Seafloor terrain and sediment characterization at Molokaʻi, Lōʻihi, and Cross Seamount via seafloor mapping

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Non-Technical Summary

The seafloor around Hawaii has a wide range of terrains, dominated by many different processes of sediment erosion and deposition. An important question to be asked is: How do such processes affect the seafloor terrain and in turn how does the terrain affect the type of sediment that is found in those regions. Is there an observable relationship? Research conducted between 27 Dec. 2010–4 Jan 2011 in Hawaii, at Molokai, Loihi, and Cross Seamount, combined seafloor mapping with sediment analysis to provide a comparison of different sediments over different terrain characteristics. The sediments from the sampling locations were dominated by a range of sediments, from coarse grained sands to very fine grained clays. The distributions of sediments were compared with the bathymetric terrain, whether samples were taken in valleys or on ridges over given slopes in the terrain, at both small and large scales. When comparing the results there was no evident relationship between sediment and either terrain characteristic, this could be a result of the limited number of sampling locations. Without further study the effects of seafloor terrain on sedimentation cannot be predicted via these methods.

Abstract

The seafloor around Hawaii has a wide range of terrains, dominated by many different processes of sediment erosion and deposition. Cross Seamount, Loihi, and the canyons north of Molokai are each governed by different sedimentation processes which lead to different patterns and types of seafloor terrain and sedimentation found in the regions. Research was conducted aboard the R/V *Thomas G. Thompson* using seafloor mapping via Kongsberg Simrad EM302 30-kHz Multibeam Echosounder, data analysis via Caris® and ArcGIS, surface sediment sampling by Shipek grab sampling and sediment grain-size analysis using a process of sieving and sedigraph studies. A total of ten locations were sampled, four at Molokai, three at Loihi and two at Cross Seamount; an additional location at Loihi did not return sediment. ArcGIS analysis produced values for slope and bathymetric position index (BPI) over both large and small scales. Sampling locations dominated by sands, 1mm–63µm in diameter, had slope values ranging from 10°–34°, while locations dominated by clays, diameters smaller than 4µm, had slopes 11°–31°. All sediment types were found over locations classified as ridges, valleys, slopes, and flat regions based on the BPI. There was no significant correlation between sediment grain-size and terrain characteristics. Without further study, consisting of more sampling locations over a wider range of bathymetric features and terrain characteristics, this method of bathymetric sediment and terrain analysis cannot accurately predict sediment type.

Introduction

The seafloor is an integral component in the oceanic system; it governs the physical, chemical, and biological characteristics of a particular location. Knowing and understanding such processes helps in not only understanding the ocean but also in understanding how human activity impacts the ocean and the ecosystem. Based on what is known about the geological processes occurring in the region, hypotheses of the kinds of sediment characteristics of the seafloor can be made, but proving those predictions true becomes more difficult. Most of what is known of the seafloor is based on remote sensing and not on actual sampling, since remote sensing is more readily available and easier to obtain (Herzfeld and Higginson, 1996). If seafloor mapping and analysis can be applied costly, time consuming, laborious, and often, destructive sampling methods can be avoided and more of the seafloor will be accessible for study (Simons and Snellen 2009).

Applications of seafloor mapping data have resulted in studies that produced maps and data that were analyzed by human interpretation to determine the types of terrain corresponding to the variances in data. USGS surveys conducted using GLORIA sonar systems in the Hawaiian Exclusive Economic Zone (EEZ) were interpreted by Robin Holcomb to produce a hypothesized view of the distribution of seafloor terrain, but without more extensive sampling done in these regions many of Holcomb’s projections are only speculations (Holcomb 2004). With developing technology, new methods of studying bathymetry for terrain and habitat characterizations have developed. In American Samoa, bathymetry studies utilized multibeam mapping, visual data, and ArcGIS applications, using spatial analysis of bathymetric position index and slope, to obtain a classification of benthic terrains and habitats as well as to distinguish features such as ridges and valleys (Lundblad et al. 2006).

The seafloor of Hawaii is remarkably understudied with respect to sedimentation and seafloor terrain. Aside from highly generalized descriptions of the sediments of around Hawaii being composed of volcanic sands and silts, and biogenic sediments in the form of foraminifera tests and reducing to clayey silts with depth, there is little information on Hawaii, let alone specific locations (Hamilton 1957; Leslie et al. 2002). The region north of Molokai is dominated by turbidity currents and run-off from the island (Matthewson 1970). Turbidity currents are thought to deposit sediments in intracanyon regions (Mathewson 1970). Loihi is dominated by hydrothermal processes and active volcanism. It is also a region heavily influenced by landslides (Garcia et al. 2006). Three pits, East Pit, West Pit, and Pele's Pit, dominate Loihi, and hydrothermal vents are believed to be present along these pits, and sand channels are hypothesized to connect the pits (Caplan-Auerbach and Duennebier 2001; Garcia et al. 2006). Cross Seamount is thought to have been heavily affected by wave erosion, uplift and subsidence, and possibly by landslides (Grigg 1993; Wessel and Keating 1994). It is believed that there are regions of exposed dykes on the summit of the seamount and there have also been observed colonies of corals on the summit, while the flat summit of Cross Seamount makes it a unique Hawaiian seamount; it is one of only two seamounts that have sedimentation on their summits (Grigg 1993; Wessel and Keating 1994). All three of these locations present unique benthic terrains, dominated by a range of sediment types. By analyzing sediments at these different locations, sedimentation can be compared to benthic terrains, which can be useful in predicting not only sedimentation but also habitats for biology. If different characterizations of benthic terrain, such as fine grained sediments over flatter grounds, or within depressions, can be correlated with sediment types, analysis of seafloor mapping can present a viable method of identifying sediment types and terrains for regions that cannot be studied directly.

Methods

Research was conducted on the R/V *Thomas G. Thompson* 27 December 2010–4 January 2011. Using the Kongsberg Simrad EM302 30-kHz Multibeam Echosounder three surveys were conducted focusing on the canyon regions off Molokai, the summit of Loihi, and the summit of Cross Seamount. A sound velocity profile (SVP) was collected using a CTD cast (conductivitytemperature-depth) and the profile was applied to the acquisition phase of the multibeam data. The raw data collected was then brought into the CARIS® editing software for processing and editing. Base surfaces were created at 5m resolution and were then converted and transferred into ArcGIS, at 10m resolution, for further analysis, including slope calculations and focal mean at both 3x3 and 10x10 cell neighborhoods for bathymetric position index (BPI), similar to the methods of the Benthic Terrain Modeler developed by NOAA Coastal Services Center (Rinehart et al. 2004; Lundblad et al. 2006). BPI values were categorized into valleys with negative index values -1 and greater, constant slopes or flat regions with index values -1–1, and ridges with index values greater than 1.

On board sediment sampling locations were determined through monitoring of the backscatter intensity of the seafloor and the topographic features of the area. Sediment was collected at four locations at the Molokai (M001–M004) site using a box core and collecting samples from the surface sediments, done in conjunction with Jim Shobe, whose project investigated erosional processes. A Shipek grab was deployed at four locations at Loihi (L000–L003) and two locations at Cross Seamount (C001–C002); surface samples were collected for analysis. Sediments were then brought to the sediment lab for grain-size analysis. Samples composed of fine grained sediments were sieved using a 63 µm sieve to separate sands from fine grained silts and clays; the fine grained sediments were then run through a sedigraph, Micrometrics model: SediGraph III V1.04. Samples consisting of coarse grained materials, as well as the separated sand fractions, were processed through a settling column. Sediment grain-sizes were analyzed based on the Udden-Wentworth phi scale (Blott and Pye 2001).

Results

The seafloor at Molokai is characterized by numerous visible channels and scarps feeding off of the shallow shelf and flowing into the deep, with a rapid change in depth (Fig. 1). Sample location depths range from 1176.6–1935.8m (Table 1). The four samples have very similar distributions of sediments, although M002 has a much larger proportion of sand relative to the other sites (Fig 2; Fig. 3). The degree of slope over the sampling locations decreases with successive stations, M001 having the highest degree of slope, 31.05° and M004 having the lowest, 14.30° (Table 1). Values of BPI were calculated and range -1.35–.26 at fine scale, 3x3 cells, and -13.7–2.08 at large scale, 10x10 cells (Table 1). For both scales of BPI M001 and M002 remain valleys. M003 is a constant slope at fine scale but is considered a ridge at the larger scale, while M004 is a constant slope at fine scale but a valley at the larger scale.

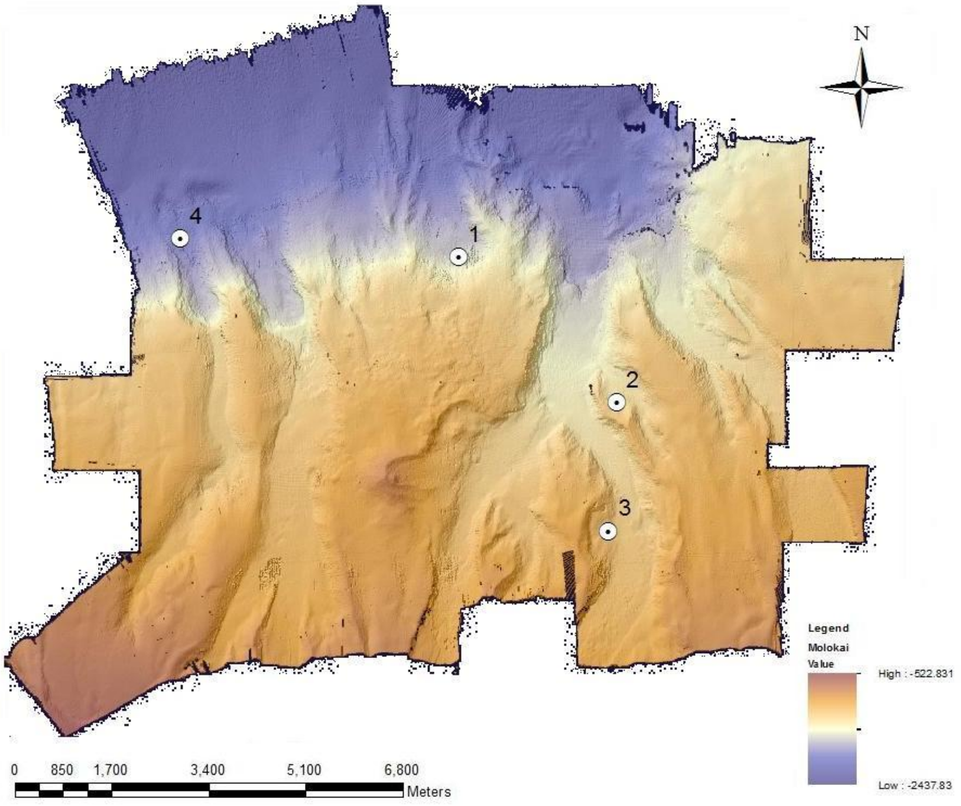

Fig. 1 Bathymetry map of Molokai survey with sampling locations marked and labeled.

Table 1. Locations of sampling stations and calculated benthic terrain characteristics.

	Station	Latitude	Longitude	Depth	3x3 BPI	10x10 BPI	Slope (°)
Molokai							
	1	21.31	-156.91	1620.56	-1.35	-13.70	31.05
	2	21.29	-156.88	1304.88	-1.07	-4.71	28.32
	3	21.27	-156.88	1176.61	0.26	2.08	15.45
	4	21.32	-156.95	1935.77	0.24	-3.53	14.30
Loihi							
	0	18.91	-155.26	1179.8	2.32	8.52	19.70
	1	18.91	-155.26	1084.61	-0.22	3.75	10.1
	2	18.91	-155.25	1347.50	-0.13	-2.42	11.02
	3	18.92	-155.26	1187.50	-6.03	-5.44	34.24
Cross Seamount							
	1	18.73	-158.24	705.32	-0.23	-0.70	20.63
	2	18.68	-158.31	936.00	-2.01	-0.63	29.70

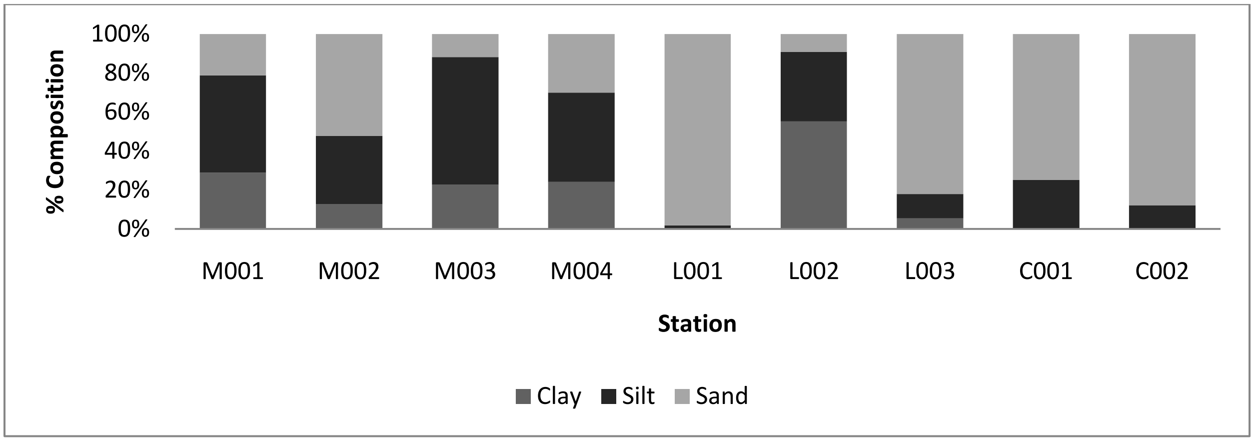

Fig. 2. Distributions of sediment sizes for each sampling location, by categories of sand silt and clay

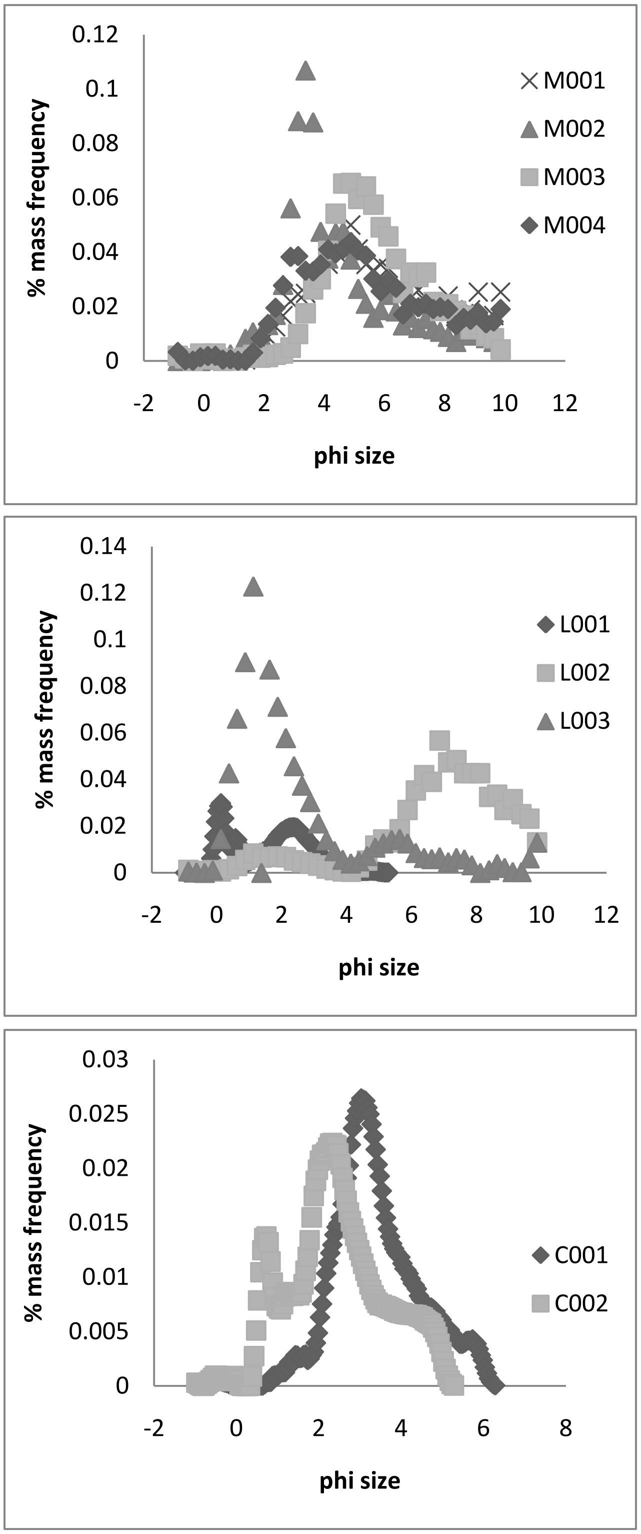

Fig. 3 Distribution of sediment based on individual phi sizes for each sampling location.

The three pits of Loihi dominate the surface and channels are seen connecting the pits, but there is also a large flat region on the summit just northeast of the East Pit (Fig. 4). The sampling location depths ranged from 1084.61–1347.50m (Table 1). L000 recovered no sediments with the Shipek grab, which either be the result of a malfunction during sampling, or a lack of sediment at that location. The sediments at Loihi are heavily influenced by the volcanism of Loihi, based on visual observations. L001 and L003 are dominated by sands, while L002 is dominated by fine grained clays, with very little sand present (Fig. 2; Fig. 3). Slopes ranged from 10.11°–34.24° (Table 1). The sites at Loihi showed the most dramatic difference between BPI scales. L000 is a ridge at both scales but becomes a more prominent ridge at the large scale. L001 is a constant slope at fine scale and becomes a ridge at larger scale, while L002 is a constant slope at finer scale and becomes a valley at larger scale. L003 is a significant valley at both scales.

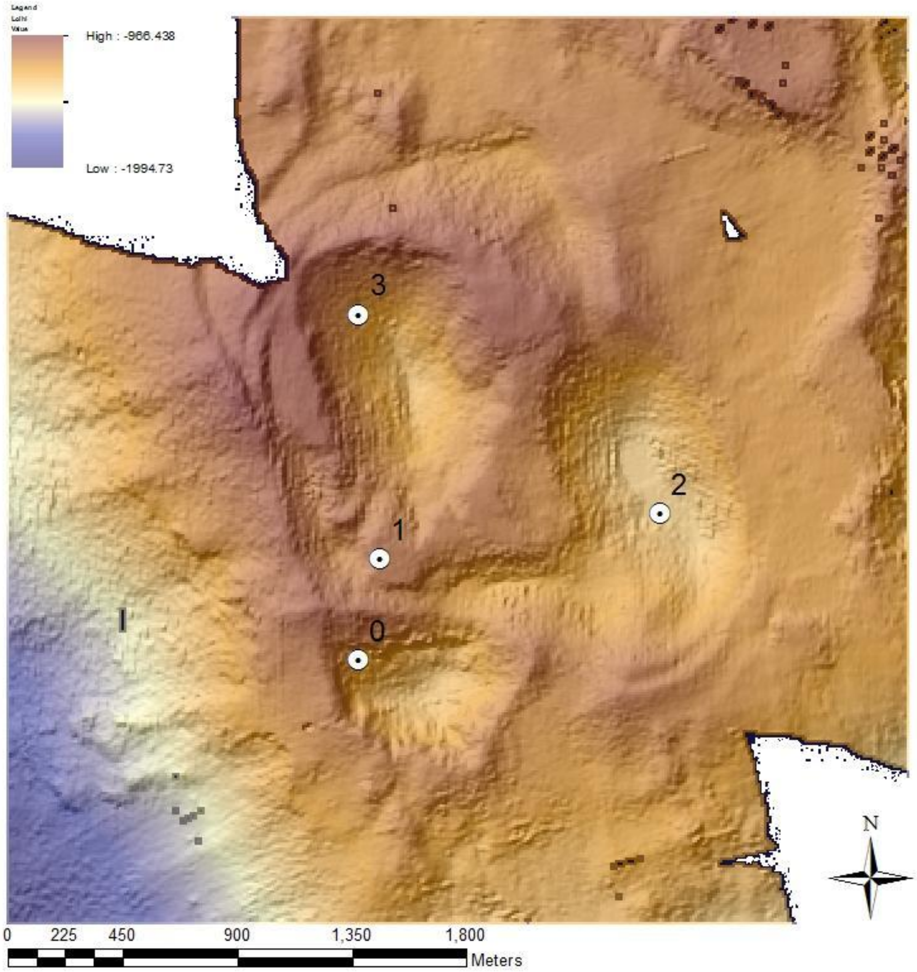

Fig. 4. Bathymetric map of the summit of Loihi, with sampling location marked and labeled.

Cross Seamount has a relatively flat summit, a few local regions of higher topography, and very steep flanks (Fig. 5). Two locations at Cross Seamount were sampled. C001 was at a depth of 705.32m and C002 was at a depth of 936.00m. Both locations are dominated by sandy sediments but C001 does have a significant proportion of fine sediment sand and finer sediment silt (Fig. 2; Fig. 3). Visual observations of Cross Seamount sands show a high abundance of foraminifera tests (Audrey Djunaedi, personal communication). C001 and C002 have similar slopes: 20.63 and 29.70, respectively. C001 is characterized as a constant slope region at both large and fine scale, while C002 is a valley at fine scale and a constant slope region at large scale.

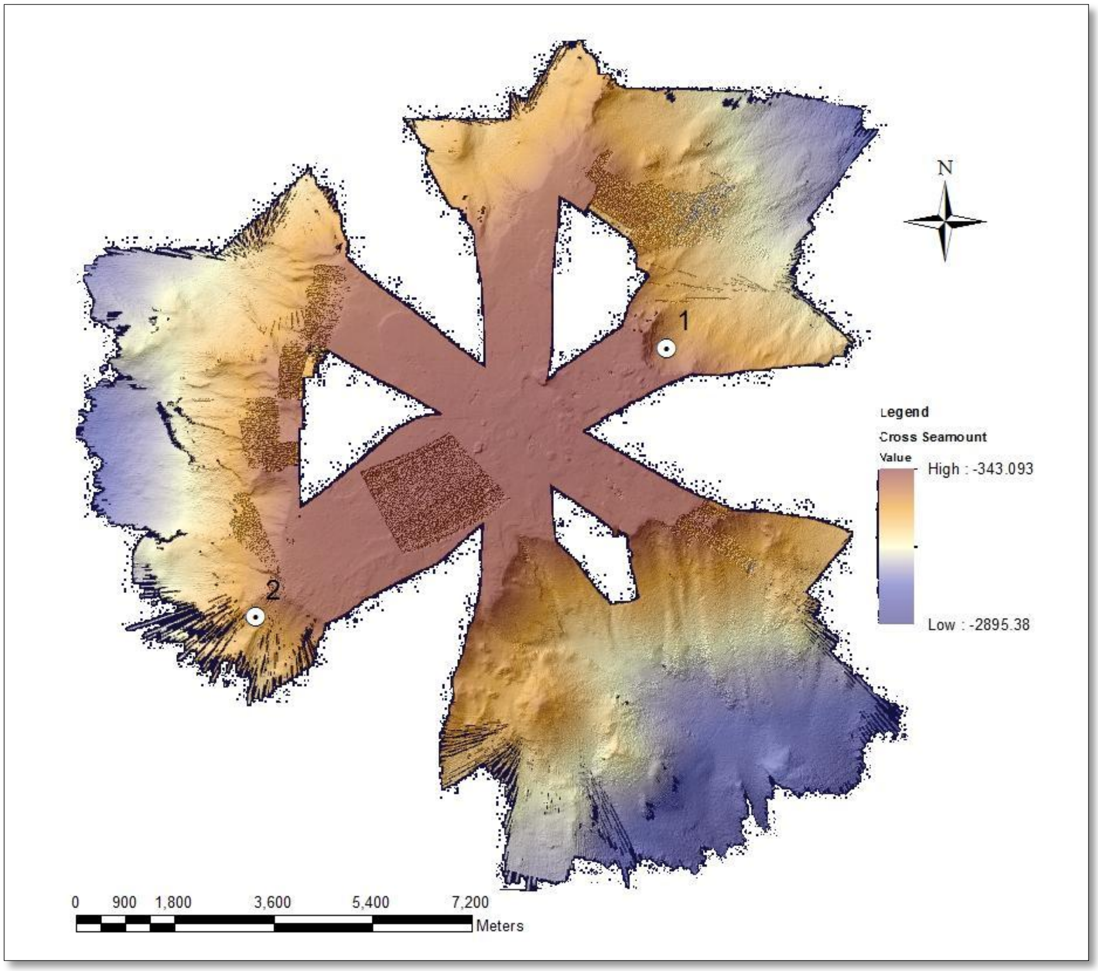

Fig. 5. Bathymetry map of Cross Seamount Survey with sampling locations marked and labeled. The section of that appears speckled represents anomalous data line, and is an artifact of the mapping process.

Discussion

Sediments characterized as sands are found on slopes ranging 10.12°–34.24°, with fine scale BPI -6.03–-0.23, and coarse scale BPI -5.44–3.75. Sediments characterized by fine sediment clays are found on slopes 11.02°–31.05°, fine scale BPI -1.35–0.26, and coarse scale

BPI -13.70–2.08. There is no significant correlation between dominant sediment grain-size, the highest % mass frequency phi size, and slope, with an R^2 value of 0.074 (Fig. 6). Likewise, there is no significant correlation between sediment and either 3x3 or 10x10 BPI, with R^2 values of 0.231 and 0.102, respectively (Fig. 6). All degrees of sediment grain-sizes were found among all ranges of benthic terrains. Although the trends represented by the data analysis did not produce significant correlations there does seem to be a possible trend developing in which sediments become finer over decreasing slopes, and over more dramatic depressions. There is confidence in the different scales of BPI and their results, because L002 is a constant slope at fine scale but a valley at the larger scale, which fits well with the observed location of it being on a flat region within the East Pit. Further reassurance is that C002 is a valley

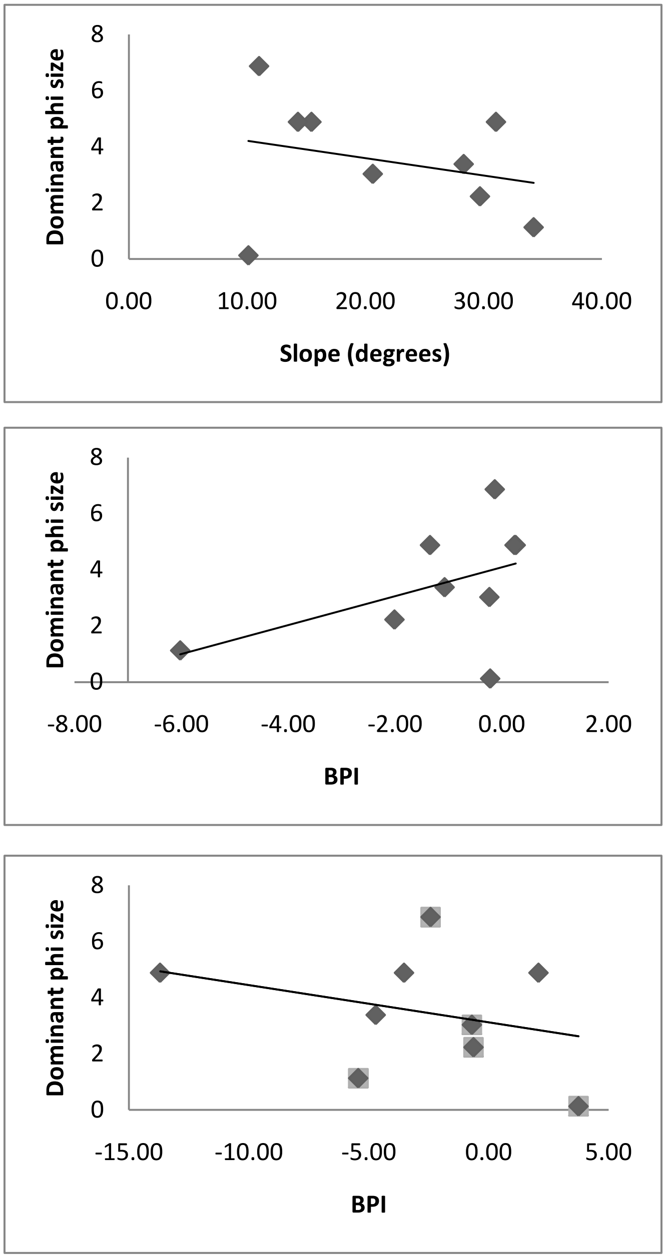

Fig. 6. Shows the sedimentation character, based on dominant phi size in the Udden-Wentworth scale where degree of fine grained increases with increasing phi, against a) slope in degrees, b) BPI for a 3x3 environment, and c) BPI for a 10x10 environment.

at fine scale but a constant slope at finer scale, consistent with its placement on the flank of the seamount. This suggests that the BPI analysis is accurate in producing characterizations of valleys, ridges, and constant slopes over varying scales. The lack of significant correlation between sediment and benthic terrain could be a result of the limited number of sampling locations, or due to the fact that locations were chosen based on the highest probability of recovering sediments and not sampled over a wide range of terrains. Further research should expand on this study to include surveys and sampling over a wider range of benthic terrains, in order to produce a more accurate and more detailed analysis of benthic terrain and sedimentation.

There is very little previous research of sedimentation and benthic terrain in the regions studied. However, the application of ArcGIS in the study of benthic habitat characterization has had success in producing effective predictions for the habitats of many organisms, as well as the applications of other methods comparing bathymetric mapping and ground-truthing (Herzfeld and Higginson 1996; Rinehart et al. 2004; Lundblad et al. 2006; Simmons and Snellen 2009). The methods of such studies are similar to this study, but were over much larger study regions with greater sampling. This suggests that the application of seafloor mapping and benthic analysis can effectively be applied in the determination of benthic habitat. This study was limited in scope, in both study sites and sampling locations for ground-truthing. Although this study failed to produce significant correlations between sediment type and benthic terrain characteristics, further studies in this field seem promising. Perhaps, by combining seafloor mapping and sediment sampling with other methods of studying the seafloor, such as backscatter analyses, seismic profiles, or ROV studies, could yield new and more effective ways of studying the seafloor terrain and its corresponding sediment.

There may be a relatively high error inherent in this study. Firstly, sampling locations drifted from projected locations slightly so it is logical to assume that some drift occurred from the recorded locations. This leads to a possible high degree of error because the terrain is so variable, a small shift in position could result in a large change in both BPI and slope calculations for the samples. Furthermore, the sediment samples present some degree of error, in the calibration of the machines, as well as the measurements of the subsamples. Also more prominent in the samples processed through the sedigraph, some margin of error results if the fine grained sediments are at low concentrations. Lastly, the determination of valley, constant slope, and ridge was set fairly arbitrarily. Although it followed the parameters outlined by the Benthic Terrain Modeler the exact divisions were not discussed, which might result in some misleading classifications; however, the process was carried out consistently across all locations, therefore the comparison should remain accurate (Rinehart et al. 2004; Lundblad et al. 2006).

Molokai, Loihi, and Cross Seamount are very different in structure. Molokai is carved with numerous submarine canyons, with a large depth range over the survey area. Loihi is a product of volcanic activity and earthquakes which have resulted in three prominent pits. While Cross Seamount is a relatively flat and shallow summated seamount. These environments are very unique and could present samples that are not truly comparable. For further research, more samples taken over each location could present a trend within each region that is different from an all encompassing approach.

Conclusions

Sampling sites at Molokai consist of a higher degree of fine grained sediments than the other locations, while there is no distinguishable trend between sediments and slope or BPI index (Fig. 2; Table 1). The sediments recovered at Loihi are the most variable within a single sampling region. The sample taken within the East Pit, L002, has a high fraction of fine grained sediments, while the other two sites where sediment was recovered are more dominated by coarse sand particles (Fig. 2; Fig. 3). Loihi shows the most promise in comparing sedimentation with benthic terrain, as the summit presents a varied terrain over which samples were taken and the sampling locations BPI changed drastically with increasing scale (Table 1). The two samples from Cross Seamount were heavily dominated by sand particles (Fig. 2; Fig. 3), while trends in benthic terrain and sedimentation cannot be discussed for Cross Seamount because there were only two sampling locations. Molokai, Loihi, and Cross Seamount are unique environments. Perhaps, their terrain and sedimentation is too heavily influenced by local factors, such as landslides or volcanism, and studies should focus on each location separately.

Both samples dominated by sand particles and samples dominated by clay particles are found over similar ranges in slope, as well as similar ranges in both scales of BPI. There is no significant correlation between sediment grain-size and benthic terrain characterizations. However, although not statistically significant there does appear to be some trending of sediments against benthic terrain, it is possible that with sufficient sampling locations a significant correlation could develop, showing increasingly finer sediments with decreasing slope, and finer sediments within large scale depressions. However, without further sampling, these results are inconclusive in providing a relationship between sediment character and benthic terrain. Future studies should focus on including more sampling locations, especially over a wider range of bathymetric features. If more samples are taken over a variety of different locations within a given survey area, and across multiple survey areas comparisons of trends between different survey areas may provide insight into how dominant oceanographic and geological processes affect sedimentation, to provide a broad scale comparison of benthic terrains and sedimentation.

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