Tectonic Geomorphology of Mounds West of the Northern Mariana Trench

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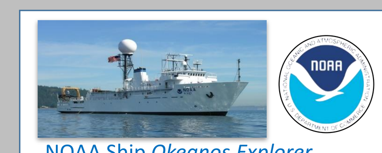
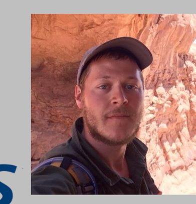

NOAA Ship *Okeanos Explorer*



ABSTRACT

NOAA's Office of Ocean Exploration and Research collected sonar data on the Philippine Plate, on the western side of the Mariana Trench's northern portion between May and June, 2016. Data collected with a Kongsberg EM302 multibeam echosounder from on board the NOAA Ship *Okeanos Explorer* were post-processed with CARIS HIPS 9.1 to create both 2D and 3D bathymetric and backscatter intensity surfaces. This study site lies adjacent to the Mariana Trench and exhibits bottom depths ranging 3000 to 7200 m. The area's geomorphology was investigated using quantitative and qualitative methods, aimed towards classifying several structurally dominated slopes and mounds according to their backscatter return and slope profiles. The sea floor in this segment of the trench is a part of the Mariana nonaccretionary front and exhibits a variable degree of consolidated versus unconsolidated sediment and roughness. By investigating the various surficial expressions associated with this section of the Mariana Trench area's seafloor, a more detailed understanding can be drawn of the tectonic and sedimentary processes dominating there.

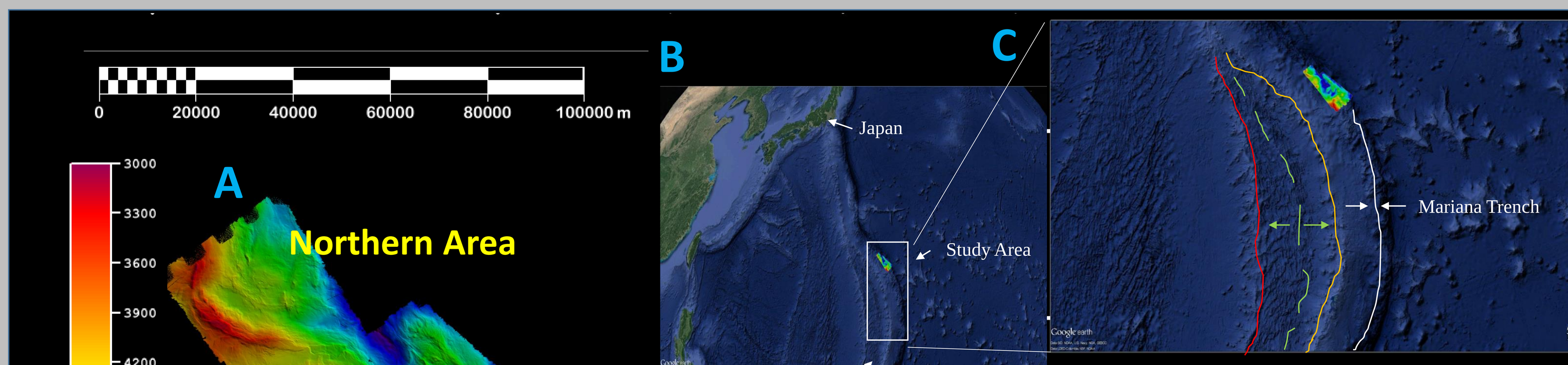


Figure 1A). 30m CUBE BASE surface with subdivided regions of interest.

Figure 1B) Google Earth Image of study area in the Philippine Sea southeast of Japan and north of Guam.

Figure 1C) Inset of study area on Forearc/accretionary front boundary. **White** line indicates trench with arrows illustrating plate movement of the westward-moving Pacific and eastward-moving Philippine Plates. **Yellow** line indicates Volcanic-Arc region slightly west of and Forearc region lying slightly east. **Green** line (broken) indicates the Back-Arc region with arrows expressing relative motion. **Red** line indicates the Remnant-Arc region.

METHODS

- Data were collected by NOAA Chief Scientist E. Lobecker on the NOAA Ship *Okeanos Explorer* using Kongsberg EM302 in May-June, 2016.
- Data were post-processed using CARIS HIPS 9.1 to create both 2D and 3D slope, back-scatter, and 30 m CUBE BASE surfaces as well as cross-section profiles of specific features (Fig. 1-4).
- Three slopes were profiled and their general seafloor roughness was calculated by dividing the total 3D surface expression distance by the total profile distance (Fig. 2, Fig. 6).
- "Steepest slope angles" were determined based on the steepest portion of each slope.
- Based on seismic reflection data, observed thrust-fault escarpments were identified (Fig. 5).
- Four mounds were profiled for qualitative analysis based on backscatter 3D images and compared to profile of a confirmed mud mound and seamount (Fig. 3, Fig.7).

BACKGROUND

The study location is located on the border of the Mariana Trench nonaccretionary front and the forearc region (Fig. 1). This tectonically-active segment of the trench has undergone a long history of compressional thrust-tectonics from the subduction of the Pacific Plate underneath the Philippine Plate (Fig. 5). The long history of forearc faulting in this zone has exposed crust and upper-mantle lithosphere (Fryer, 1996). The entire subduction zone is constrained in the north with the subduction and collision of the Ogasawara Plateau, and in the south with the Caroline Ridge (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). Based on past studies (Fryer, 1996), the presence of escarpments suggests the features here are mud mounds. Recent research conducted in the central region of the Mariana Trench show that seamounts have more of a rounded symmetry and pointed top as compared to mud mounds (Owens and Sautter, 2016). If any seamounts are subducted along with the Pacific Plate, the edge of the Philippine Plate can uplift (Fryer, 2016). Through time, as the Pacific Plate has been subducted, it experiences "roll back" toward the east, meaning the entire trench has been slowly migrating eastward through time (Fryer, 2016). The purpose of this study is to target specific structural features to gain a better understanding of where they occur and their geomorphology on the seafloor. This information will provide useful insight for the future of the many Mariana archipelagos.

Mud Mound Morphology

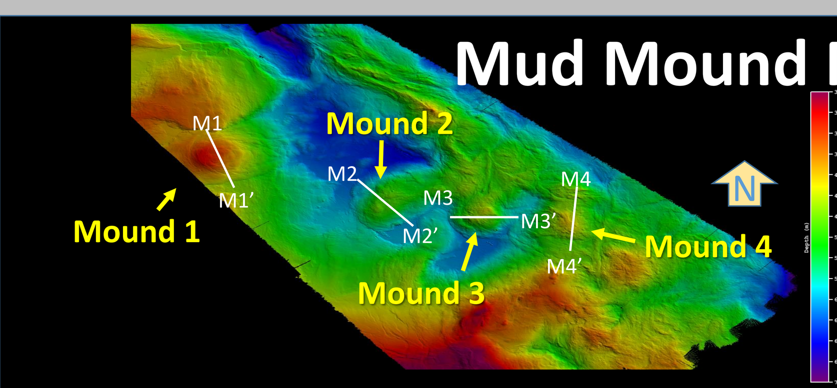
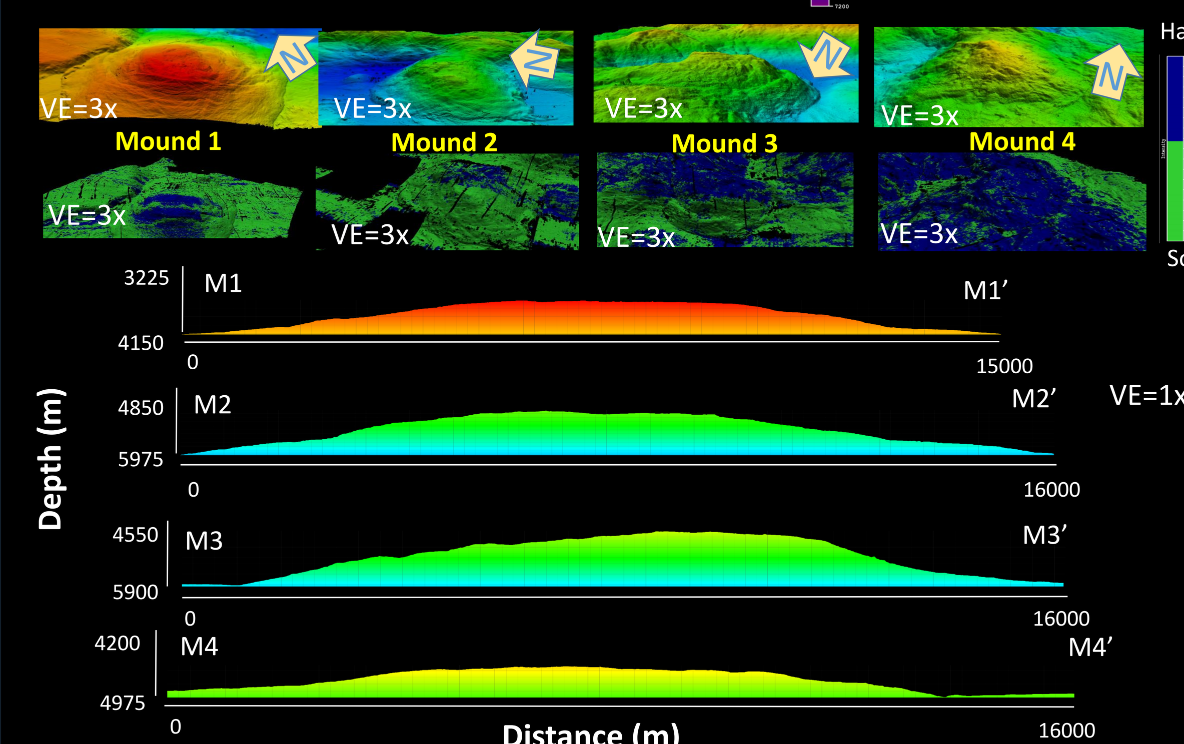
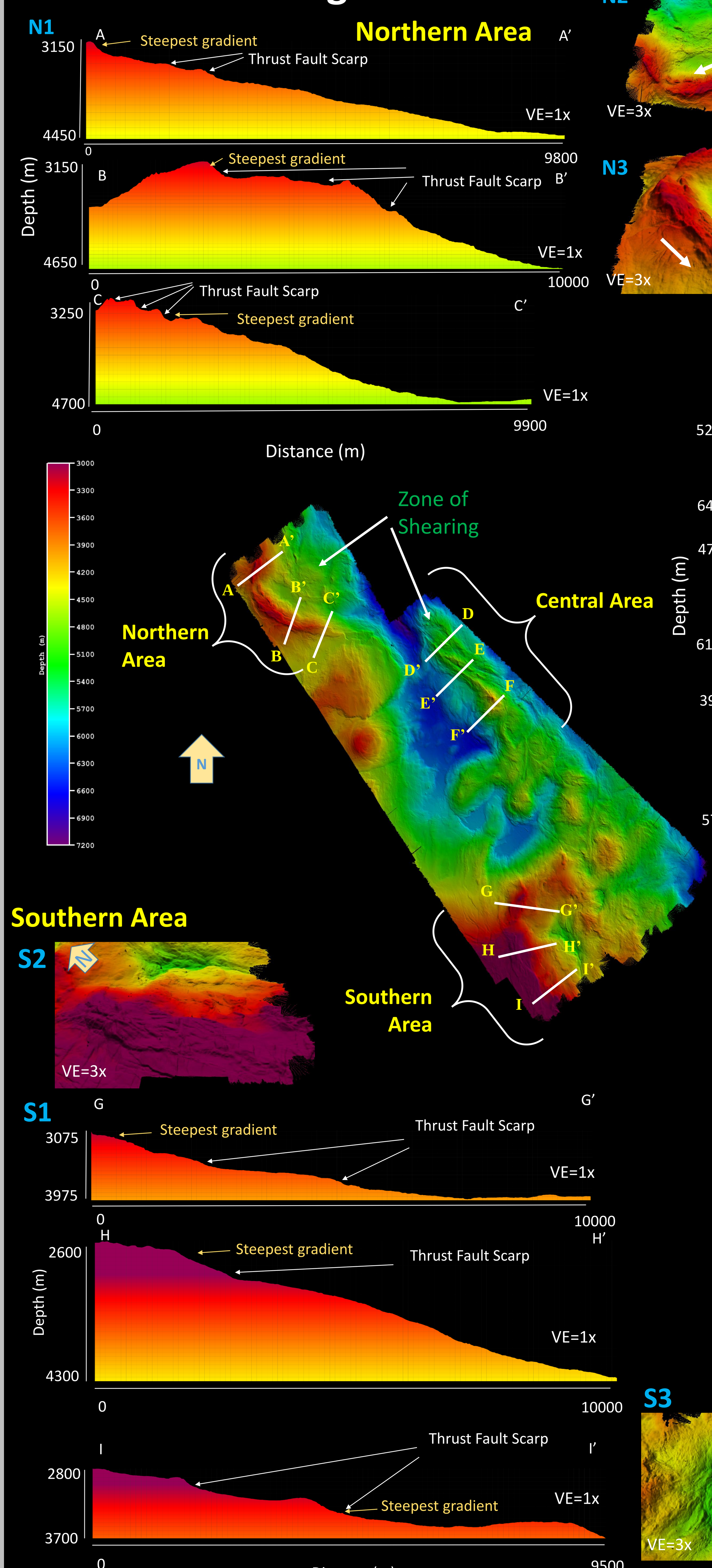


Figure 3. 3D BASE surfaces, Backscatter Intensity and Profiles for Mounds 1-4.



Seafloor Roughness



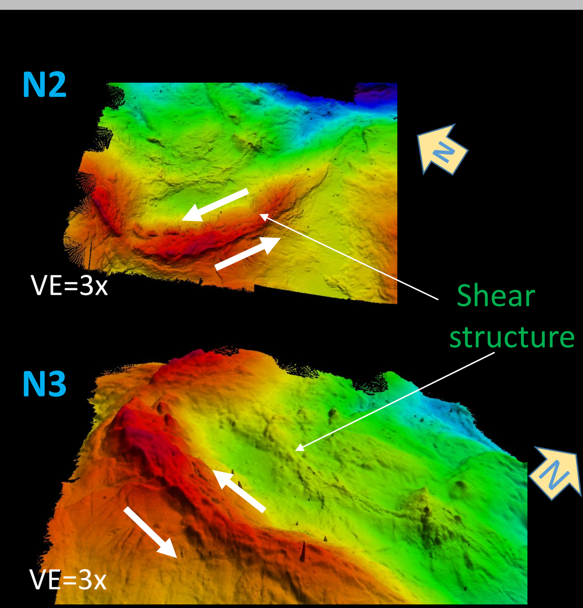
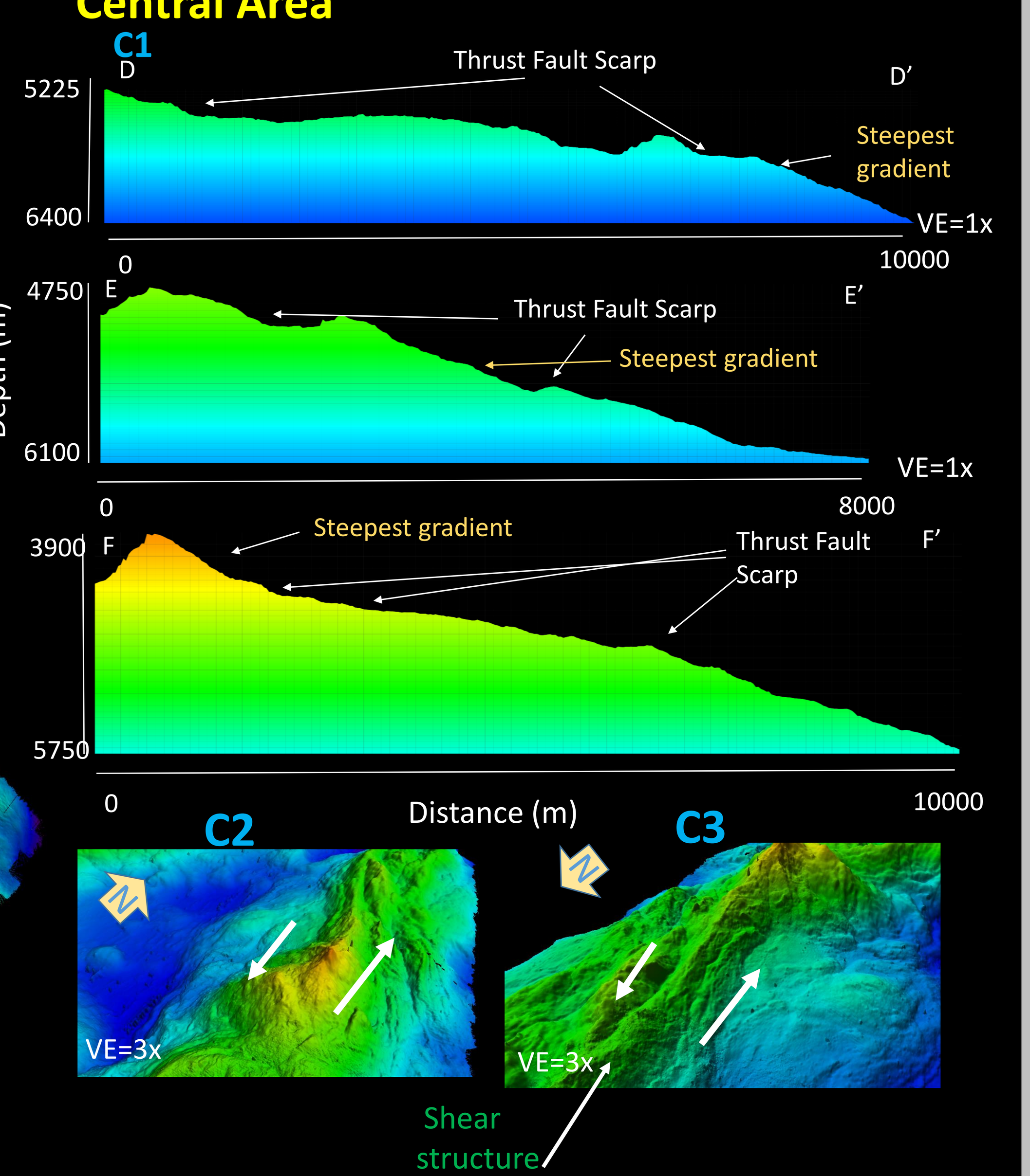


Figure 2. **Northern Area N1)** Slope profiles for A-A' Northern Flank, B-B' Central Flank, C-C' Southern Flank, with thrust-fault scarps and steepest gradient marked. **N2-N3)** 3D surfaces with shear-structure labeled.

Central Area (C1, C2, C3) and **Southern Area (S1, S2, S3)** are also shown.



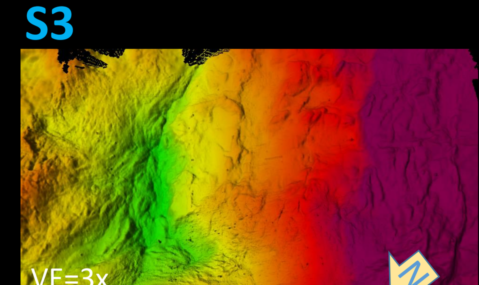
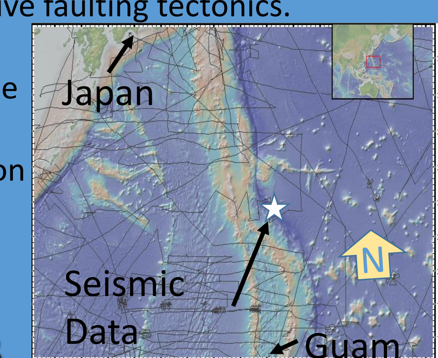


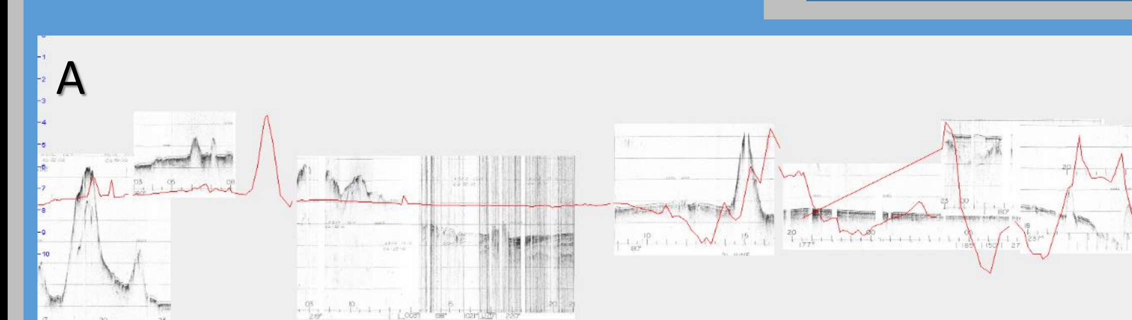
Figure 6 (right). **A)** Sea floor roughness along profiles A through I. Roughness = total 3D slope distance / profile distance. **B)** Distances and slope angles for Profile A-I.

B

Profile	Sea Floor Roughness	Profile Distance (m)	3D/Slope Distance (m)	Greatest Slope angle (°)
A-A'	1.0106	29927.22	30243.41	13.0
B-B'	1.0162	16983.12	17258.24	20.0
C-C'	1.0126	16969.09	17183.49	18.0
D-D'	1.0175	29970.20	30494.21	15.0
E-E'	1.0142	16962.85	17203.01	18.0
F-F'	1.0217	16962.85	17330.20	22.0
G-G'	1.0099	29977.12	30273.98	16.0
H-H'	1.0130	16916.47	17136.90	16.0
I-I'	1.0061	16928.07	17031.98	15.0

Figure 5. A) GeoMap App Image of Analogue Seismic Reflection Data for Northern Mariana Trench in the Philippine Sea with red line being the main sea-floor reflector and the spikes representing active faulting tectonics.
B) Inset map of location along the Mariana Trench showing reflection profile location.





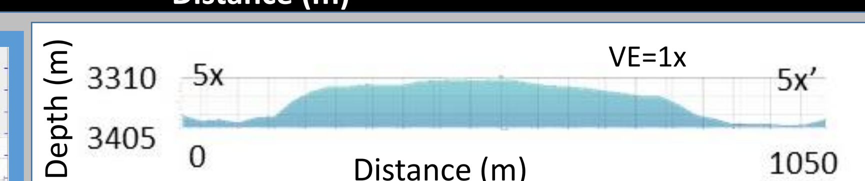


Figure 7. Profile of mud-mound from Central Mariana Trench. This mound has the same vertical exaggeration as the mud mounds in this study, though it is far smaller. Note the similar morphology to mud mounds in this study (Fig. 3). (Figure from Owens and Sautter, 2016).

RESULTS

- Slope profiles indicate variable steepness with *en echelon* thrust escarpments cropping up throughout the study area. Slopes range from 10 to 35 degrees and were found to be associated with exposed surfaces of harder backscatter return (Fig. 2).
- Backscatter intensity returns for the four mounds yielded higher intensities compared with surrounding seafloor (Fig. 3). All exhibited a hard backscatter return intensity of -25 to -13 dB similar to slope backscatter intensity (Fig. 3C).
- General seafloor roughness ranged 1.0099 to 1.0217, where values of 1 indicate a smooth surface (Fig 6). Each "step" on the surface is an escarpment which has experienced displacement, upheaving harder substrate and dislodging the smooth surface.
- Mounds 1-4 were found to be non-symmetrical based on profile views (Data limitations such as total width of base surface data collected restricted full quantification.) (Fig. 3D)
- Comparative morphology of Mounds 1-4 with a nearby mud-mound and seamount (Owens and Sautter, 2016) indicates the features in the study are mud-mounds (Fig. 3, Fig. 7)

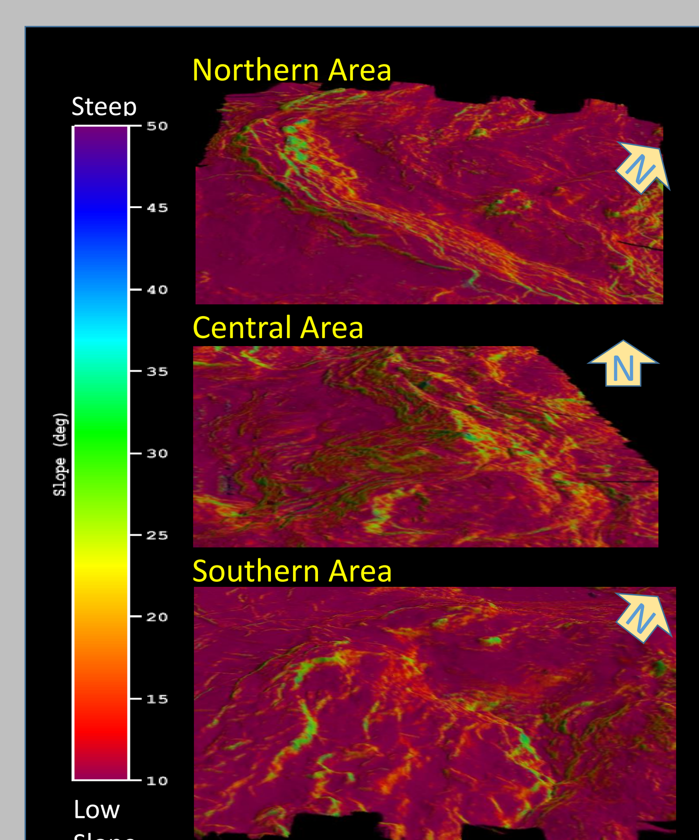
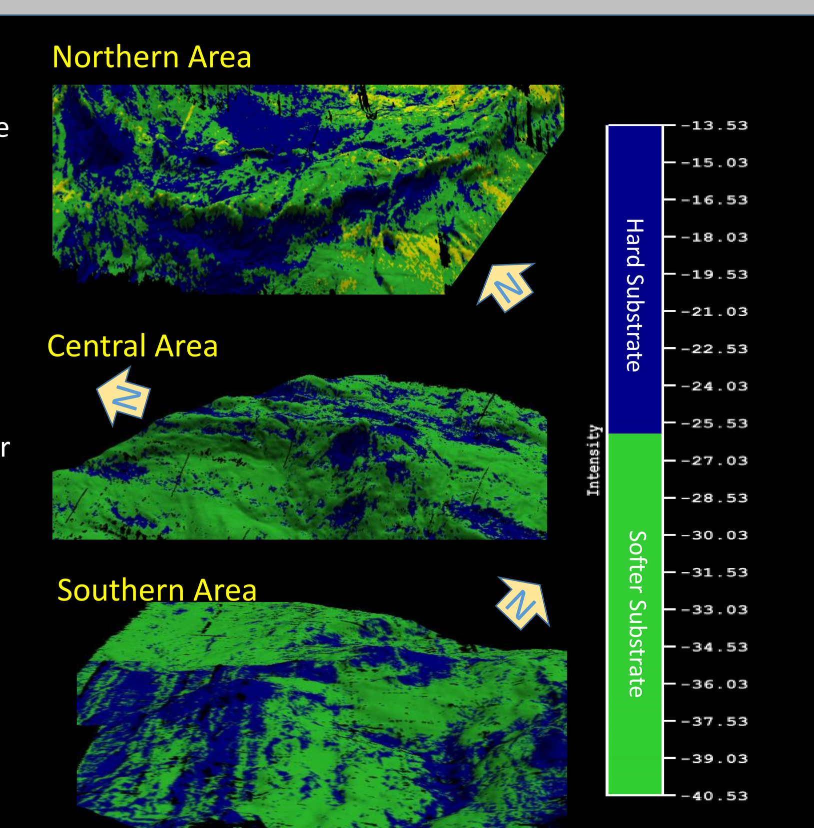


Figure 4. **Left)** 3D Slope surface draped over bathymetry for the three study areas, where yellow-green areas show the steepest areas.
Right) Draped 3D Classified Backscatter Intensity surface for where blue indicates the higher bottom return, suggesting harder substrate. Harder seafloor appears to relate to steepest areas.
VE=3x for all images.



DISCUSSION

Morphology of slope features indicates a fault-formed origin based on observed thrust-escarpments, seismic reflection data, and tectonic fabric expressed as general seafloor roughness on the BASE surface (Fig. 2, Fig. 4). The surficial expressions of numerous thrust escarpments, mud mounds, zones of shear deformation, and tension cracks is indicative of subduction zone faulting mechanics (Fig. 2, Fig. 3). Within these tension cracks (both micro- and macro-), sediments are deposited and are consolidated well enough so that they are still able to maintain the structural integrity of the slopes and cliffs (Ogawa, 1997). The tension cracks on this trench segment are related to open tensile failures from the SE-NW dominant stress-orientation in the region of this study. The mud mounds on this surface are tectonically derived based on comparative morphology (Fig.3, Fig. 7). The Pacific Plate is subducting beneath the Philippine Plate at an oblique angle, along with the numerous microplates bounded in the north and south (Ogawa, 1997). The multi-directional stress accumulates and results in an intricate series of micro- and macro- cracks that can be found on the many gentle slopes and steep cliffs of the Marianas (Ogawa, 1997). These features are the result of both compressional and tensional stress mechanics, and show the chaotic distribution of seismic activity here (Fig. 5). Slope profiles and backscatter intensity collected from the Northern, Central, and Southern sites illustrate the hard substrate that is exposed on the various thrust-escarpments (Fig. 4). This hard substrate is highly associated with the steepest gradients of the slopes, along with the upper most portion of the mud mound features (Fig. 4, Fig. 3). The roughness is most prominent on the slopes but can also vary on the mud mound features (Fig. 2, Fig. 6, Fig. 3).
In summary, the data collected from backscatter, slope, and profiles provide evidence that the features here are tectonic in origin, and the seafloor in this segment of the trench is highly susceptible to fault displacement and deformation through compression, tension, and subsidence. A more detailed seismic study should be conducted for this region in order to gain a better understanding of the distribution of tectonically derived versus volcanic features in the Marianas and where they may crop up in the future.

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