Philippine Plate. These fluids then help to hydrate the minerals within the faulted mantle of the fore-arc and create a serpentinite mud (Fryer and Chadwick, 2016). While these mud mounds could easily be confused with seamounts on a bathymetric surface (Fig. 5), recent research conducted in the central region of the Mariana Trench showed that seamounts have more of a rounded symmetry and pointed top as compared to mud mounds (Owens and Sautter, 2016).

Overall, the Northern Mariana Subduction Region has five defined geologic zones that are typical of this type of convergent plate boundary. Additional bathymetric data should be collected to conduct further research in order to gain a better understanding of some of the more unusual features found at this study site, and relate features found in the northern Mariana region to the remainder of the Mariana subduction zone.

Figure 5. Comparative morphology of seamounts (volcanoes) from the volcanic arc (A) and (B) a large mudmound located in the fore-arc basin. The right sides of the two mudmound profiles show that the eastern side of the mud mound has a tilted seabed, indicating that this is likely where serpentine mud flows occur.



Mudmound and Volcano profiles shown at the same scale illustrate their relative morphologies.

VE= 1.67x

The Mariana Trench

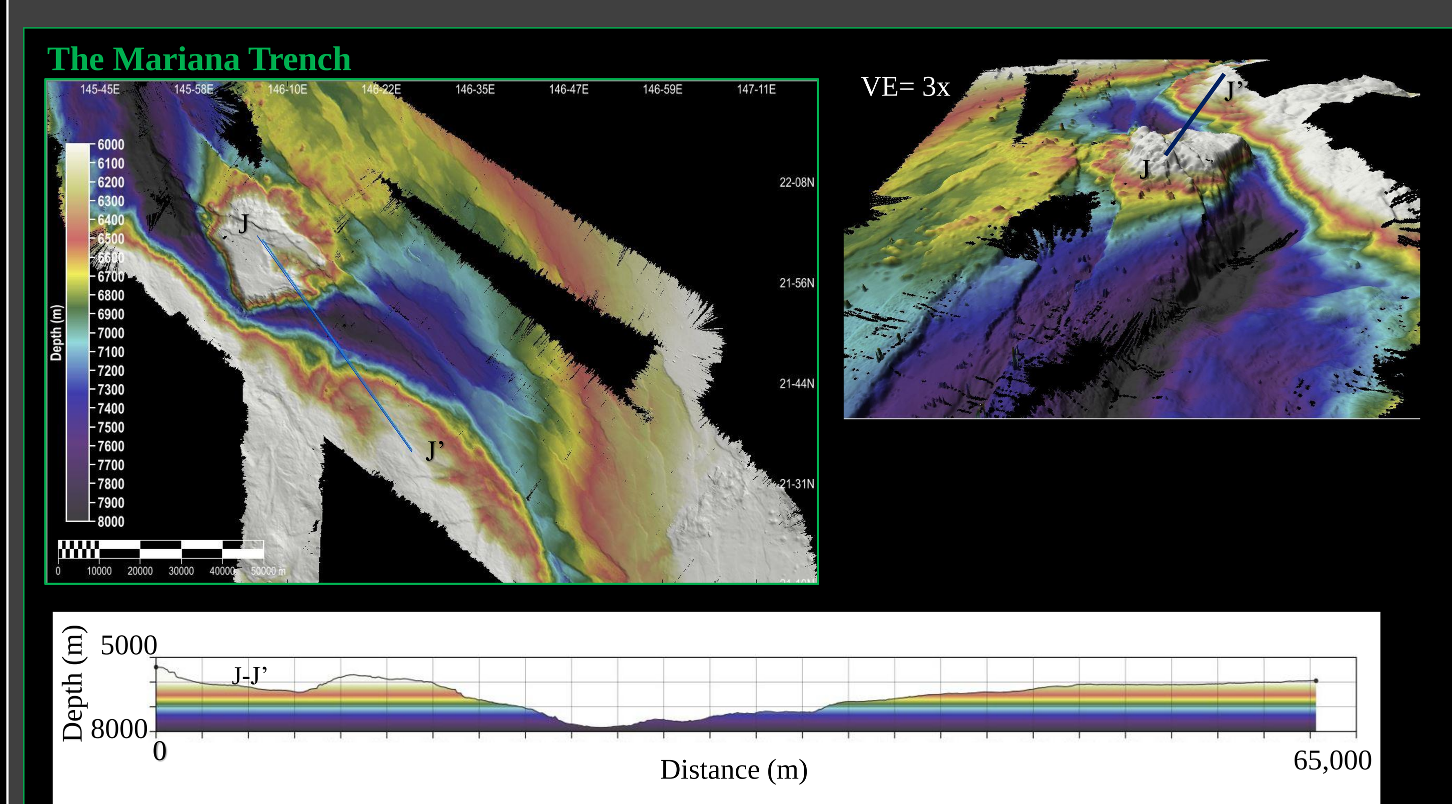


Figure 4. Although the Mariana Trench exceeds depths of 10,000 meters, the greatest depth within this study area was found to be approximately 8,800 m. Differences in maximum depth are most likely due to varying rates of subduction and melting along and within the trench.

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