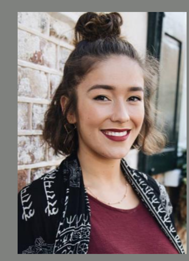
Geomorphologic Characterization of Recent and Pre-Existing Slump Features at Campeche Escarpment



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Abstract

In March of 2013, the Monterey Bay Aquarium Research Institute conducted bathymetric surveys along the Campeche Escarpment in the southern Gulf of Mexico, north of the Yucatan Peninsula. Multibeam sonar data were collected onboard the R/V *Falkor* and were post-processed using CARIS HIPS 10.2. The escarpment traces the platform of the Yucatan Shelf, which represents the closest Cretaceous-Paleogene (K-Pg) boundary outcrops to the 65 Ma Chicxulub impact structure. Consequently, Cretaceous landslides were generated along the length of the escarpment. The impact has already been proven to have caused the largest debris flow described on earth to date. The escarpment survey spans approximately 600 km in length, encompassing more than 80 submarine canyons, 3 of which are significantly steeper and wider. Associated slump features within numerous canyons were identified, as well as debris flows and other geologic indicators of slump failure. In this study, we characterize fifty of the submarine canyons using cross-channel profiles along each canyon's axis and measuring variations in channel width and symmetry at selected depths above the thalweg. The canyons showed a wide range of variation, but were quantitatively categorized into 3 distinct canyon types (A, B, C) based on width and slope. Additional investigations of the canyons along Campeche Escarpment would provide further understanding of the geologic history of the Gulf of Mexico.

Location of Campeche Escarpment

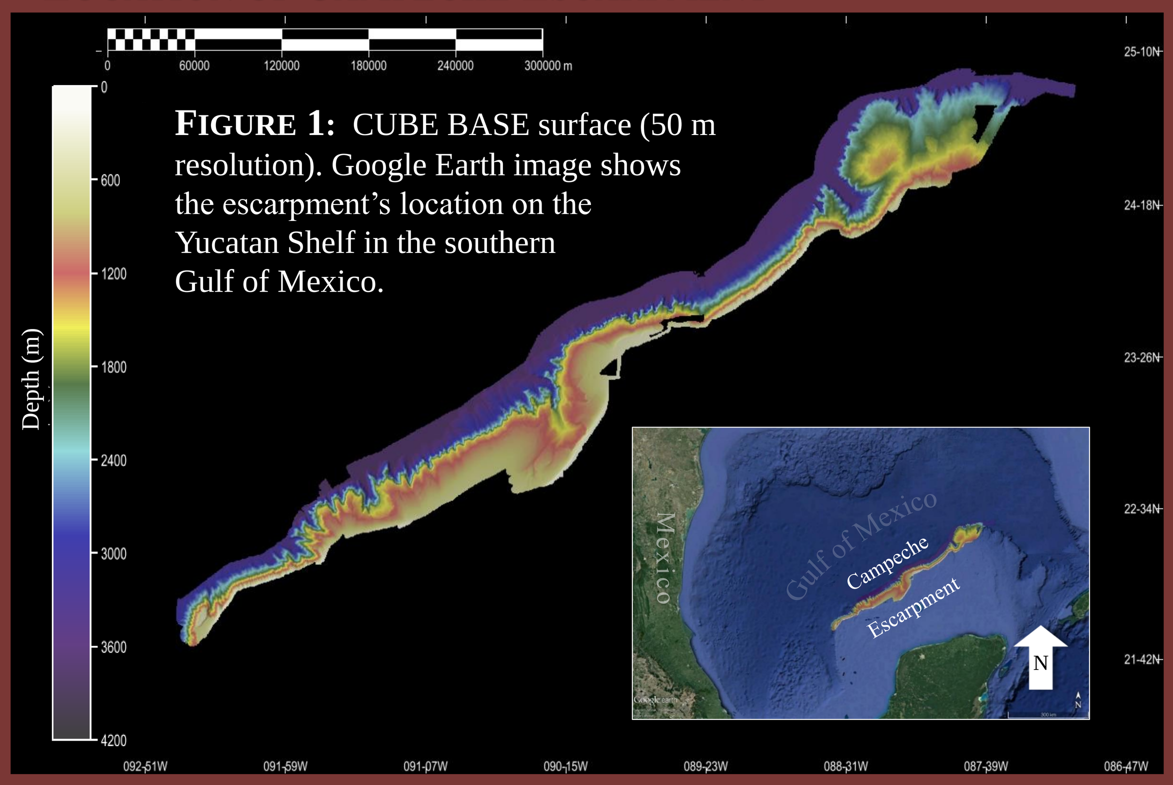


Figure 1: CUBE BASE surface (50 m resolution). Google Earth image shows the escarpment's location on the Yucatan Shelf in the southern Gulf of Mexico.

Methods

- Bathymetric surveys were conducted by the Monterey Bay Aquarium Research Institute (MBARI) on the Schmidt Ocean Institute's R/V *Falkor* with a Kongsberg EM302 and EM710.
- CARIS HIPS & SIPS 10.2 was used to post-process raw multibeam sonar data and render CUBE BASE surfaces at 50 m resolution.
- 3D images, contour maps, and profiles were generated, and slopes and distances were measured.
- 50 canyons were analyzed for the purpose of this study along the escarpment (Figure 3). Profiles were measured along the canyon axis (thalweg) from 1400 to 2600 m from the canyon head, and cross-sectional profiles were made perpendicular to the thalweg at 1400, 2000, and 2600 m from the canyon head (Figure 4; Figure 5). Cross-canyon profiles extended to the contour 200 m above the thalweg.
- Canyons types were determined using the data collected plotted onto scatter plots and visually, as well as by statistically categorizing the canyons into three types based on average canyon width, sinuosity, slope angle, and canyon symmetry (Figure 6).
- Canyon width and distance to canyon wall measurements were made for each cross-sectional profile at 200 m above the thalweg, and canyon wall slope was calculated for each profile using trigonometric functions (Figure 2).

Table 1.

Average Measurements	Type A n=27	Type B n=15	Type C n=8	ALL
	27	15	8	50
Width (m) for 3 Depths	1,365	2,671	5,259	3,098
X-X' Width (m)	1,485	4,295	11,857	5,879
Cross-Canyon Slope at X-X' (°)	16.0	7.5	1.6	8.6
Y-Y' Width (m)	1,255	1,929	2,087	1,757
Cross-Canyon Slope at Y-Y' (°)	19.0	15.0	14.0	16.0
Z-Z' Width (m)	1,354	1,787	1,834	1,659
Cross-Canyon Slope at Z-Z' (°)	15.0	15.0	15.0	15.0
X:Z Width Index Symmetry	1.2	3.1	8.5	4.3
Index Sinuosity	1.023	1.023	1.054	1.034
Canyon Axis Slope Angle (°)	11.1	13.5	12.6	12.4

Averaged canyon measurements for each canyon type.

Refer to Figure 2 for definition of measurements.

All statistics were calculated using Microsoft Excel

Results (Table 1)

- Canyon profiling shows a significant difference in canyon axis symmetry from X-X' (shallow) to Z-Z' (deep) as quantified by the X:Z index symmetry (Figure 4).
- Canyon type C has a greater variation in width from shallow to deep as seen by its index symmetry of 8.5.
- Canyon type C (5259 m) is nearly 2x wider than canyon Type B (2671 m) and almost 4x that of canyon Type A (1365).
- All 3 canyon types are fairly straight, with low sinuosity.
- The average canyon axis slope of the canyons quantified is 12.4°; canyon Type B has the steepest slope and Type A the lowest slope.
- There is a positive relationship between canyon width and cross-canyon slope, the wider canyons are flatter and the narrower canyons are steeper (Figure 5A).
- The correlation coefficient between the canyon width and cross-canyon slope at X-X' is 0.8, indicating a significant positive correlation between those variables.

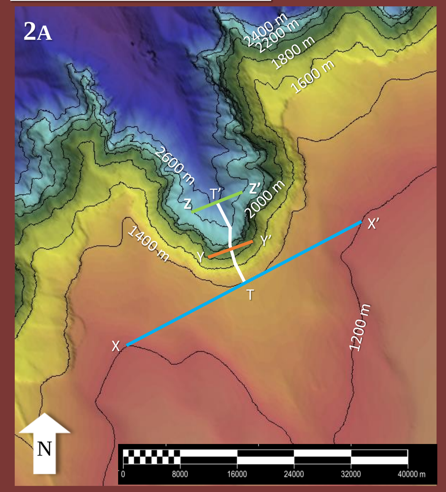
Acknowledgements

This research would not have been possible without MBARI and the crew of the R/V *Falkor* for collecting the data. Additionally, we would like to thank CARIS for Academic Partnership, and the support from the Department of Geology and Environmental Science and the School of Science and Mathematics at the College of Charleston. This project was conducted as part of the College of Charleston BEAMS Program.

Figures 2A-2C

Example profile with methods of measurement (Table 1).

Profile Locations

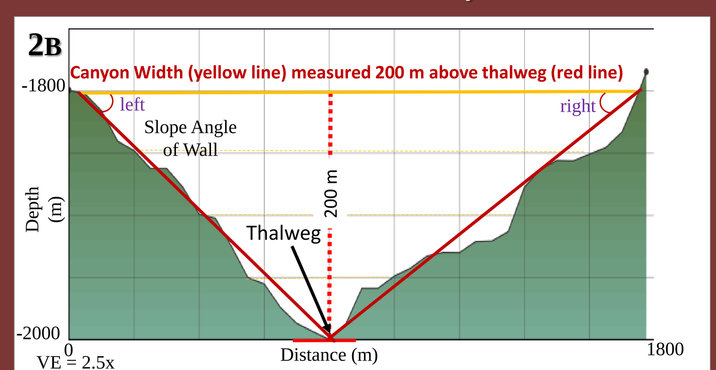


2A) Using contours at 200 m intervals, the T-T' **Canyon Axis Profile** was measured from 1400 to 2600 m. This line was measured along the canyon's **thalweg**. X-X', Y-Y', and Z-Z' **Cross-Canyon Profiles** were measured perpendicular to T-T' at the 1400 m, 2000 m, and 2600 m contours, respectively. These profiles spanned to the next (shallower) 200 m contour.
Example: the X-X' Cross-Canyon Profile (blue line) is perpendicular to T-T' at the 1400 m axis point and extends to the 1200 m contour on each side.

2B) Method for calculating Cross-Canyon Symmetry Index.

2C) Method for calculating Canyon Sinuosity.

Cross-Canyon Symmetry Index



Calculating Cross-Canyon Symmetry Index

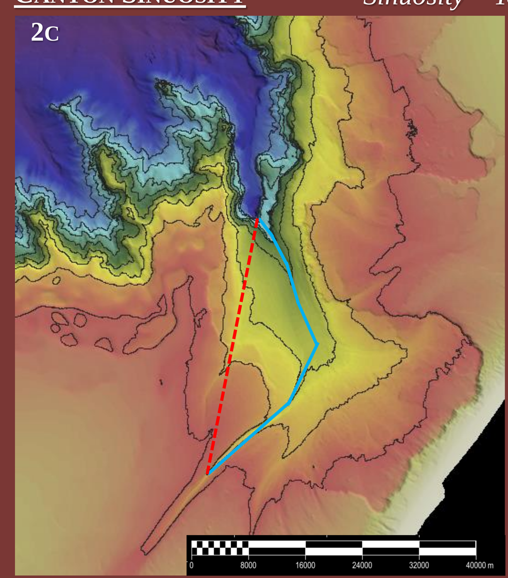
- The east and west slope angles were determined using trigonometry of right triangles.
- The Symmetry Index (SI) was calculated using the formula:

SI = left slope angle / right slope angle

Value interpretation

1.0 = Symmetric Canyon
> 1.0 = Left-Asymmetric canyon: left wall steeper than right wall
< 1.0 = Right-Asymmetric canyon: right wall steeper than left wall

Canyon Sinuosity *Sinuosity = Total Distance / Direct Distance*



Canyon Sinuosity
Index of canyon's curvature along the thalweg (Total Distance) relative to a straight-line distance (Direct Distance).

Total Distance: Distance from 1400 m contour to 2600 m contour—measured along the thalweg
blue line

Direct Distance: Straight-line distance from 1400 to 2600 m contour at the thalweg
red dashed line

Value interpretation
1.0 = Straight canyon
> 1.0 = Curved canyon (the greater the value, the more sinuous the canyon)

Discussion & Conclusion

Campeche Escarpment offers a unique opportunity to study a large number of morphologically distinctive submarine canyons along a single stretch of continental shelf. This study quantified 50 of the 80+ canyons, allowing the canyons to be quantitatively characterized into three canyon Types—A, B, and C. A number of factors were considered in the characterization. Quantitatively, the canyon Types were identified using the methods identified in Figure 2. Correlations between data variables were examined (Figure 5), and the canyons were separated into types based on their statistical groupings.

Type A Canyons are generally narrow and linear with relatively little variation in canyon width from shallow to deep. Of the three, Type A canyons had the steepest cross-canyon slope angles. There is a notable correlation between canyon width and cross-canyon slope angles—wider canyons are flatter, whereas narrower canyons are steeper (Figure 5A). These canyons were found to be grouped at each end of the study area (Figure 3).

Type B Canyons are the steepest of the three canyon types (Figure 6), and show more variation in cross-canyon width (width index symmetry of 3.1) (Table 1).

Type C Canyons were the most unique and least common of the three canyon types (accounting for only 8 of the 50 canyons) with the greatest difference in canyon width across the axis (index symmetry of 8.5) (Table 1). Type C canyons were both the widest and flattest of the three canyon types and, like Type B, were found scattered amongst the middle of the escarpment.

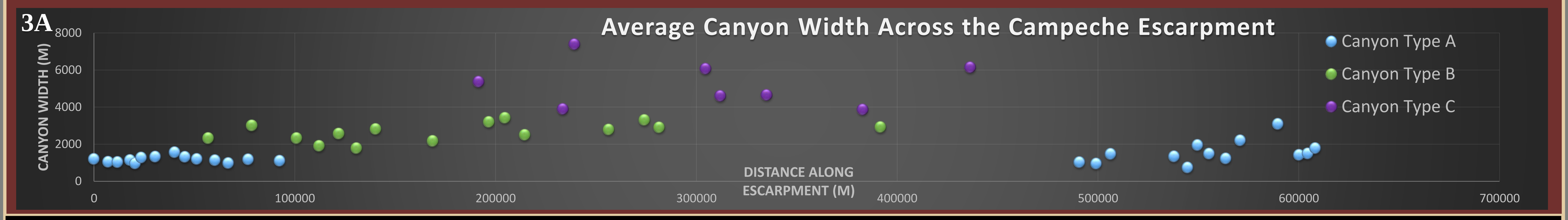
Further characterization of Campeche Escarpment submarine canyons would provide insight into the unique geologic history of the region. The statistical grouping and characterization of these prehistoric canyons could provide insight into past and future slump failure and other canyon hazards. Further studies could couple the statistical characterization of the prehistoric canyons with current hazard risk and provide further assessment that could translate to modern day risk assessment, allowing scientists to formulate and improve landslide risk mitigation and preparedness.

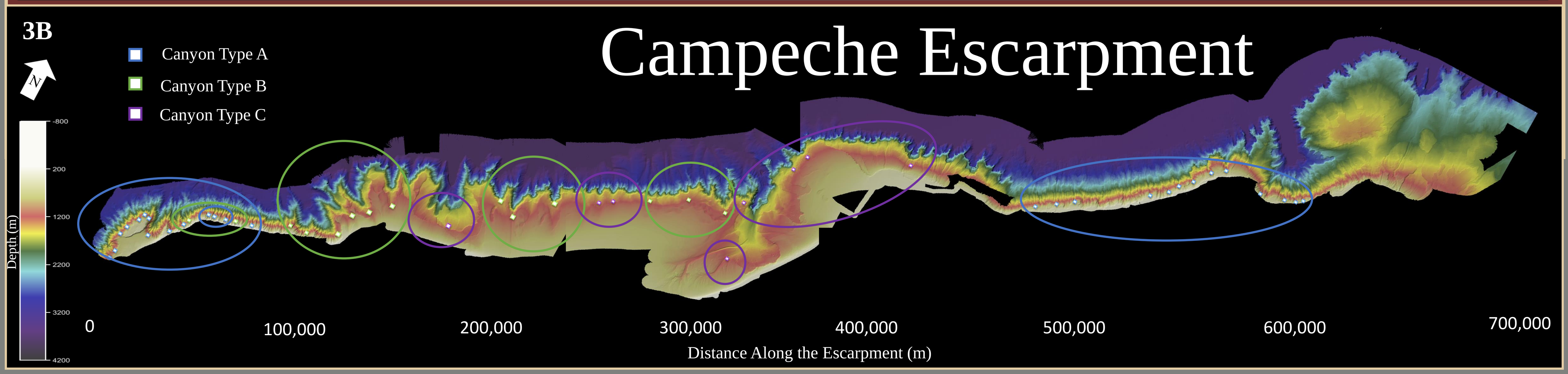
Background

The Campeche Escarpment forms the northern margin of the Yucatán Shelf in the Gulf of Mexico (Fig. 1). The escarpment is characterized by the 80+ submarine canyons found along its 612 km long continental slope. Although earlier studies identified only 15 of these canyons, the accuracy of the escarpment's characterization can now be improved as a result of newer high-resolution multibeam data used (Lindsay et al., 1975). The geomorphology of Campeche Escarpment is relatively unknown despite its proximity to the Chicxulub impact structure that is believed to have induced the large scale slope features found along the length of the escarpment. The most recent study by Tucker and Sautter (2017) applied a unique methodology for canyon characterization for three of the most prominent submarine canyons incised on Campeche Escarpment. Expanding on these methods, 50 canyons along the escarpment were examined and characterized quantitatively to determine differences in their geomorphology. Of the 50 Canyons, three canyon types were identified based on a number of quantitative elements examined in Figure 2. Type A, Type B, and Type C with 27, 15, and 8 canyons respectively. Characterizing the geomorphology of submarine canyons is crucial to understanding the geologic history of the region.

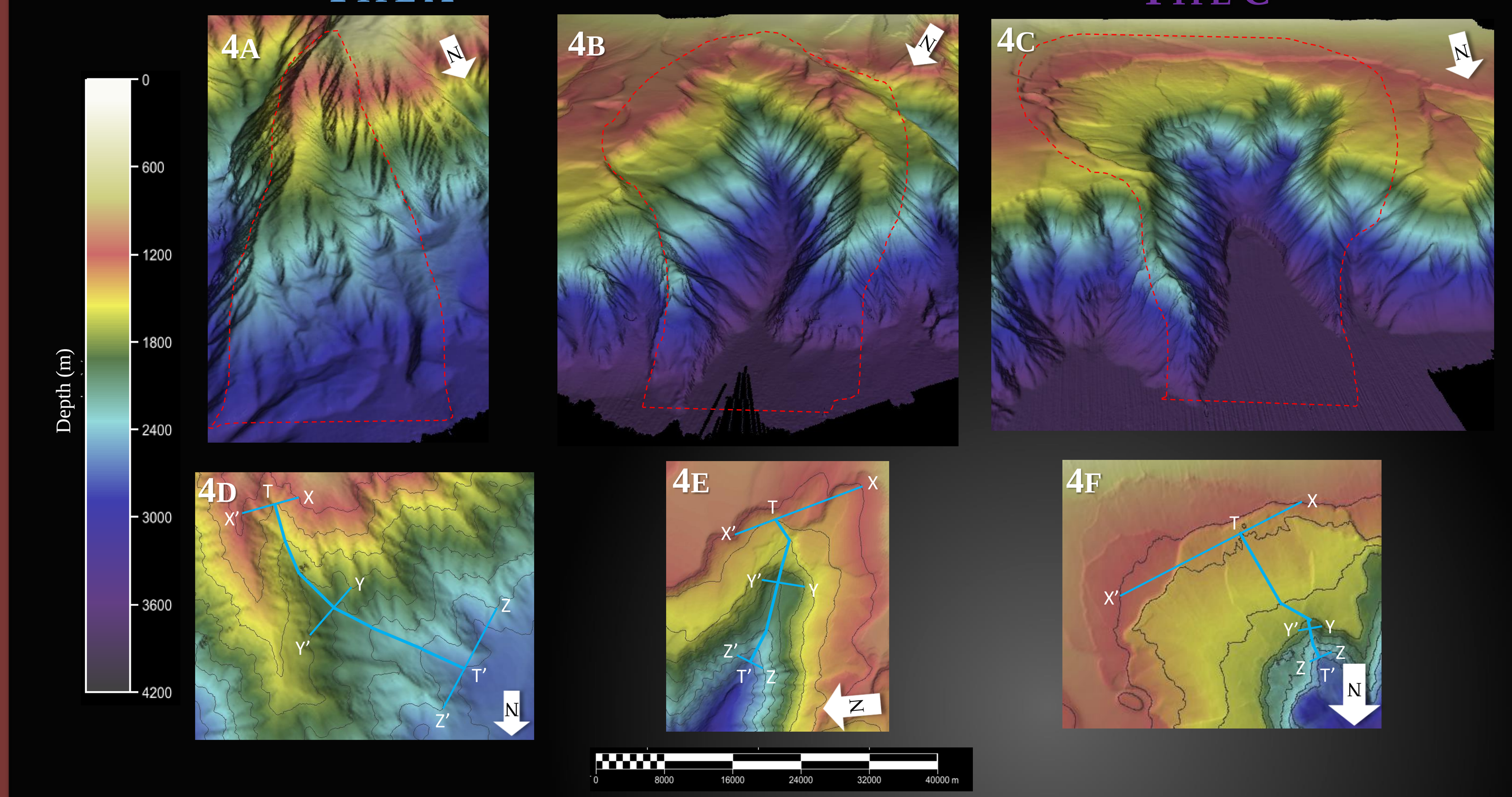
Figures 3A-3B

Average Canyon Width was calculated by averaging X-X', Y-Y', and Z-Z' width values for each canyon. Figure 3B shows the actual location of each canyon quantified in the study, shown with the same x-axis as Figure 3A. This figure illustrates the specific grouping of each canyon types A, B, & C.





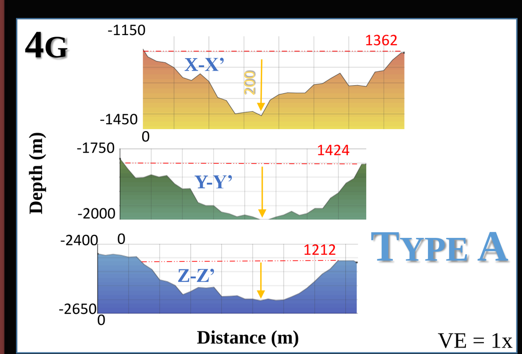
Figures 4A-4I

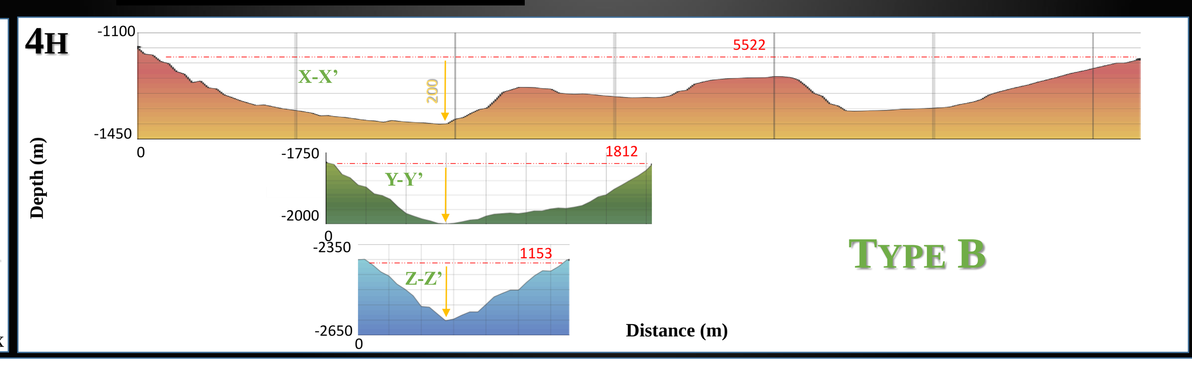


Figures 4A-4B: 3D images of selected canyons with 2.3x vertical exaggeration.

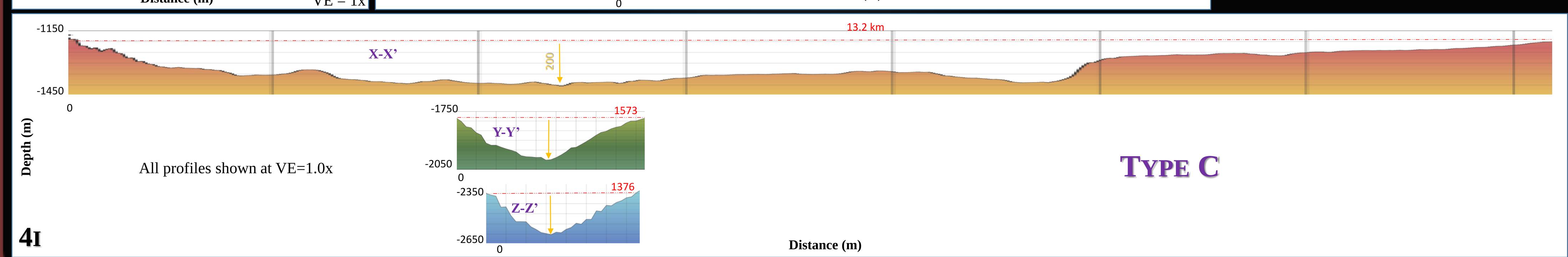
Figures 4D-4F: Contoured bathymetry with locations of along-axis profiles lines (Fig. 5) and cross-channel profiles lines.

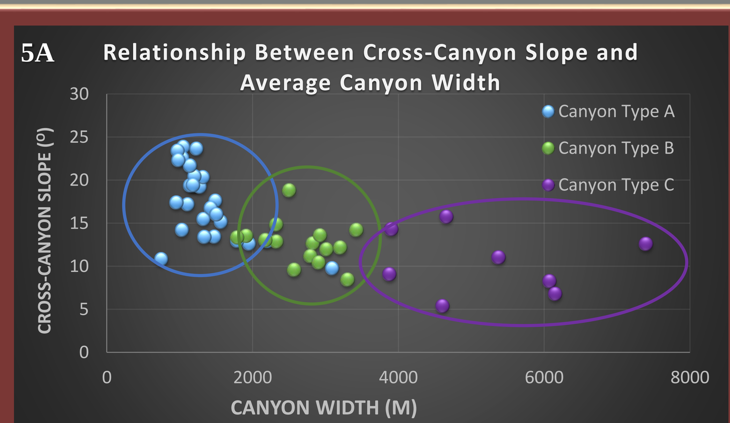
Figures 4G-4I: Cross-channel profiles for each canyon taken at depths of 1400 m (X-X'), 2000 m (Y-Y'), and 2600 m (Z-Z') at equal scales (i.e., no vertical exaggeration and aligned perpendicular to the thalweg. A yellow arrow points to the thalweg of each canyon, and a red dashed line is 200 m above the thalweg.



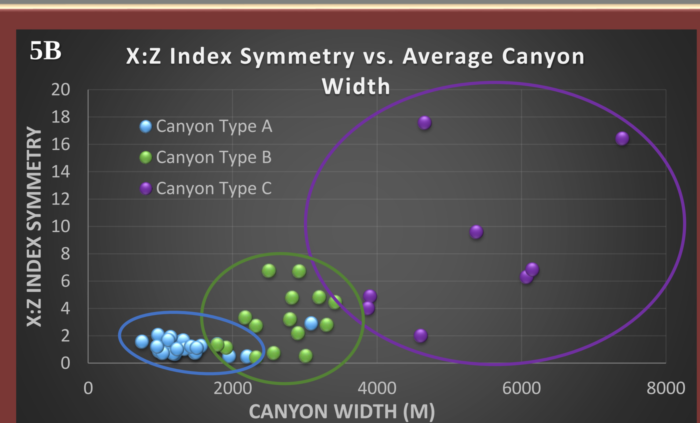


*Note these are three of the sampled canyons that best represent each canyon type (i.e., measurements were closest to the averages for each type).

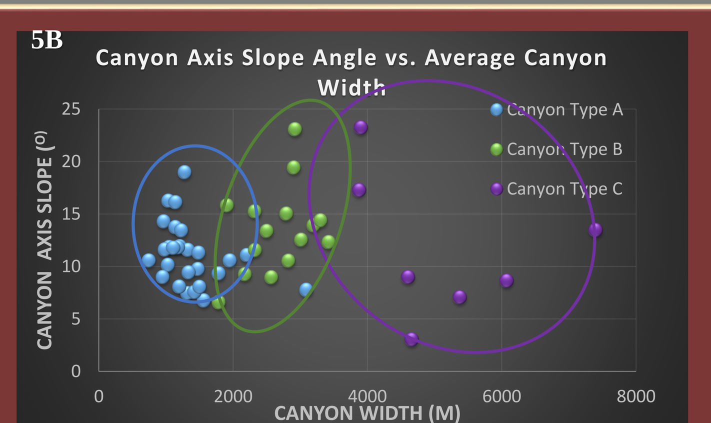




5A: An inverse relationship exists between Cross-Canyon Slope angle and average canyon width. Canyons with higher sloped walls are typically narrower canyons. (Refer to figure 2 for measurement methods.)



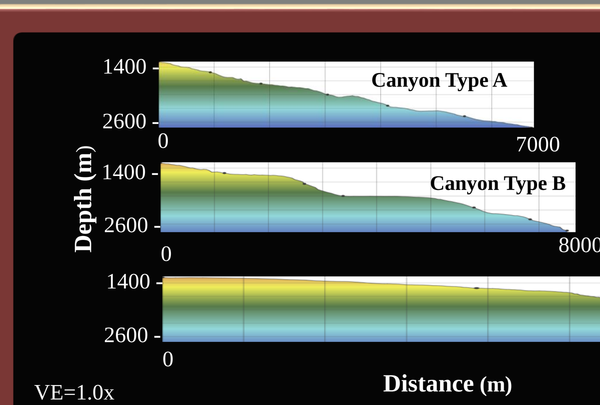
5B: Relationship between X:Z index symmetry and canyon width. The wider canyons (e.g. Type C) have a greater index symmetry, meaning the X-X' canyon width is significantly greater than the Z-Z' canyon width. Whereas the narrower canyons (e.g. Type A) have a lower index symmetry between X-X' and Z-Z'. These relationships are best observed by the profiles in Figure 4G-4I.



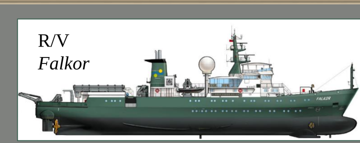
5C: The relationship between Canyon Axis Slope (T-T') and canyon width exhibits no direct correlation. However, there is a an observable difference between the canyon types. Type A canyons have a narrow range of axis slopes and narrow widths, whereas Type C canyons have a huge range of axis slope and are significantly wider than Type A. Type B falls in between.

Figures 5A-5C
Scatter plots showing the relationships among measured variables.

Figure 6.
Scaled profiles with no vertical exaggeration were measured along the axis (T-T') for each of the 50 measured canyons. An example axis is shown for each canyon type (A, B, and C). The Canyon Axis was determined by identifying the thalweg from contour maps (Fig. 2A). Refer to Fig. 4D-4F for profile line locations.



Three of the sampled canyons that best represent each canyon type.



References

Lindsay, J.F., Shipley, T.H., and Worzel, J.L., 1975, Role of canyons in the growth of Campeche Escarpment: Geology, v. 3, p. 533-536.

Tucker, W.S, and Sautter, L.R.. (2017, March). Campeche Escarpment Submarine Canyon Geomorphic Characterization. Poster session presented at the U.S Hydro 2017 Conference, Galveston, TX.