Grain Size on the Saipan Coast Across Varying Slopes and Distances from Shore

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Abstract

Submarine topography affects sediment transport, deposition, and benthic habitats by influencing erosion and current flow. This study investigated a correlation between sediment grain size and submarine slope, and correlation between grain size and offshore distance. The hypothesis was that average grain size would be larger at locations closer to shore and with steeper slopes. Sediment samples were collected over an 11-day research cruise at five Western Saipan stations with various bathymetric slopes and offshore distances. Seafloor topography was mapped using ship-mounted multibeam acoustic sensors, and sediment samples were dried, sieved into seven grain-size categories, and analyzed by percent weight distribution. Average grain size (microns) at each station was compared to both seafloor slope and distance from shore. After weight distributions were calculated, a linear regression test determined statistical significance. Overall trends suggested areas with steeper slopes contained larger grains, with the steepest slopes of 9% and 12.5% containing the largest sediment, averaging 940 and 760 microns, respectively. Locations farther from shore also contained finer grains, with the farthest site at 15.63 km averaging 225 micron grains. Although the graph showed correlation, the hypothesis could not be confirmed because the results lacked statistical significance, with a p-value of 0.27 for grain size and slope, and 0.26 for grain size and distance from shore. Although the study was unable to confirm that slope or distance from shore affects sediment grain size along western Saipan, it provides initial observations of deposition patterns in a region where few previous studies have been conducted.

Plain Language Summary

The slope of the ocean floor plays a significant role in how sediment settles at the bottom of the ocean. Steep underwater hills can experience stronger erosion, and sediment may not settle there as easily. Flatter areas, on the other hand, may allow for the accumulation of finer sediments. Understanding these patterns is important because sediment size and composition influences marine habitats, nutrient cycling, and the potential for these underwater hills to erode.

This study analyzed whether steeper seafloor slopes along the western coast of Saipan are associated with larger sediment grains. Over the course of an 11-day research cruise, sediment samples were collected from five locations with different slopes and distances from shore using a sediment grab sampling claw. The samples were then dried out and sifted into eight grain size categories using a sieve machine, and the average grain size was calculated and compared to both slope and distance from shore.

After compiling graphs featuring a trendline comparing slope to average grain size and distance from shore to grain size, the graphs showed that locations with steeper slopes and areas closer to shore generally had larger grains, with sediments being composed of different materials, including shell fragments, halimeda, and coarse sand. Flatter locations and areas farther offshore also had finer sediment. However, statistical tests showed that these relationships were not strong enough to confirm a correlation between these factors, meaning that although the hypothesis that steeper areas closer to shore have larger grain sizes is not explicitly disproven, observed trends may have occurred by chance due to the sample size, and a relationship could not be confirmed. Because very few studies have examined sediment patterns within this region of Saipan, this project provides useful observations and establishes a foundation for future research with larger sample sizes and more controlled measurements.

Introduction

The topography of submarine landforms has a significant impact on many submarine processes such as circulation, sediment transport, and the success or failure of benthic ecosystems. Because submarine structures interfere with underwater current flow, the shape the structures take can be significantly impacted by the flow patterns they cross, generating eddies and internal waves, and altering currents. These variable currents can erode significant amounts of sediment, creating unique geological formations with changing topography, including the gradient of the slope. The shape of underwater hills and valleys controls sediment thickness, grain-size, and benthic habitats. Previous studies have shown that slope topography controls sediment deposition patterns, with steeper slopes often containing coarser sediments because finer particles are more easily eroded or transported away (Du et al., 2020). Steeper slopes are generally known to be more unstable, with landslides occurring more easily (Hance, 2003). Bathymetric data also showed that slope gradients and current focusing can affect sediment deposition and inhibit a significant amount of accumulation on steep slopes, especially with finer grains that are easier to erode. This sediment failure limits long-term accumulation of all sediment sizes compared to nearby shallow-grade basins. Nearshore sediment studies have also demonstrated that grain sizes generally become coarser closer to shore, while finer sediments are transported and deposited farther offshore (Miller and Zeigler, 1976). These studies suggest that finer sediments often bypass steep slopes, while flatter areas act as depocenters, leading to coarser sediment size averages along the steeper areas. Du and Hance have demonstrated that bathymetric slope has a direct influence on grain-size sorting and thickness distribution, with larger grains dominating steeper slopes. Although this study focuses on sediment transported from shore, one variable factor affecting sediment size is the source. Biogenic sediments are often larger than sandy sediments, and if they originate from marine organisms, they do not need to be transported by currents in order to make it away from shore. Furthermore, tropical Pacific islands, including Saipan, have nearby coral reefs, which tend to produce a large amount of biogenic sediment (Ainesi, 2024). Necessary background information about sediment thickness and grain size along submarine slopes is provided, but there is a lack of studies focused specifically around the western side of the island of Saipan, which is why this study focuses on Saipan, as well as the various topographical features nearby. The western side of Saipan exhibits varying slopes that contain a mixture of gradual and steep features, as well as U-shaped basins, which makes it an ideal area of study. These contrasting landforms provide a wider range of topographical scenarios, with both flat and steep slopes. This topography is useful for determining if depositional patterns align with the expectation of larger grain size averages occurring on steeper slopes and closer to shore. Limitations of this study included the short, 11-day timespan of the research cruise and the time-consuming process of running a sediment grab, which restricted the number of sampling locations. Additionally, deposition is influenced by many environmental factors, including currents, at-sea biological sediment production, and volcanic material, which may have affected the observed grain-size patterns by travelling in patterns other than the traditional “shore to sea” transport. It is important that we understand these relationships because sediment thickness and grain-size affect benthic habitats, nutrient cycling, and geohazard potential such as submarine slope failure. Identifying how slope controls sediment accumulation will allow us to improve our predictions of seabed evolution, support marine spatial planning and infrastructure development, and allow us to better anticipate ecological responses to changing oceanographic conditions.

This study addresses the question: How is the grain size of deposited sediment correlated to the slope of underwater topographical landforms? My hypothesis is that locations with steeper slopes will be bypassed by smaller sediment grains, resulting in larger sediment size averages that require higher amounts of energy to transport, whereas gradual slopes will allow finer sediment to settle due to higher gravitational transport in the steeper areas. If the hypothesis holds true, I expect my graph to resemble a positive relationship between sediment size and seafloor slope.

Methods

Data were collected during an 11-day research cruise in the Western Pacific along a transect off the western coast of Saipan. We used a ship-mounted multibeam system to image the seafloor, allowing us to determine submarine slope by calculating the ratio of distance between adjacent stations and depth increase or decrease. The slope calculated from the multibeam data was complemented by previously mapped bathymetric data from the same area, confirming the accuracy of the calculated slope. The sampling transect was located just to the west of Saipan, beginning at (15.232 ° N, 145.571° E) and ending at (15.215° N, 145.628° E), with sediment grab locations at (15.232° N, 145.571° E), (15.225° N, 145.595° E), (15.221° N, 145.610° E), (15.217° N, 145.621° E), and (15.215° N, 145.628° E) (Figure 3). Each sampling location is assigned a station number, ranging from 35-39, listed above sequentially. The bathymetric topography across this transect fluctuates between no slope, gradual slope, steep slopes, and small U-shaped basins (Figure 4). Using the sediment grab, we collected samples from the bottom to be examined for composition and grain size (Figure 5). The sediment grab was sent down at five locations as described above.

After all five sediment samples were collected, they were dried out in a 60° C oven and measured out at approximately 30 grams each, as that was the weight of the smallest sample, and a fair test would use the same amount of sediment from all stations (Figure 6). They were then run through a sieve machine that sorted the grains by size and assigned them to a corresponding Phi (Φ) value. The largest size classification was 2000-4000 microns (-2 to -1 Φ), followed by 1000-2000 microns (-1 to 0 Φ), then 500-1000 microns (0-1 Φ), then 250-500 microns (1-2 Φ), 125-250 microns (2-3 Φ), 62-125 microns (3-4 Φ), 31-62 microns (4-5 Φ), and finally, 0-31 microns (5+ Φ). A category for sediment larger than 4000 microns was present on the sieve machine, but the samples did not contain any sediment that large. After the sediments were sorted, they were analyzed to determine what percentage of the total weight fell within each size classification, with an average Phi value being calculated from each sample. That Phi value was then converted into a single average grain size in microns.

Statistical analysis involved plugging the data into R Studio to calculate a line of best fit using a linear regression model and a significant p-value of 0.05, which determines the presence or absence of correlation. There may be some uncertainty in the exact submarine slope at a given location, so horizontal error bars are included to demonstrate potential variability between calculated slope and actual slope. One concern that may affect data quality is varying distance between sampling location and the source of the sediment. Locations further from the shore are expected to have finer grains simply due to being more easily transportable, causing larger grains to be deposited before it has a chance to reach the sampling location. Separate figures will indicate distance from the source compared to grain size.

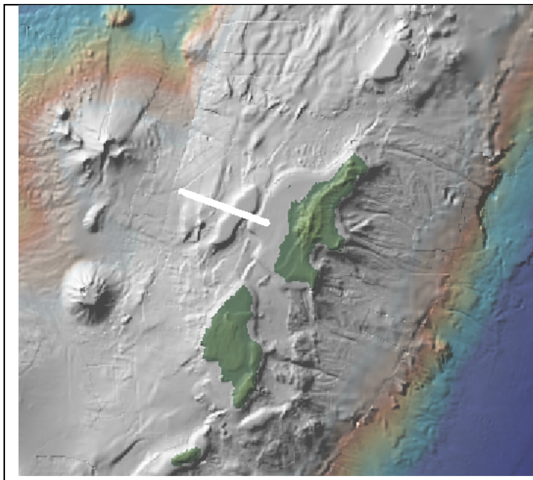

Figure 3. Sampling transect off the west coast of Saipan, ranging from Station 35 (15.232° N, 145.571° E) to Station 39 (15.215° N, 145.628° E).

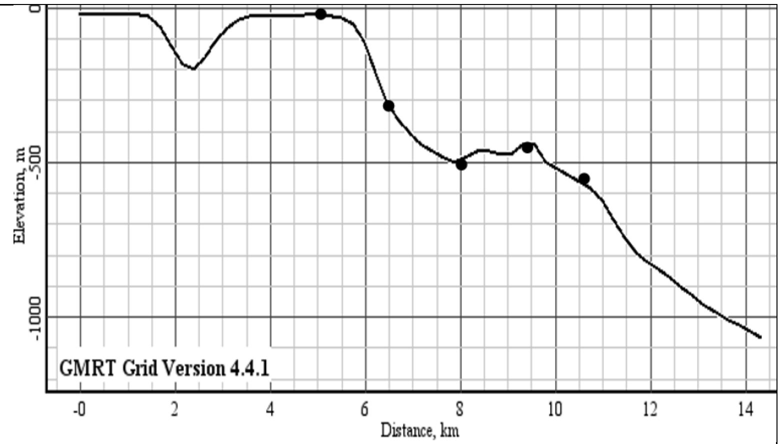

Figure 4. Bathymetric plot of sampling transect shown in Figure 3. Sediment grab locations are indicated by black dots. The leftmost dot is Station 39 and increases to Station 39 on the right.

Figure 5. Sediment inside the sediment grab claw immediately after being brought up from the seafloor at Station 39.

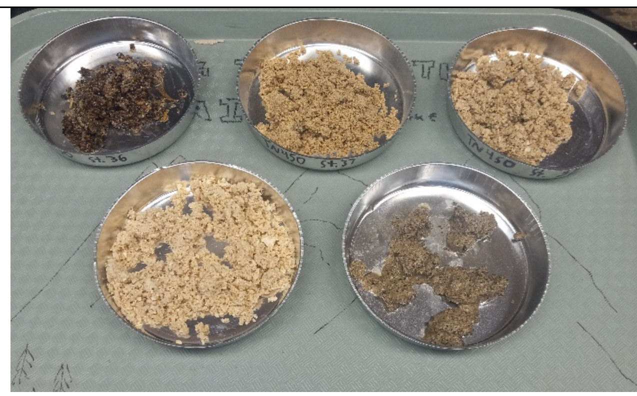

Figure 6. Sediment samples inside the lab after drying. Sediment on the top left is from station 36, top middle is station 37, top right is station 38, bottom left is station 39, and bottom right is station 35. Composition of each sample is described below in results section.

Results

One station, located at (15.232° N, 145.571° E), had a flat slope, and resides 15.63 km from the shore. The sediment sample pulled from this station was dark brown, fine-grained with small chunks of basalt. The sieve results showed 22.52% of grains between 31 and 62 microns, with percentages decreasing as grains got larger or smaller, with the largest grains fitting in the 2000-4000 micron category (0.37% of sample), and the smallest grains fitting in the 0-31 micron category (13.67% of sample) (Figure 7, Figure 8).

Another station, located at (15.217° N, 145.621° E), also had a flat slope, and was 10.10 km from shore. It had some fine and medium sand, but was overall on the coarser side, with a lot of biogenic sediment, such as broken halimeda. It also contained a small amount of basalt chunks. Sediment at this location was distributed more evenly, with 23.1% of the sample sitting between 125 and 250 microns, and slightly less (between 17.03% and 21.31%) ranging from 500-2000 microns. 11.57% of the sample was in the 62-125 micron range, with a very small percentage of grains exceeding 2000 or falling below 62 microns.

A third sampling location was located at (15.221° N, 145.61° E), had a 3.4% slope gradient (mostly flat), and was 11.38 km from shore. This sample contained dark tan sand of fine to medium size, and was overall fairly uniform. The most abundant size at station 37 was 62-125 microns, with 45.12% of the sample fitting within that category. The 125-250 micron range also had a fair amount of sediment, weighing in at 31.38% of the total sample weight, for a total of 76.5% of the entire sample fitting in these two categories. All other categories contained less than 7% of the total sample weight.

A fourth station was located at (15.215° N, 145.628° E), and had a slope of 9%. It was 9.41 km from shore. This sample was light tan with pink grains and coral fragments, and it had medium to coarse sand with a significant amount of large shell fragments, halimeda, and other biogenic particles. The most abundant size range in this sample was 250-500 microns, with 33.45% of the sample falling within that range. A significant amount of sediment was sized at 500-1000 microns, 125-250 microns, and 62-125 microns, with sediment weight percentages of 23.5%, 26.3%, and 10.72%, respectively.

Finally, the steepest slope was located at (15.225° N, 145.595° E), had a gradient of 12.5%, and was 12.97 km from shore. It contained coarse chunks of dark brown matter, much of which appeared to be a mixture of angular material, coarse sand, and long thin grains. Much of this sample appeared to be biogenic. 51.65% of this sample fit within the 500-1000 micron size category, with percentage of sample within each category decreasing significantly on either side of that category. 0.85% of total sediment weight was above 2000 microns, and 1.8% of total weight was below 31 microns.

After plotting percentages of sediment weight in each size category, I was able to calculate an average size at each station and its corresponding slope. Station 35, with a slope of 0, averaged out at 225 microns. Station 36, which had a slope of 0.125, had an average size of 760 microns. Station 37 had a slope of 0.034 and a mean grain size of 217 microns. Station 38 had a slope of 0, and its average grain size was 700 microns. Station 39, with a slope of 0.09, had a respective average grain size of 940 microns (Figure 9). Similarly, I compared average grain size to the distance from shore each sample was taken (Figure 10).

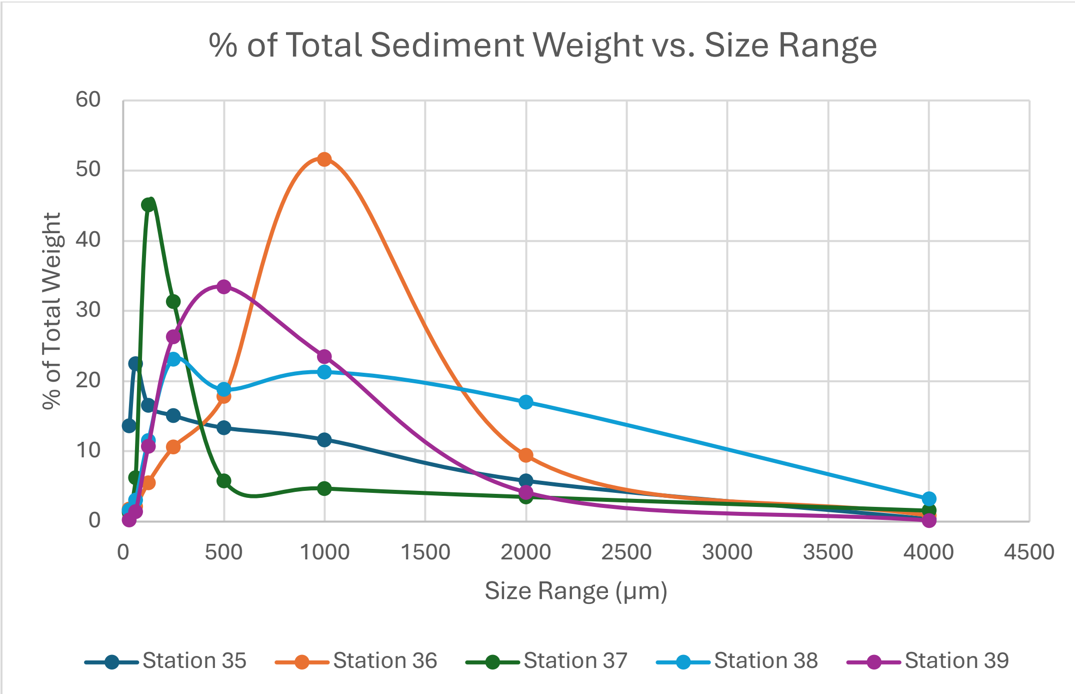

Figure 7. Percentage of total sample weight falling under each size classification, with each station represented by different colors.

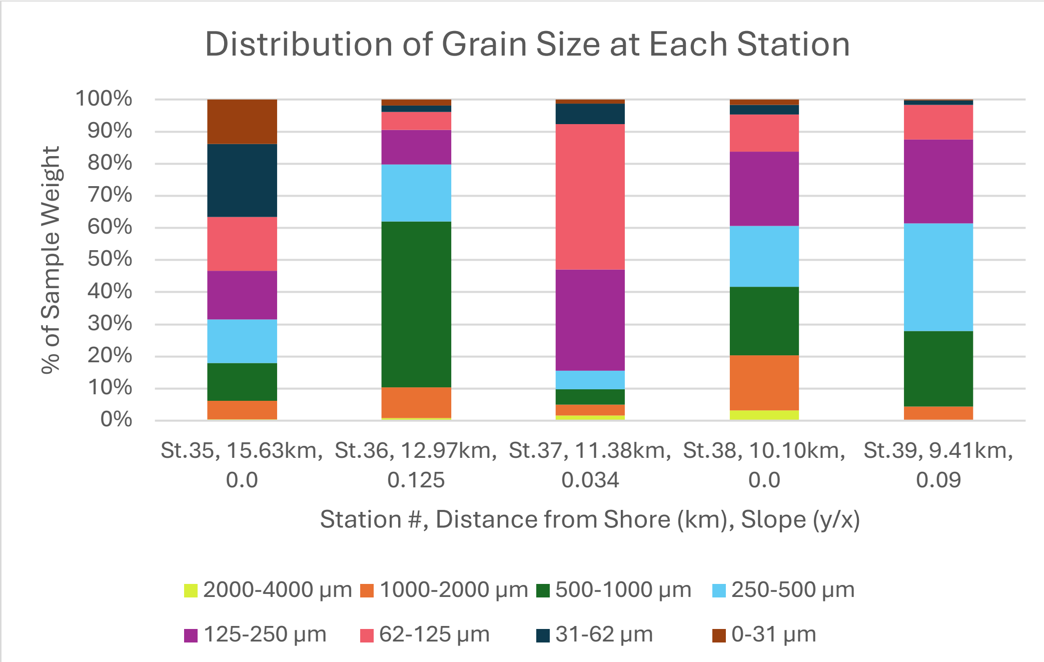

Figure 8. A representation of how abundant each grain size category is at each station. Each bar represents a station, with distance from shore and slope also included. Each color represents a size category, and all size categories add up to 100% of total sample weight at each station.

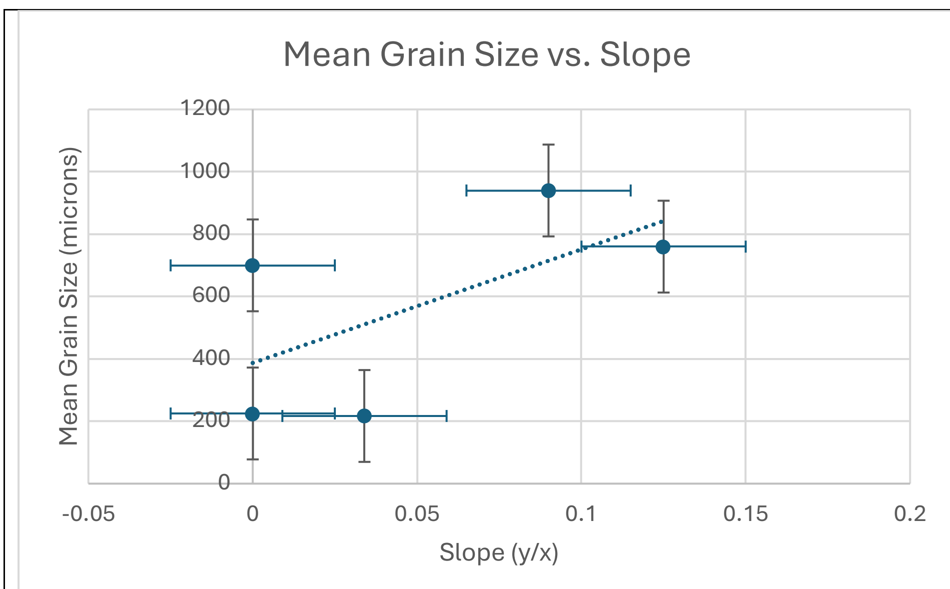

Figure 9. Average grain size compared to submarine slope.

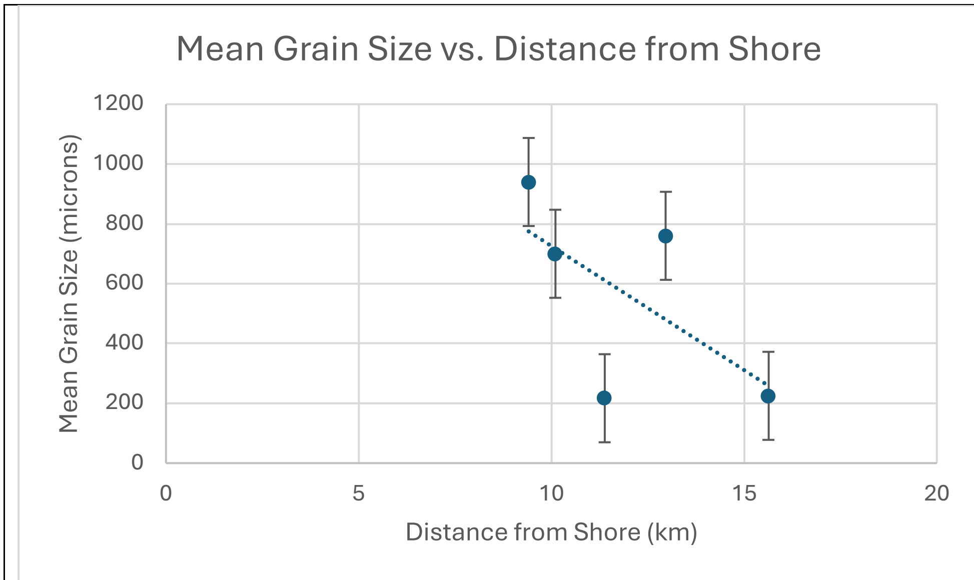

Figure 10. Average grain size compared to distance the sample was taken from shore.

Discussion

Stations with the steepest slopes, particularly stations 36 and 39, contained an average grain size that was substantially larger than stations with a flatter seafloor. Alternately, stations 35 and 37, which had flat bathymetry, were overall dominated by finer sediment sizes. Even though there was significant variation in the average grain size between these two stations, they both had smaller grains than the steeper sloped stations 36 and 39. After running a statistical test on the data, statistical significance suggesting a correlation between slope and grain size, as well as distance from shore and grain size, was not present. The trendline for the relationship between grain size and seafloor slope appears to have a correlation, but there is not enough confidence to confirm it. A linear regression test on this data suggested a p-value of 0.27, which is not statistically significant against a threshold of 0.05. Although the trend in this data appears promising, there is not enough evidence to confidently rule out the null hypothesis, suggesting that it is still possible for seafloor slope to have no effect on grain size. The primary reason for this is likely because not enough data was collected. If the sample size is too small, the odds increase significantly of a trendline looking a certain way by chance, rather than actual statistically significant correlation, even when the trendline is very steep.

The relationship between grain size and distance from shore had a similar issue. The line of best fit suggested that stations that are farther from shore have smaller grains, while the stations closer to shore have larger grains, which would be in support of my hypothesis. However, the p-value of this test was 0.26, which is also not statistically significant when compared to a threshold p-value of 0.05. It would make sense that larger grains are closer to shore because they cannot be carried as easily by the currents, causing them to be deposited closer to the source at which they originated than smaller grains that are easier to transport, as it is a result of required current velocity to transport sediment. (Hu, 2023). However, the data collected in this study was unable to confirm that there is a relationship between grain size and distance from shore along the west coast of Saipan. Again, I believe the main reason for this is an insufficient sample size, as the odds of this correlation occurring by chance are too high.

To improve this study, I would run two separate experiments. The first would test for a correlation between slope and grain size, but all samples in this test would be as close to an equal distance from shore as I can get, giving us a more accurate estimate of how grain size is correlated slope alone. The second would examine grain size compared to distance from shore, and the slope at all sampling locations would be zero. I would collect 20 samples for each test, or 40 samples total. This would provide more controls and more sample data.

Differences in sediment composition may also explain some of the variability between stations. Station 38, which had a flat slope, contained a significant amount of biogenic sediment compared to the others, with material such as shell fragments and halimeda. These carbonate sediments likely accumulate differently than the sandy sediments, as the sand originates from the shore, but the biogenic sediment is produced locally from marine organisms in the water column. This abundance of biogenic sediment drove up the average grain size, contributing to larger grains on a slope that was expected to have smaller grains. These differing sediment sources may obscure patterns that would otherwise exist between slope, distance from shore, and grain size. Additionally, the presence of volcanic basalt fragments indicates that the sandy samples originated from multiple sources, including the weathering of coastal rocks and the eruption of volcanic material, potentially influencing the depositional environment in ways that were not addressed in this study.

Conclusion

This research project studied the relationship between sediment grain size and submarine slope, as well as the relationship between grain size and the distance from shore at which the sample was taken along a transect off the west coast of Saipan. Using bathymetric data and sediment grain-size analysis from five sediment grab sites, the study aimed to understand whether or not steeper submarine slopes are related to coarser sediment sizes. My hypothesis predicted that finer, easier transported grains would be transported away from steeper slopes via erosion and currents, leaving behind the coarser grains and resulting in larger grain size averages in areas with a steeper slope.

The results displayed some qualitative patterns that appeared to support hypothesis. Stations with steeper slopes generally contained coarser sediment composed of medium to coarse sand, as well as biogenic material such as shell fragments and halimeda, while flatter stations contained finer sediments. This aligns with previous research, suggesting that steeper submarine slopes may experience stronger sediment transport and bypass from finer material, while flatter areas may provide depositional environments that support the accumulation of finer sediments without a significant amount of erosion. However, statistical analysis did not demonstrate a significant relationship between slope and grain size or between distance from shore and grain size. Linear regression analysis on each relationship produced p-values of 0.27 and 0.26, respectively. Because both values exceed the significance threshold of 0.05, the observed relationships, although they appear to be correlated when mapped out on a graph, are not statistically significant, and cannot confidently confirm the hypothesis that submarine slope and distance from shore controls sediment grain size off the west coast of Saipan.

The lack of statistical significance is likely due to the multiple factors affecting grain size, such as sediment source and complex currents. The required time to collect one sample compared to the amount of time available to complete data collection was also off, forcing the sample size to be lower than desired. A larger sample size would produce a result that could more confidently rule the null hypothesis in or out. Secondly, multiple factors appear to influence sediment distribution along the Saipan coast in addition to slope and proximity to shore, such as sediment source, biological sediment production, and volcanic eruptions. For example, Station 38 exhibited coarse sediment despite having a flat slope, and it contained a considerable amount of halimeda and other large shell fragments suggesting that local biogenic input may have strongly affected grain sizes independently of bathymetric topography.

Overall, this study did not provide enough evidence to suggest that seafloor slope and sampling distance from shore influences sediment particle size, but qualitative trends suggest that there may be an association between steeper slopes and larger grain sizes, as well as sampling locations closer to shore providing larger grains. If a relationship is present, it can be confirmed in future studies using larger sample sizes. Although no statistical significance was found, this study still contributes valuable observations about sedimentation patterns along the western coast of Saipan. No previous studies have specifically examined the relationship between submarine slope, distance from shore, and sediment grain size in this sampling area. The data collected here provides a foundation for future experiments and demonstrates the various environmental factors interacting with each other when studying marine sedimentary deposition patterns.

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