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Historical sea level and accommodation zones along Baja California

Kim Swanson

[1]*University of Washington, School of Oceanography,*
Box 355351, Seattle, Washington 98195
[*]kimm001@u.washington.edu
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NONTECHNICAL SUMMARY

Change in sea level is an ongoing process which alters the coastal ecosystem on a continuous basis. The physical changes in the world's coastal ecosystem due to sea level change have occurred many times over the course of Earth's history. While there are a number of large scale processes which contribute to localized variation in the sea level, such as land subsidence changes in the rate of sedimentation from local rivers, and alteration in coastal circulation patterns, climate change remains the dominant process and control of sea level. Climate and sea level variability have left behind evidence in the structural formation of the seafloor that can be seen today in the form of a step-like pattern on the continental shelf. A high resolution multibeam sonar survey was used to gather evidence of historic sea level change from the sea floor along 4 transects of the Baja California peninsula and mainland Mexico continental shelf. Variation in the structural pattern along these transects is used to identify potential historical shorelines. Step-like structures were found at three locations at the lowest point of sea level, indicating a change in a global process for historic sea level, and intermediate step-like patterns are evident that a variety of distance along the transect until the present day shoreline. This research provides insight into the spatial variability of sea level rise and contributes to our understanding of the complexity associated with local scale planning for sea level rise.

ABSTRACT

The Pacific coast of Baja California is an ideal place for seeking evidence of climate change through observations of step-like pattern in the bathymetric structure of the continental shelf. These step patterns, or marine terraces, are indicative of sustained periods of sea level over the Holocene geological epoch that began 12,000 years ago and the late Pleistocene. The Pleistocene epoch lasted from 2,588,000 to 12,000 years ago. The last glaciation occurred 21,000 years ago when sea level was about 120 m lower. Using the Kongsberg EM302 Echosounder multibeam sonar and Knudsen dual frequency sub-bottom profiler, four transects were surveyed along Baja California and on the coast of Mexico between 17 March 2012 and 27 March 2012. These data were post processed using CARIS HIPs/SIPs vers. 7.1.1. to produce base surfaces of transects originating at the shelf break and orthogonal to the shoreline. Multiple resolution surfaces and associated profiles provided for the calculation of accommodation space with associated points of surface inflection. The four transects illustrate varying degrees of historic sea level change across this active continental shelf which is dominated by evidence of current sediment transport and accumulation.

Over the course of its history, the Earth has been through many cycles of climate change and consequently, sea level change (Lambeck and Chappell 2001). The continental shelf off of Baja California has gradual slopes and areas without incisions which made it an ideal location for surveying for evidence of sea level stands (Le Dantec et. Al 2010). A step-like pattern on the continental shelf in the sediment can be indicative of sustained periods of sea level. The step-like structure evident today were created during the Holocene and late Pleistocene, the two most recent geologic epochs. A similar study was conducted on San Nicolas Island, California where on-land marine terraces were identified and dated using Uranium from ancient fauna embedded in the rock (Muhs et al. 2012). The sediment collected over these last epochs have a higher likelihood of being undisturbed here than it would in areas that have incisions, very energetic currents, or high sedimentation rates. In the United States alone, over 20 million will be directly affected by sea level rise by 2030 (Curtis and Schneider 2011).

The Baja California peninsula sits between spreading along the northern section of the Eastern Pacific Rise in the Gulf of California and the subduction zone in the Pacific Ocean. The Pacific Plate is subducting under Baja California, causing it to stay relative stationary as the spreading on the eastern side of Baja continues to push westward (Fig. 1). Baja California is a tectonic block between the North American and Pacific Plates and is being uplifted at an average rate of 0.12 mka-1 (Mayer, L., and K. R. Vincent 1999). Uplift is an increase in elevation relative to a geodetic datum which is often related to sea level. Only evidence of sea level stands from the beginning of the Holocene and late Pleistocene were present and the assumed total uplift of the area was 1.44m over the last 21,000 years. Although uplift is a competing process with sea level rise, its effect will be negligible in the future on a scale of a few hundred years. For identifying sea level in the past, however, it was worthwhile to consider because a 1.44m change in sea level, or elevation, over an area of seafloor with a low slope was significant in its onshore progression.

Accommodation spaces can be defined as the space between the seafloor and the surface available for sediment deposition. The calculation of accommodation space not only includes the depth of the zone from surface to seafloor, but also its inshore progression. Both parameters have effects on sediment transport and deposition along the continental shelf. For example, a large accommodation zone that was

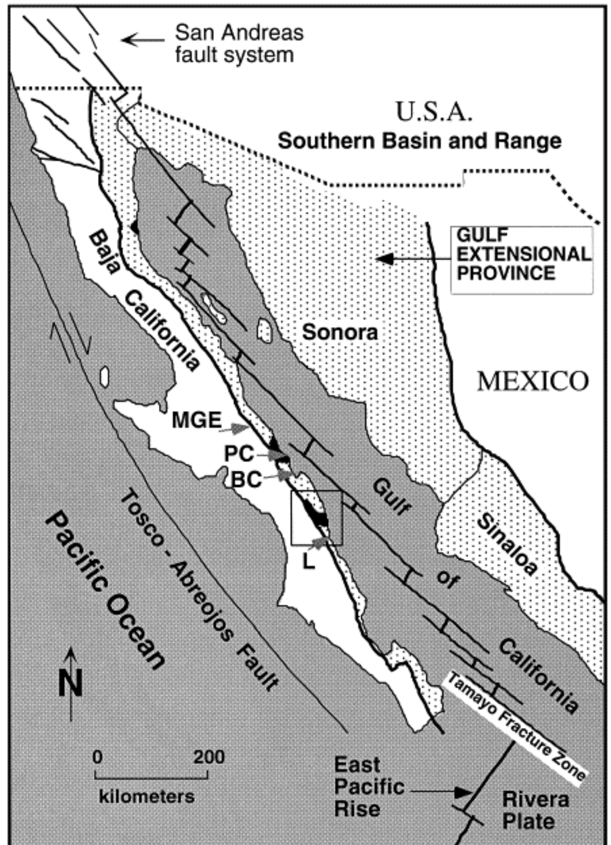

Figure 1. Map of Baja California showing surrounding tectonic processes (Mayer, L. and K.R. Vincent 1999).

both deep and far offshore would deposit more sediment on the shelf rather than after the step, a process known as aggradation. A shallow accommodation nearshore would likely deposit more sediment on the step itself, a process known as progradation. Aggradation and progradation and erosion, or the formation of highstands or lowstands respectively, mark the coastline associated with sea level at that point in time and leave the surface of the continental shelf with a different slope characteristics than the surrounding area (Porebski and Steel 2006).

This paper presents results from both multibeam and sub-bottom profiler data acquired 16 March 2012 to 27 March 2012 on the R/V Thomas G. Thompson from San Diego, California to Manzanillo, Mexico. The multibeam survey data provides evidence of sea level stands in the forms of step-like structural changes along linear transects of the sea floor. The sub-bottom profiler data were used to specifically identify steps that were likely hidden by recent sediment deposition.

These findings are globally relevant to current climate change and sea level rise. Populations near the coast will be directly impacted by climate change in the near future because as the planet warms, sea level will rise due to the melting of ice caps and heat expansion. Understanding our climatic past is key to predicting the behavior of our environment in the future and will affect our ability to respond to or prepare for the implications of climate change.

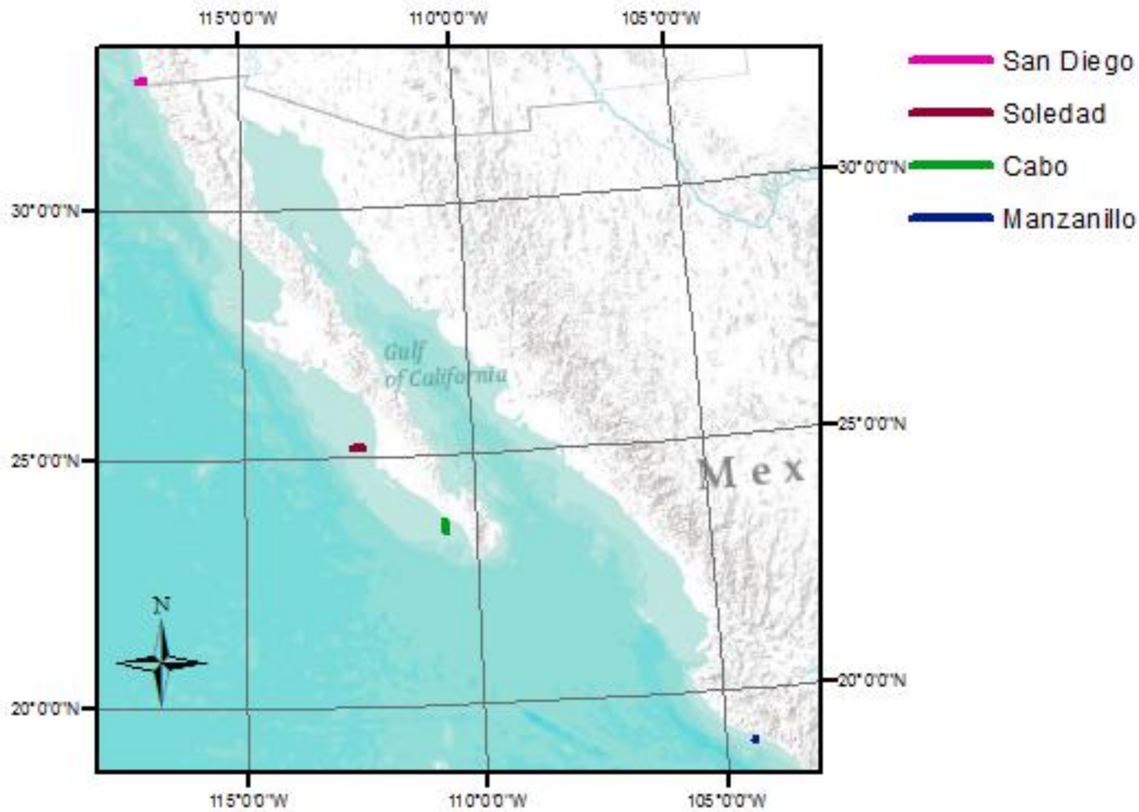

Figure 2. Map of transects taken along Baja California and mainland Mexico.

METHODS

A hydrographic survey research cruise aboard the R/V Thomas G. Thompson took place from 16 March 2012 to 27 March 2012. It began in San Diego, California and ended in Manzanillo, Mexico. The first transect was done just outside of San Diego, California and served as a patch test for the Kongsberg EM302 Echosounder multibeam sonar and the Knudsen dual frequency sub-bottom profiler in addition to the first set of data. Swath width was about 4 times the water depth. The first transect was right out of San Diego and was about 13.5km long. This transect was chosen for its location just outside the port to aid in large-scale pattern recognition. The second transect was near 25°N and begain just outside the shelf and ended inshore with a depth of 92.6m. The entire transect was about 8 km long. This location is unique to the other two because between 3500 and 6000 years ago, sea level was about 4m higher than present (Pirazzoli, P.A. 1991). This region of Baja California was submerged 3km inshore from the current shoreline. The third transect was near the tip of Baja California and was about 22.5 km long.

This location differs from the second because at maximum sea level, only 0.1 km were submerged inshore. The fourth transect was from just outside Manzanillo, Mexico into port and was about 5.75 km long. This location was chosen for similar reasons as the first transect (Fig. 2). A sound velocity profile was collected at each transect except the first due to inclement weather.

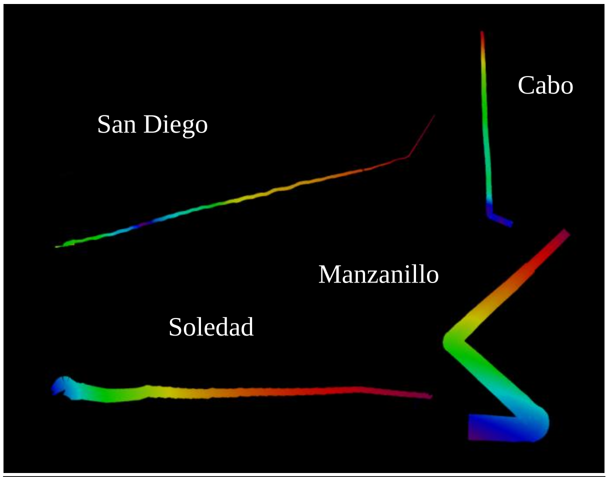

Figure 3. Surfaces of each transect.

Each of these locations have unique characteristics that could help exclude any local forcings but are similar enough to be comparable for marine terraces.

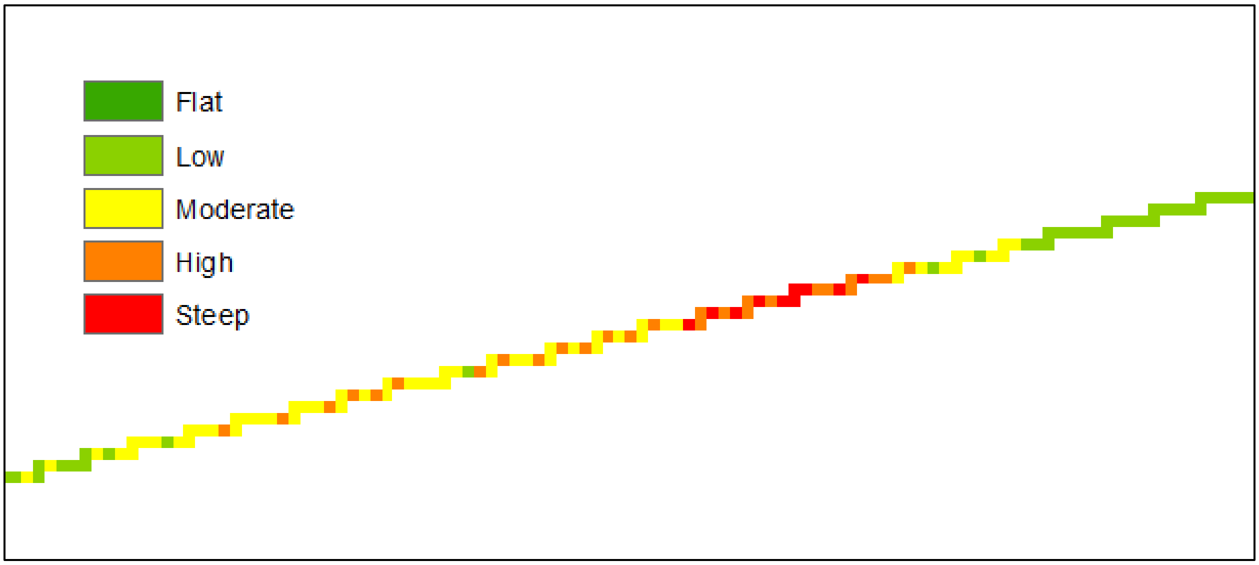

Figure 4. Close up of a step defined by the slope function on the San Diego transect.

The multibeam data were post processed using CARIS HIPs/SIPs vers. 7.1.1. to create base surfaces of each transect (Fig. 3). Each surface was then imported into ArcMap 10. All the surfaces had a slope calculation run on them to create a histogram. From each of these transects, a profile was created. Marine terraces identified using the multi-beam and single beam sonars were used to calculate accommodation space for sediment transport with associated points of surface inflection at each step. The sub-bottom profiler data were post processed using SounderSuite: PostSurvey 2.52. From the multibeam data, the average number of steps, the average slopes of each steps and of the continental shelf and the elevations of each step were determined using ArcMap 10 (Fig. 4). In ArcMap 10, histograms were created with slope on the x axis and the number of pixels on the y axis. These histograms were created by taking the maximum slope of the neighbors surrounding each grid cell. Five classes of data were created for each transect.

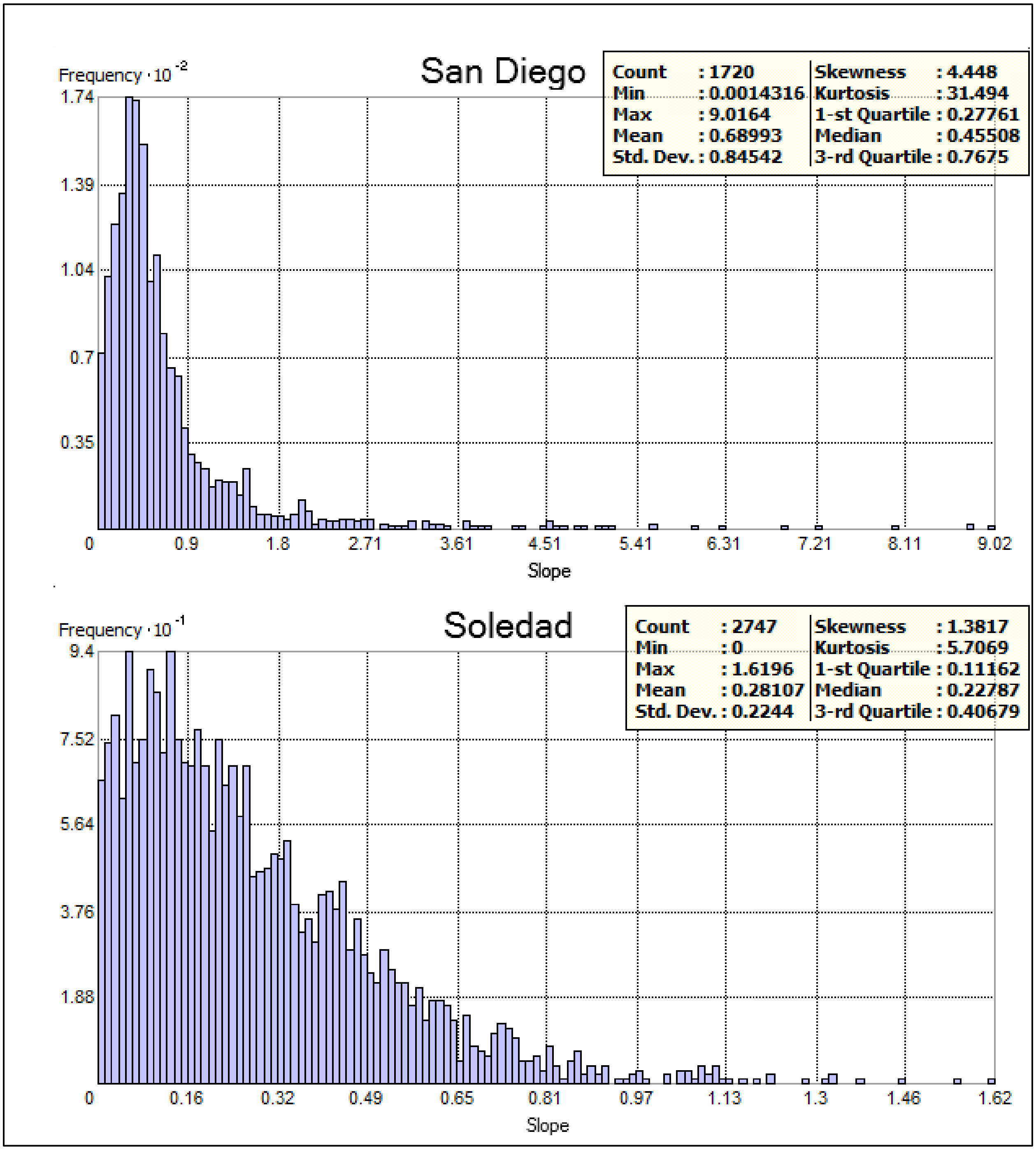

Figure 5. Histograms of slopes of the transects near San Diego and Soledad.

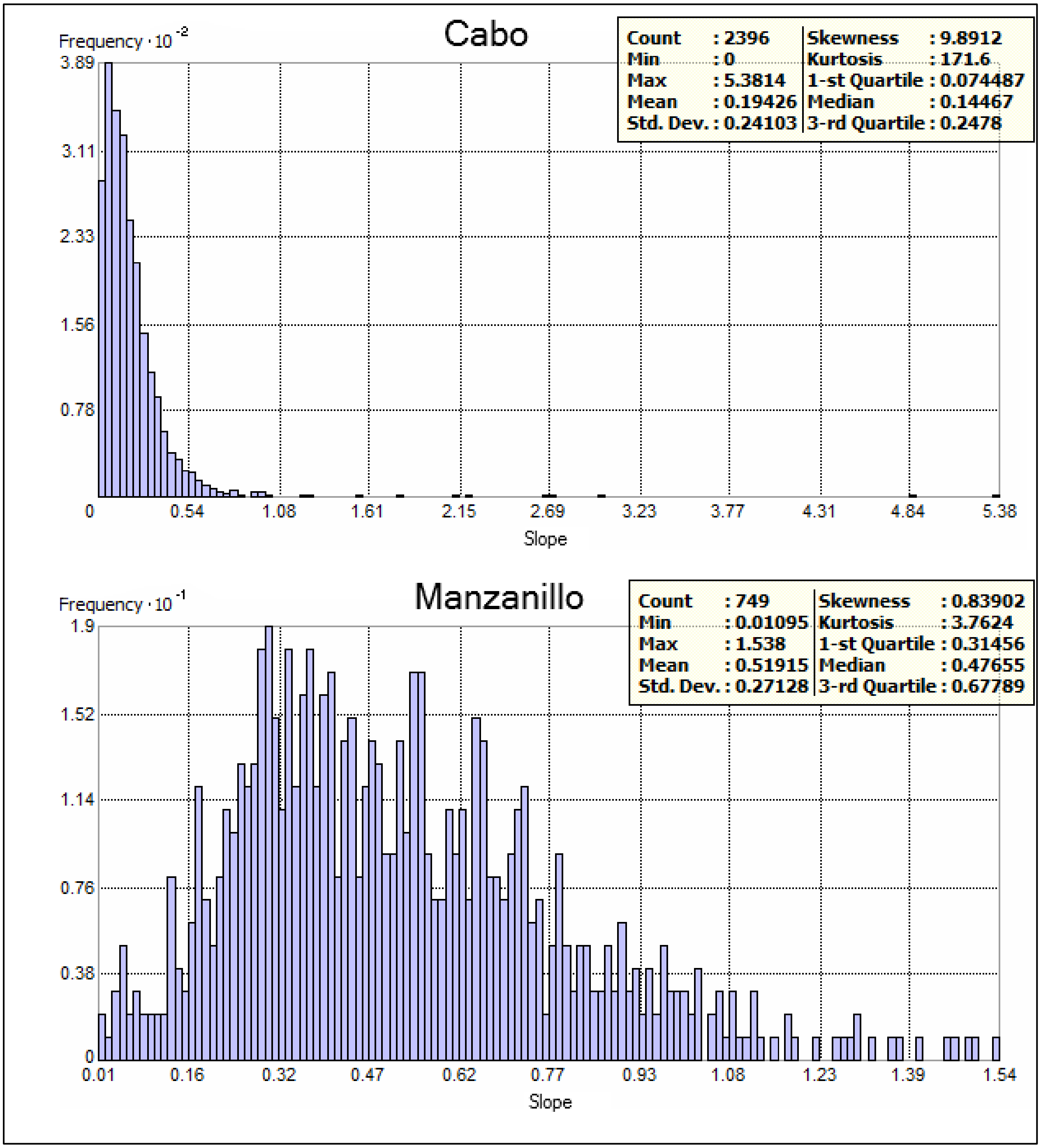

Figure 6. Histograms of slopes of the transects near Cabo and Manzanillo.

RESULTS

A step was defined as an abrupt and great change in slope relative to the immediate area. The San Diego transect had two steps with significant changes in slope. Soledad had only one step that was very small, with a change in slope of about 0.8. Cabo had about 8 steps while Manzanillo had 4 steps. A total of 15 steps were found along Baja California. The San Diego transect had the steepest slopes with the steepest at 9.016 (Fig. 3). The Cabo transect had a somewhat more gradual overall slope with the steepest at 5.381. The other two transects had very gradual slopes with their steepest slopes at 1.619. Every transect had its peak in the histogram at its most gradual slopes including San Diego, the transect with the steepest slopes (Figs. 5 and 6).

Both San Diego and Cabo had steps around 110 m evident in profiles from the multibeam data. The sub-bottom profiler data from Soledad recorded what could have been a step at 110 m, but it was difficult to tell (Fig. 7). The accommodation zone for the San Diego transect was found to be 624,250 m^2 while the Cabo accommodation zone was calculated to be 1.1x106 m^2 (Fig. 8). Accommodation zone for Soledad was not calculated because the transect ended too deep.

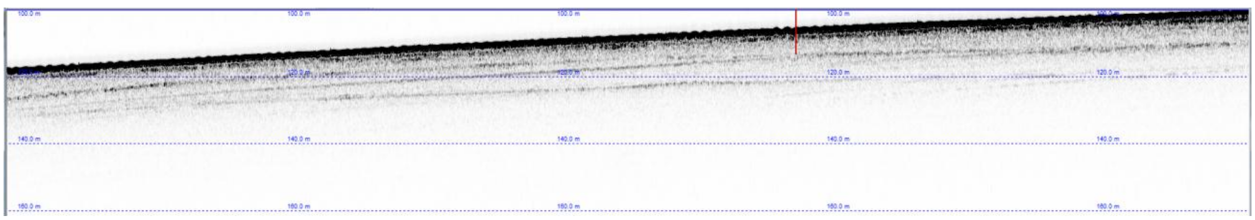

Figure 7. Sub-bottom profiler data for the Soledad transect. The red line indicates where the step at 110 m is.

DISCUSSION

The lowest step from each transect likely formed during the lowest sea level, which occurred around 21,000 years ago (Pirazzoli, Pa.A. 1991). These steps occur at the same depth in San Diego and Cabo and are likely all caused by the same period of sea level (Fig. 4). The second transect was completely flat on the surface because of the high sedimentation rate in the Soledad Basin. At least one step was interpreted from the sub-bottom profiler data underneath the surface, at around 110m. The step is likely not seen on the surface itself due to the area's high sedimentation rate. The sedimentation rate in the Soledad Basin is 1.08 m ky-1 and could easily bury steps within 21,000 years at a rate so high(van Geen A. et al. 2003). Recent sediment has been deposited on top of the ancient steps created at a period of sea level during the Late Pleistocene. Since the last glaciation, the area could have deposited nearly 23 m if the sedimentation rate has been constant. The other small steps evident in the slope data did not correlate well with depths at other stations and therefore were not interpreted as having been formed by sea level stand. These small steps were formed by small-scale local forcings or sea level stand, but it is impossible to say which without additional data. The small dip in the Cabo transect near 80 m appeared as a step from the slope data, but upon further inspection of the multibeam data, seemed to look like something anthropogenic in origin.

The accommodation zones for San Diego and Cabo are spaces that had become available for sedimentation since the last glaciation 21,000 years ago. The Earth is currently in a period of high sea level stand with a resulting large accommodation zone. The addition of these spaces have allowed for sediment to be deposited on the current marine slopes. The Soledad transect is a prime example of how additional accommodation space can allow for sediment deposition over the shelf and over steps.

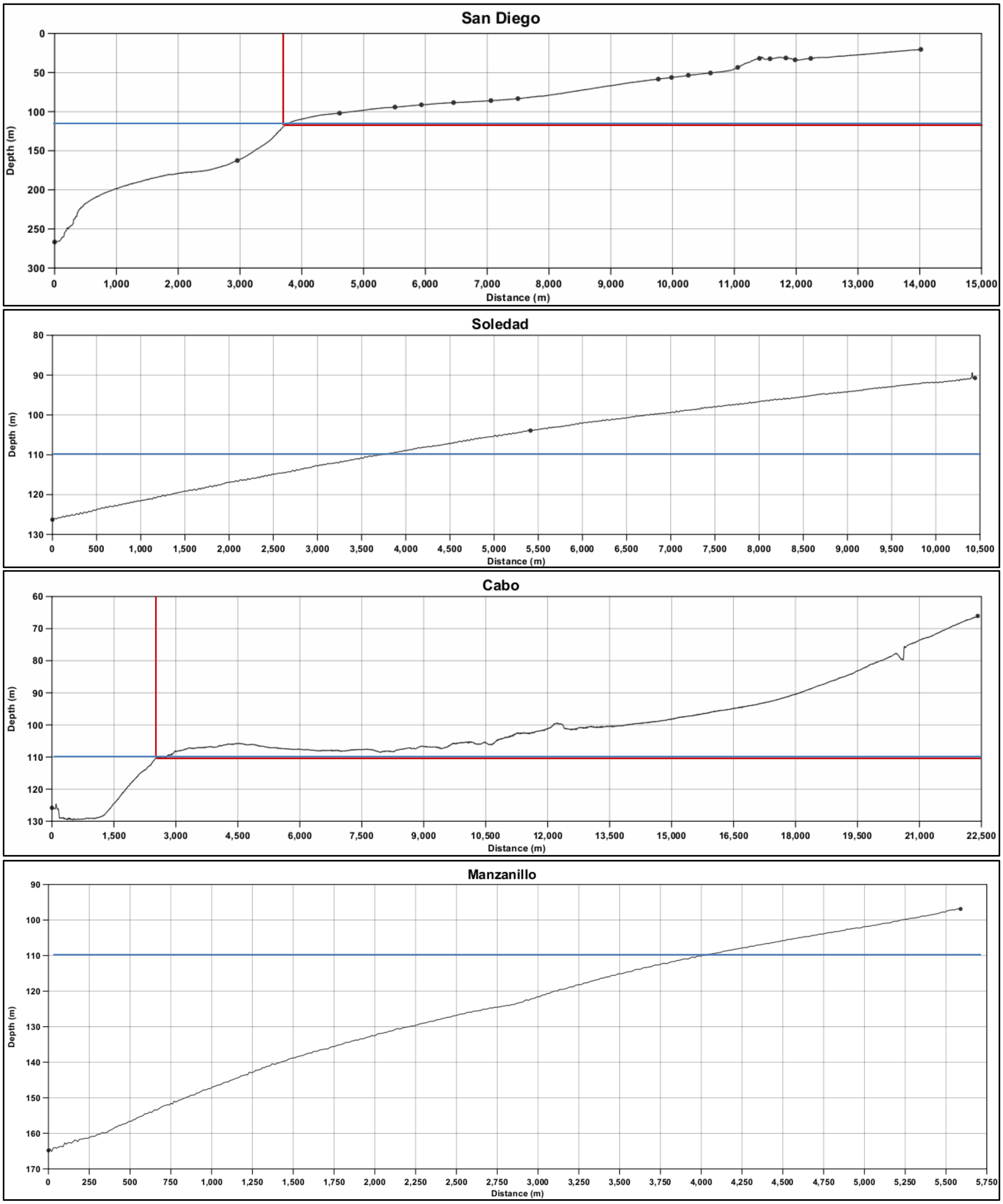

Figure 8. Profiles of the transects near all four transects. The red line indicates where accommodation zone was identified. A reference elevation is provided at 110 m by the blue line.

While sea level does have a direct control over accommodation zone, it does not necessarily control sedimentation rates. Local environmental factors have the most direct influence over sedimentation rate and distribution (Schlager 1993). While it is difficult to say what exactly will happen, it is entirely possible that as sea level rises and erodes the beach, more sediment may be deposited on the shelf below.

In the future, it would be worthwhile to survey more transects in the area. Surveying close to other transects would help in ruling out local or anomalous steps. Retrieving cores from steps to date them would also give definitive answers on the timescale of their formation. Shallow submarine channel surveys and analysis would be helpful if they could be linked to terrestrial watershed and dated to determine whether the channel was at one point above sea level. It would also be interesting to look for marine terraces above sea level and date them as Muhs et al. did on San Nicolas Island, California in 2012. Dating old steps above sea level would enhance the regional timeline of sea level change, and could provide more answers to future climate change.

CONCLUSIONS

Four transects were surveyed using the Kongsberg EM302 Echosounder multibeam sonar and the Knudsen dual frequency sub-bottom profiler along Baja California. Each transect was analyzed for steps. These steps were identified as abrupt changes in slope relative to the neighbor of each grid cell. A large step was found at 110 m on three separate transects and was likely formed during the Late Pleistocene. Accommodation zones were calculated for San Diego and Cabo from where the deepest step formed to sea level and both were found to have large zones, with Cabo having the largest.

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