Mapping annual sediment change in the Monterey Canyon head using serial multibeam bathymetry surveys

Abstract

Submarine canyons were once thought to be the result of river processes during periods of glaciation and lower sea levels. The Monterey Canyon is one of the most studied submarine canyons due to its close proximity to the coast. The goal of this study is to understand how sediment changes in the Monterey Bay Submarine Canyon head. It is important to determine the amount of sediment change because the Moss Landing Harbor jetties could be in danger of being swallowed by the canyon by an encroaching canyon lip. Is the Monterey Submarine Canyon head changing or is it static? By taking serial multibeam surveys, we were able to quantify geomorphic changes have occurred between the surveys. Raster subtraction analyses of DEMs revealed a pattern of consistent sediment erosion over the years assessed. These data analyses suggest that the Monterey canyon is in a constant erosional phase. A trace of the canyon lip of each survey determined that the jetties are at risk of being swallowed by the canyon in the near future.

Introduction

Submarine canyons are very interesting features of the seafloor. Many submarine canyons look similar to terrestrial canyons and some submarine canyons are of comparable size to terrestrial canyons. Thus, they were once thought to be the result of river processes during periods of glaciation and lower sea levels. Another process that could form a canyon is turbidity currents, intermittent gravity-driven flows of turbulent water, that are triggered by earthquakes. These turbidity currents tear down the continental slope, scraping and carving a canyon (Perkins 2005, Goodrich and Merle 2001).

There have been many studies on how sediment moves within submarine canyons. Liu (2004) found that there is a net deposition of marine sediment in the Kao-ping Submarine Canyon. He states that this marine sediment was transported by a landward flow up the canyon toward a dead end. Mullenbach (2004) found that in the

Eel Canyon, there is a net deposition during the winter flooding season. However, according to Okey (1997), the Monterey Submarine Canyon heads experience sediment flushing events during the winter storm season. After the flushing events, during the summer months, sediment and organic debris are accumulated in the head, which is then removed by the next winter flushing event. Previous studies of the Monterey Canyon have showed that there is sediment movement in the canyon within a half year (Smith and others 2005).

The Monterey Canyon is an ideal study site because it is one of the most studied submarine canyons due to its close proximity to the coast. The head of the canyon lies yards from the Moss Landing Harbor, which was constructed by the Army's Corps of engineers in 1946 (Ruiz 2003). Also, the canyon reaches abyssal depths closer than many other submarine canyons (Waters 1995). A long-term time series of bathymetric surveys is needed to determine sediment change over time.

The goal of this study is to understand the how sediment moves temporally in the Monterey Submarine Canyon head. Therefore, is the Monterey Submarine Canyon head changing or is it static? In addition, is the Monterey Canyon experiencing a net change or does it experience seasonal oscillations and no net sediment change? The null hypothesis is that the canyon is static; there is no sediment movement over time. The alternative hypotheses are that the canyon is not static, it experiences season oscillations, it is filling up with constant deposition, or it is constantly eroding over time. Also, different parts of the canyon could experience different dynamics.

If the canyon head is found to be eroding toward shore, then the structures on the coast could be at risk. Some of the structures at risk near the Monterey Submarine

Canyon would be Moss Landing Marine Labs and Monterey Bay Aquarium Research Institute. The Moss Landing harbor jetties also lie at the mouth of the Monterey Submarine Canyon head. The jetties would be the first human made structures that an eroding Monterey Canyon would claim. If it is shown that there is an erosion pattern around the Moss Landing harbor jetties, further studies could determine what ought to be done to minimize damage to the harbor.

There are many benefits to the scientific community from this study. Determining the locations of sediment change could help researchers determine where they would likely find long-lived benthic communities and opportunistic benthic populations. Also, researchers could determine the effects of sediment accumulation and flushing on the benthic communities.

By taking semi-annual multibeam surveys between September 2002 and February 2005, followed by processing the data on computers, we quantify geomorphic change and calculate volumes of sediment deposited and eroded. The surveys for this study are September 2002, March 2003, September 2003, September 2004, and February 2005.

Methods

Site Description

The crew of the CSUMB Seafloor Mapping Lab took 5 surveys of the Monterey Submarine canyon. The CSUMB SFML mapped the upper 5 kilometers of the canyon, beginning from the Moss Landing harbor.

The canyon head terminates outside the mouth of the Moss Landing harbor. The head is comprised of four main tributaries that meet at the axis. The axis of the canyon is lined with sediment waves. The canyon meanders to the narrows of the canyon approximately 3 kilometers from the canyon head (Smith et al. 2005, Figure 1).

Data Collection

The three surveys in 2002 and 2003 were conducted aboard the R/V MacGinitie and the two surveys in 2004 and 2005 were conducted aboard the R/V VenTresca. The same survey lines were used for each survey. The sonar used is a Reson 8101 multibeam sonar, which was pole-mounted at the bow of the MacGinitie or on starboard side of the VenTresca. A Triton-Elics International Isis Sonar data acquisition system was used to record the data during the survey. Motion sensor data corrections such as heave, roll, pitch, and yaw were recorded with an Aplannix HDMS heading and motion sensor. At different locations and different times of the surveys, sound velocity profiles were collected with an AML SV+ sound velocity profiler. Differential GPS was used to get horizontal positioning for the September 2002 survey and predicted tides were used for the tide model. Real Time Kinematic (RTK) GPS was used to get the horizontal position and vertical position for the later surveys. The tide models that were used for the surveys came from RTK GPS height position.

Data Processing

Once all the data had been collected, the lines were imported and cleaned in CARIS HIPS and SIPS. Each line was cleaned in swath editor and subset editor. Once cleaned in CARIS, the xyz data were exported and the three-dimensional digital elevation model was viewed in Fledermaus to check for missed bad points. After all the data had been cleaned and checked in Fledermaus, the base surface grids were exported at 3m resolution, grey scale and 10 color, to geotiff files and the xyz data to a text file. With the cleaned datasets in the Fledermaus DMagic program, the Fledermaus grids were exported to ArcGIS grids.

Data Analysis

Using the different methods of positioning, DGPS and RTK GPS, resulted in a possible horizontal misalignment of the surveys. Therefore, in the summer of 2005, the R/V VenTresca was parked at the Elkhorn Slough visitor's center. Position data was recorded using the different methods of navigation, DGPS and RTK. The positioning using RTK is assumed to be the more accurate of the 2 methods. The offset of using DGPS was found to be -0.25m for easting and 0.71m for northing from the positioning using RTK. These offsets were applied in ArcGIS to the bathymetric grid of the September 2002 survey. The September 2002 survey was the only survey in this study that used DGPS.

The ArcGIS grids are raster images, with each pixel having a depth value. ArcGIS is able to calculate differences between raster images. Raster subtractions are subtractions between two different raster images. The bathymetric grids were vertically registered to ensure that the raster subtractions reflect the change in geomorphology of the seafloor. A small area of on the shelf, which likely remained unchanged, was evaluated for the vertical differences between each survey. The average vertical difference of the area was then subtracted from or added to the raster subtraction.

Raster subtractions were done between each half-year. Since I cannot be sure of the accuracy of the data, I chose to not view the changes of ±1.5m. Sediment change in areas where change is not expected, such as the shelf, is observed when viewing data ±1.5m. This approach removes much of the artifacts that are in the datasets. Using these data, I was also able to calculate the total sediment volume change. By using a new polygon shapefile as a mask, I was able to focus volume calculations to a specific area. To create a layer that only has the data within the area of focus, I used the raster calculator with just the sediment change dataset in the equation with the mask option set in the spatial analyst options. In raster calculator, I then input the "[masked sediment change dataset] < -1.5" into the equation. This creates a layer with 2 classifications, 0 and 1. The "1" class is everything that has eroded more than 1.5 meters inside the masked area. Using the zonal statistics analysis, I created a .dbf file that has all the values for the layer. The MEAN value gives the average elevation difference and the AREA value gives the area of the selected pixels. By multiplying the AREA*MEAN values, I determined the volume change of the eroded sediment. I repeated these steps for the deposition of the masked area. With the 2 volume changes, I could calculate the net change in the area by adding the 2 values together.

According to Smith(2005), excluding the data between ±1.5 meters has two implications. The calculations could be either an overestimate if there was a large amount of erosion less than 1.5 meters or an underestimate if there was a large amount of deposition less than 1.5 meters. Therefore, I used error estimates calculated by multiplying 1.5 by the area of the pixels with a change not within ±1.5 meters.

To track the movement of the canyon lip, lines were traced by hand around the lip of the canyon using the bathymetric grids in ArcGIS.

Results

General Morphology

The bathymetric images created of the Monterey Bay Submarine Canyon provide detailed information regarding its morphology (Figures 1, 2). The axis of the canyon is lined with sediment dunes.

Seasonal changes in geomorphology

Analysis of the change in sediment volume between each season was achieved by using zonal statistics on the raster subtractions. The analysis was limited to the upper 3.5 km of the canyon to incorporate data that all surveys include.

The first winter season (September 2002 – March 2003) had a large amount of sediment deposited in the head of the canyon (Figure 3). However, there was much more sediment that eroded. The approximate total amount of sediment that deposited was 232,000 ± 146,000 m^3, and the approximate total amount of sediment that eroded is 793,000 ± 513,000 m3 (refer to table 1).

The first summer season (March 2003 – September 2003) had a large area of sediment that eroded due to a landslide on the north wall (Figure 3). Much of the sediment from that landslide was deposited on the canyon floor. However, there is still more erosion than deposition in the canyon. The approximate total amount of sediment that deposited was 255,000 ± 157,000 m^3, and the approximate total amount of sediment that eroded is 575,000 ± 328,000 m^3 (refer to table 1).

The second winter season that was surveyed (September 2004 – February 2005) had a large area of deposition in the northern head (Figure 3). Also, an area of erosion was observed in the southern lip of the canyon head. However, there were large holes in the bathymetric data of September 2004 due to large amounts of schools of fish during the survey. Therefore, not all the sediment change is observed between these surveys. The approximate total amount of sediment that deposited was 160,000 ± 98,000m^3, and the approximate total amount of sediment that eroded is 207,000 ± 136,000m^3 (Refer to table 1).

Over the whole 3-year study, there has been a large amount of sediment movement (Figure 3). The net sediment change was 1,423,000 ± 959,000 m^3 eroded (refer to table 1). The most sediment was lost from the walls, narrow bends, canyon head, and walls of the axis channel. Deposition was mostly located in the head of the canyon near the mouth of the harbor.

The trace of the canyon lip showed little change 1 kilometer from the canyon head (Figure 4). However, the lip of the upper 1 km of the canyon did change including around the Moss Landing harbor jetties (Figure 5). The canyon appears to be moving outward (A,B,C,D of figure 5) and inward (B of figure 5).

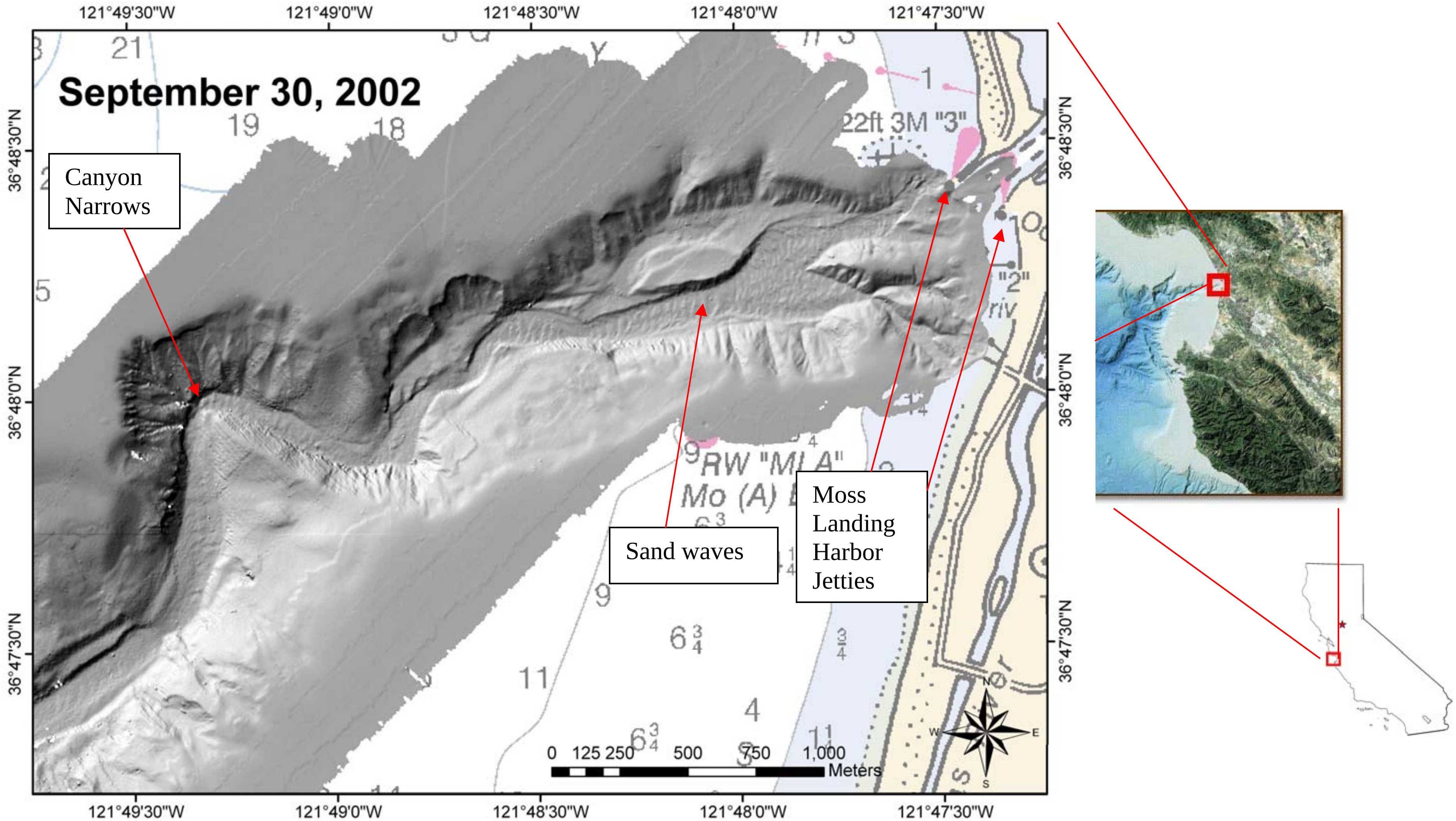

Figure 1. Monterey Bay Submarine Canyon collected September 30, 2002. 3m resolution with sun illumination from the northwest.

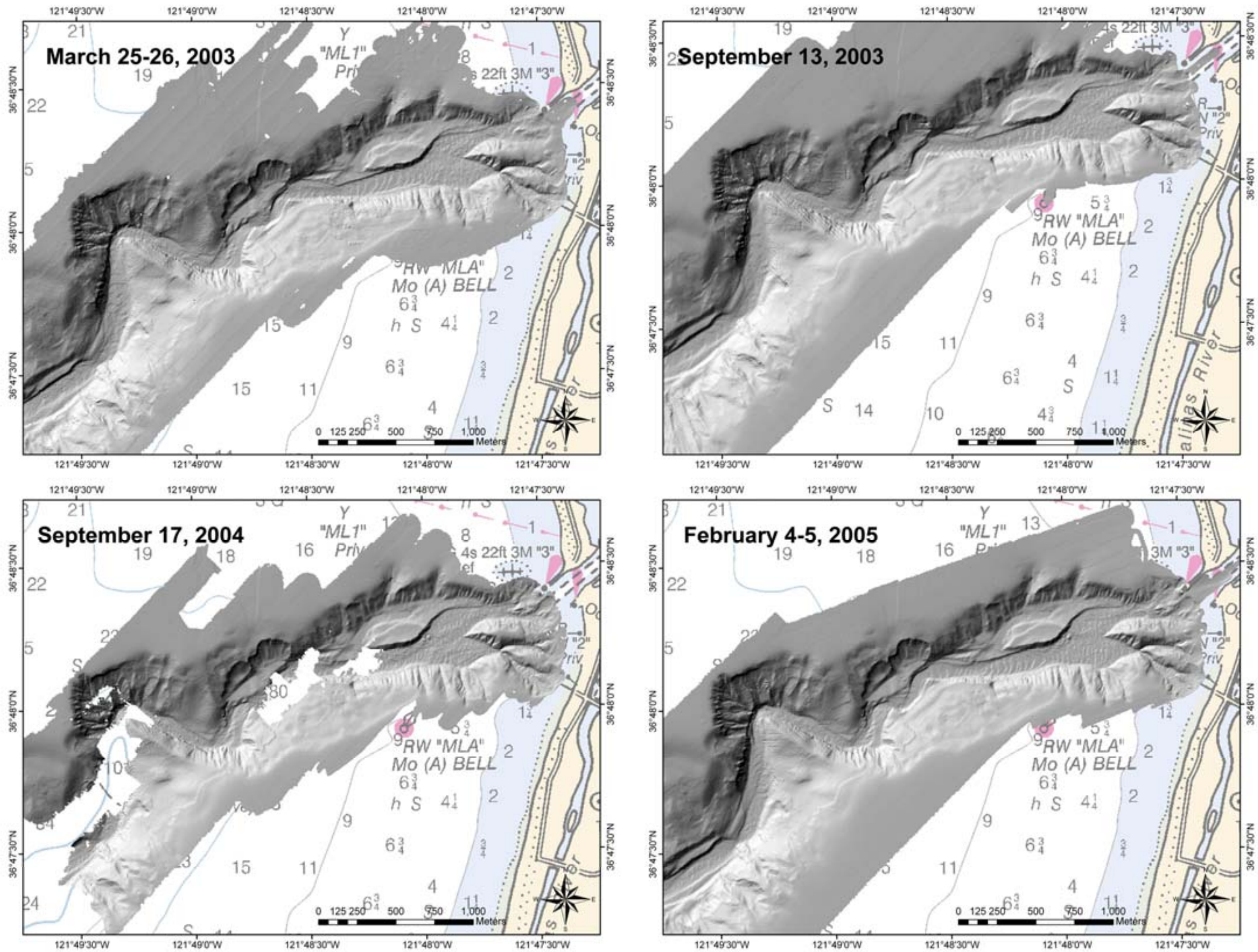

Figure 2. Subsequent Monterey Bay Submarine Canyon collected after September 2002. 3m resolution with sun illumination from the northwest. Holes in the September 19, 2004 survey as a result of schools of fish.

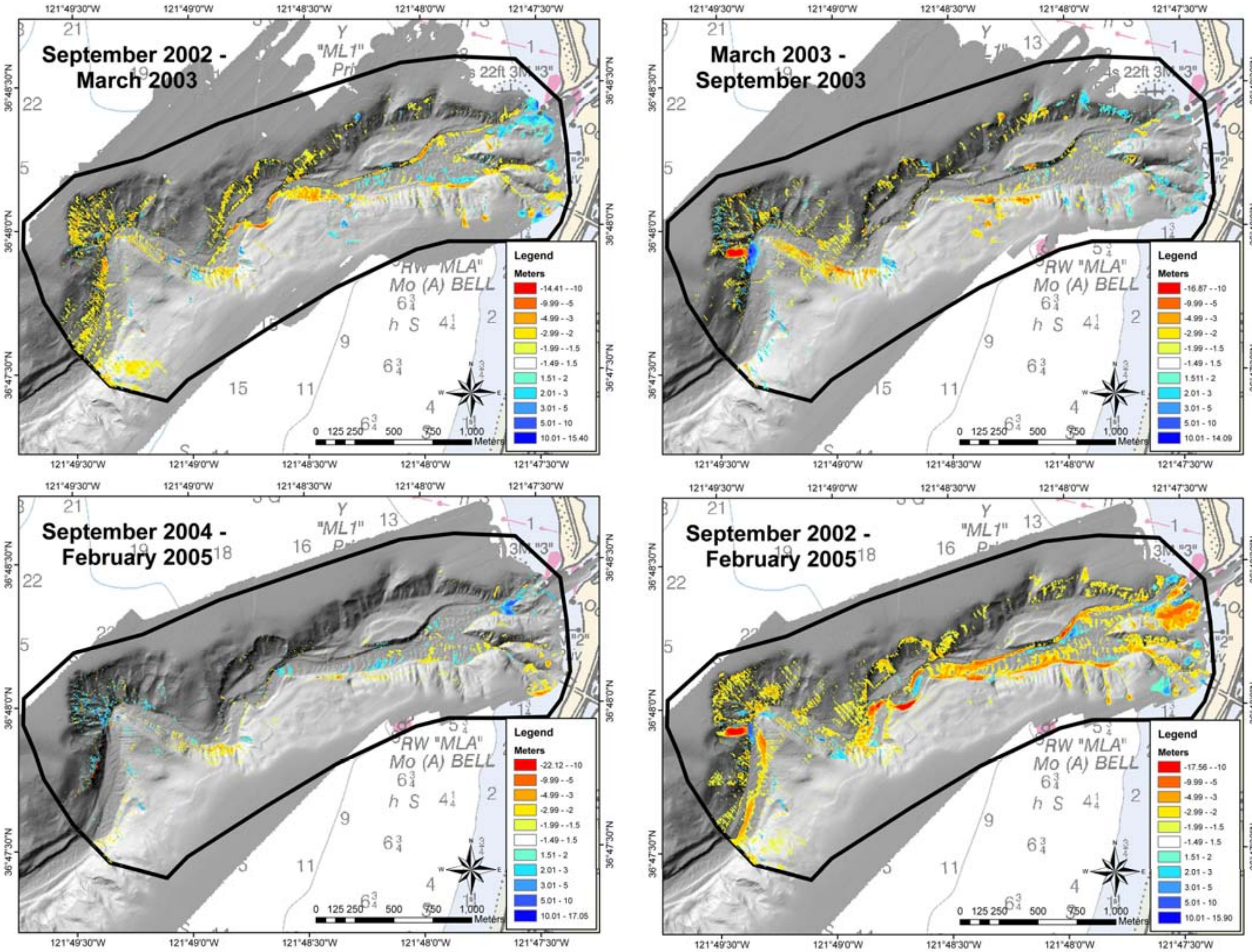

Figure 3. Monterey Bay Submarine Canyon illustrating sediment change between September 19, 2002 and February 4, 2005. Warmer colors indicate erosion and cooler colors indicate deposition.

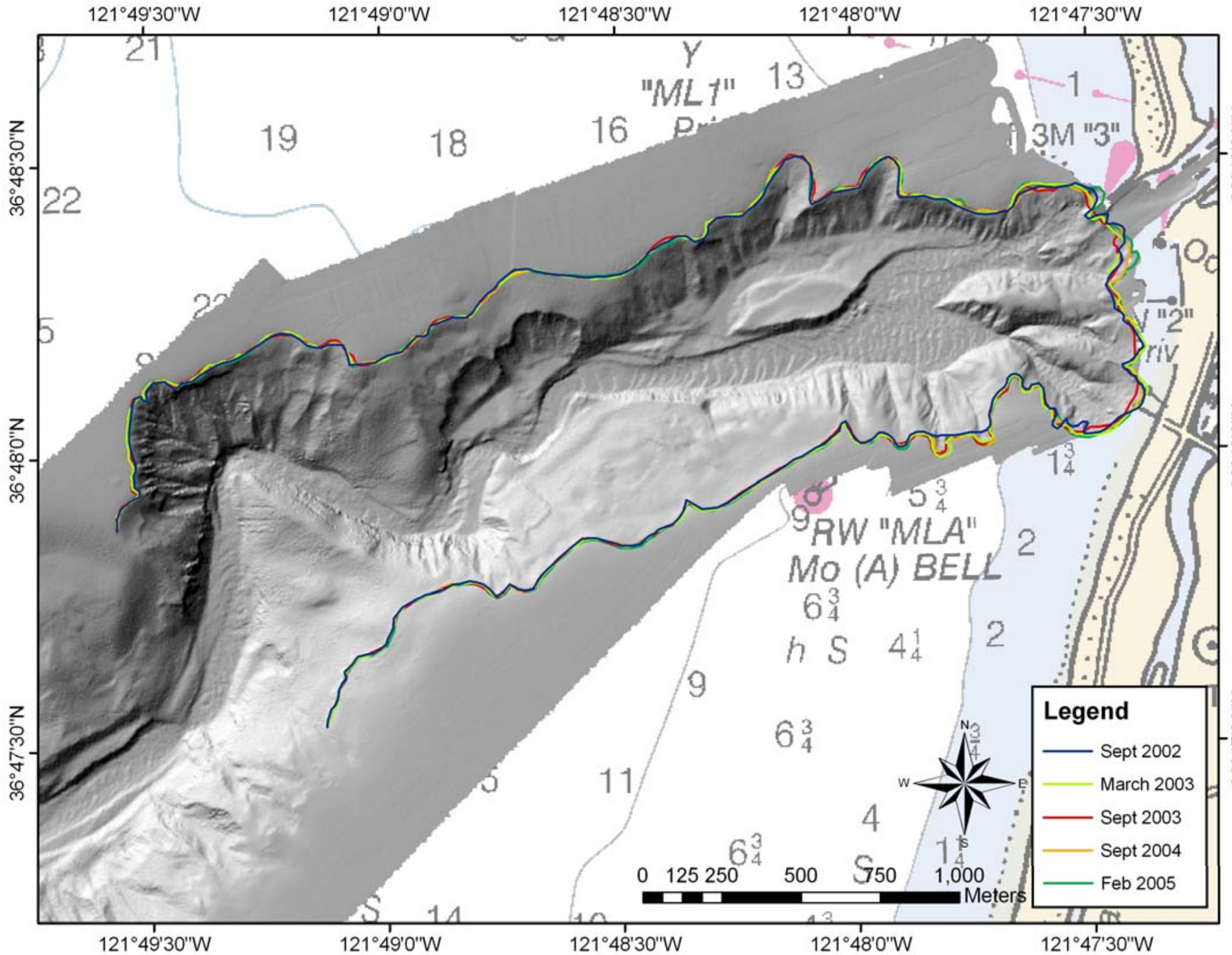

Figure 4. Line trace of the Monterey Submarine Canyon lip.

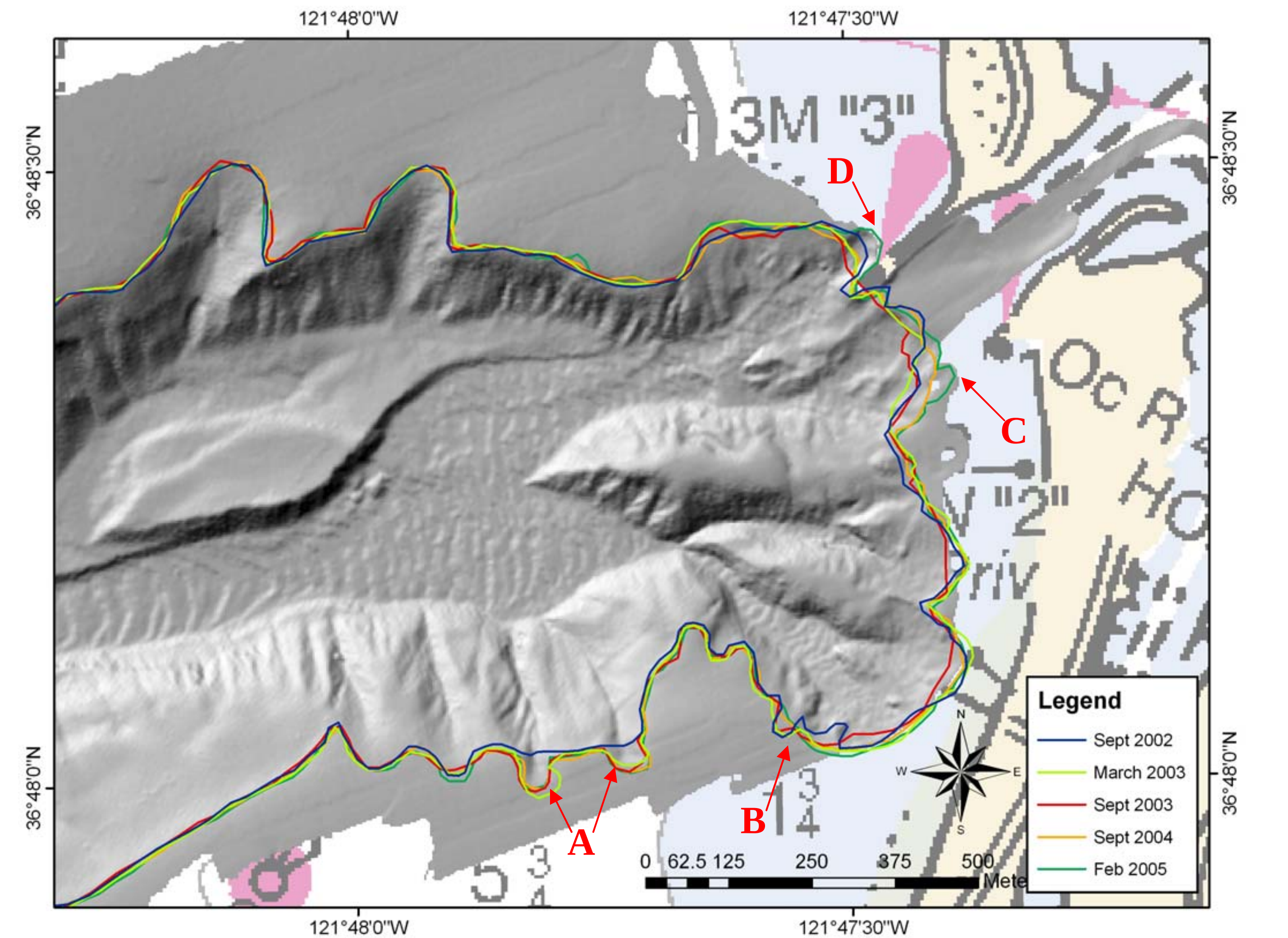

Figure 5. Line trace of the Monterey Submarine Canyon lip around the head.

Table 1. The approximate amount of sediment change between surveys.

Surveys compared	Deposition (m^3)	Erosion (m^3)	Net Sediment Change (m^3)
Sept 2002 - March 2003	232,000 ± 146,000	-793,000 ± 513,000	-561,000 ± 659,000
March 2003 - Sept 2003	255,000 ± 157,000	-575,000 ± 328,000	-320,000 ± 485,000
Sept 2004 - Feb 2005	160,000 ± 98,000	-207,000 ± 136,000	-47,000 ± 234,000
Sept 2002 - Feb 2005	180,000 ± 109,000	-1,603,000 ± 851,000	-1,423,000 ± 959,000

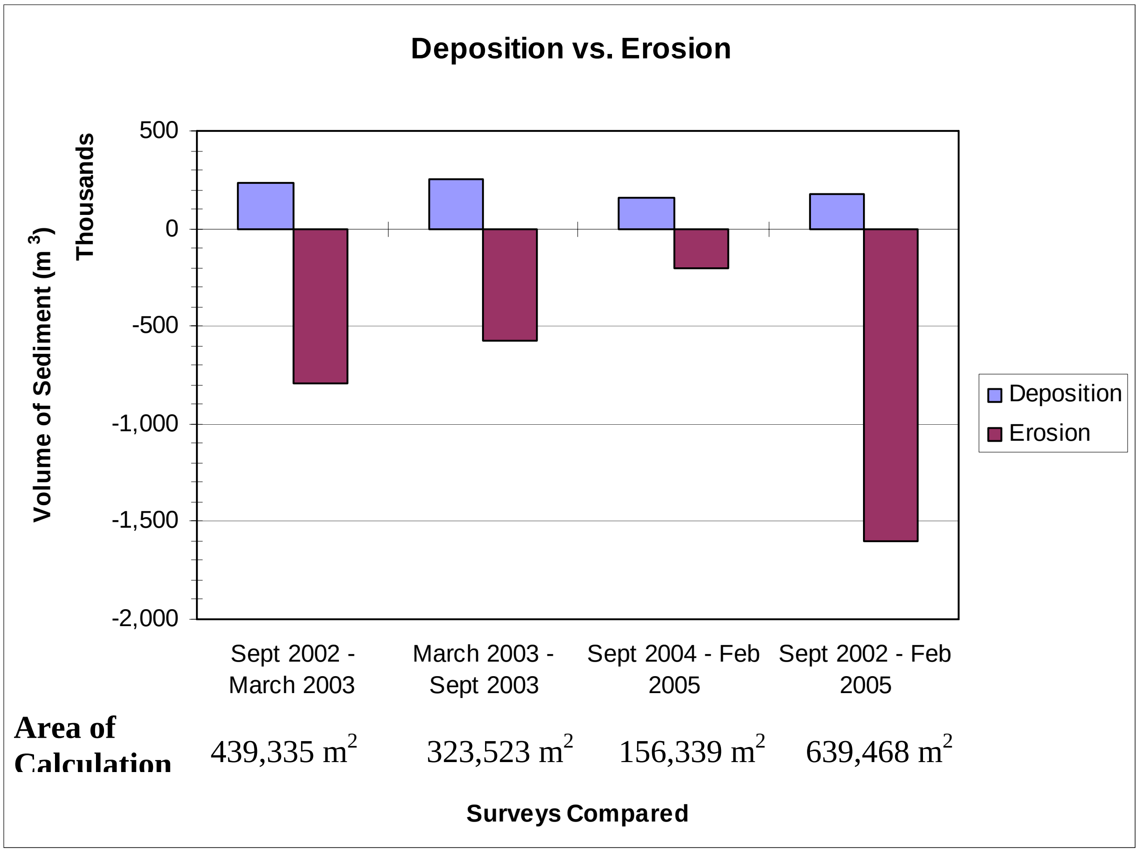

Figure 6. Graph comparing deposition and erosion between each survey.

Discussion

From the 3 semi annual subtractions, the hypothesis that the canyon is static is not supported when considering the entire canyon head area. Winter and summer months in 2003 and 2004 experienced larger amounts of erosion than deposition (Figure 6). In addition, the Monterey Submarine Canyon head appears to be in a constant erosional phase rather than an oscillating pattern. Over the 3-year time series data, there was much more erosion than deposition. If the Monterey Canyon head were in an oscillating pattern, we would expect the net sediment change to be closer to 0.

The canyon lip exhibited different amounts of change at different areas of the canyon. The deeper areas of the canyon lip exhibited little change over the 3-year period. Closer to shore, the lip of the canyon exhibited visible movement. One area of the lip moving outward is where Smith (2005) and Ruiz (2003) described 2 growing gullies in the south tributary (A of figure 5). East of the gullies (B of figure 5) is an area of the canyon lip that moved inward approximately 30m between September 2003 and September 2004. Also, in this area, the wall moved outward by approximately 50m over the 3-year period. The lip near the south jetty of the harbor has moved approximately 60m between September 2003 and February 2005 (C of figure 5). This rate is about 30m a year. The lip around the north jetty appears to be moving outward, but the data coverage of the lip was incomplete for the surveys (D of figure 5). The trace shows the edge of the survey area.

The February 2005 survey shows that the lip is close to shore around both the north and south jetties. If the canyon near the south jetty continues to move at 30m/year, the lip could be at the jetty in 2 years. Both jetties could be at risk of being swallowed by the canyon in the near future. There are no other areas of the outward movement of the canyon lip that appear to be endangering coastal structures.

This study produced high-resolution bathymetric grids of the Monterey Bay Submarine Canyon. However, due to schools of fish in the bay during the September 2004 survey, there were large holes in key areas of the data. Therefore, the subtraction between the September 2004 survey and the February 2005 survey does not include all the sediment change that occurred in the canyon. If there was a significant amount of sediment deposition or erosion in the areas of the holes, the sediment calculations in this study could be underestimated or overestimated. Furthermore, the edges of the holes of the September 2004 data produce artifacts, which has been included in the sediment change calculations. These artifacts could also make the sediment calculations underestimated or overestimated.

Liu (2004) and Mullenbach (2004) found net deposition in canyons using sediment core studies. They tested several points in those canyons. Using bathymetric surveys of the Monterey Canyon over time, this study found that there was a net trend toward erosion rather than deposition over the entire canyon head.

This study of the Monterey Canyon is probably a good model for other active submarine canyons that terminate near a river system. However, this model of net erosion cannot be applied to deeper canyons that do not terminate near shore. Deep canyons experience many other deep-water processes that canyons further up the continental shelf do not experience.

Continuing to survey the Monterey Submarine Canyon could provide evidence of other patterns of geomorphic change. There are many areas that could be mapped in further detail in future surveys. Surveying the lip that approaches the harbor jetties would help determine a rate at which the canyon is approaching the shore. Additionally, surveys of the Slough and Canyon at the same time could provide a stronger connection between amount of erosion in Elkhorn Slough and amount of deposition in the Monterey Bay Submarine Canyon.

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