U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Prepared in cooperation with the
CALIFORNIA DEPARTMENT OF TRANSPORTATION

SCIENTIFIC INVESTIGATIONS MAP 2853

INTRODUCTION

The purpose of this study is to quantify the long-term cliff retreat rates within nine study sections of coastline along the Big Sur coast. The geographic limits of the study sections, ranging from 2.5 km to 8.0 km in along-coast length, correspond to the study sections along which sediment yields were previously determined (figs. 1 and 2) (Hapke and others, 2004). This study was undertaken because there was a fundamental lack of data on the rates at which the coastal cliffs along California State Route 1 (herein called Coast Highway 1) are retreating landward. The California Department of Transportation (Caltrans) committed resources through the Coastal Highway Management Plan to support the necessary research activities related to filling data gaps.

EROSION REFERENCE FEATURE

The erosion reference feature used to calculate the erosion rates is well defined in some areas as a sharp cliff edge (fig. 3, location A), such as where marine terraces are present. In other parts of the coast, the cliff edge is very poorly defined. In these areas the erosion reference feature used is the edge of the manmade road grade where the basal part of the slope is visibly active from the slope base to the road grade (fig. 3, location B). The erosion reference feature in this case is not extended upward to the top of the visibly active slope above the road for several reasons. In many places, such as shown by the arrow above location B on figure 3, the slope above the road is engineered and therefore may only appear active as a result of anthropogenic activities. In addition, the top of the active slope above the road is often the site of large landslides that result from deep-seated processes rather than the more surficial processes (slumping and blockfalls) associated with the lower slope cliff edge. Finally, in other areas the erosion reference feature used to measure cliff erosion is the active lower part of the slope where the slope is not visibly active to the road grade (fig. 3, location C). To avoid confusion, the term "cliff retreat rate" will be used to refer to the landward retreat of all of these features.

METHODS

The primary tools used for this analysis were digital photogrammetry and geographic information system (GIS). Digital photogrammetry was used to process the historical (1942) and recent (1994) vertical aerial photographs to generate three-dimensional stereo models. The cliff edges were digitized directly from the models while viewing in stereo to ensure that the actual break in slope was digitized as the erosion reference feature (cliff edge). The cliff edges were then brought into a GIS where a shore-parallel baseline was generated. The baseline can follow the shape of the coast, or it may be a straight line with the same azimuth as the average orientation of the coastline. For the average rates presented for each study section (figs. 4*A-I*), a coast-parallel baseline was used for greater accuracy. However, for purposes of visual clarity on figures 4*A-I* , a straight baseline parallel to the regional azimuth of the coast was used. Once the baseline was established, orthogonal transects extending from the baseline to the coast were generated using the Digitial Shoreline Assessment System, or DSAS (Thieler and others, 2003). The spacing of the transects for the average erosion rate calculations was 15 m; on figures 4*A-I*, the spacing shown is 25 m. DSAS was then used to calculate the positional difference between the two cliff edges along each transect to establish cliff retreat rates.

COASTAL CLIFF RETREAT

The results of the cliff retreat analysis are shown in table 1 and figures 4*A-I*. The shore-parallel length for each section and the average cliff retreat rates are provided for nine study sections of coastline. The average cliff retreat rate for the total of 45 km of coastline studied along Coast Highway 1 is 18 ± 6 cm/yr based on the analysis for the nine study sections. The error, shown by a dotted line on figures 4*A-I*, represents 2 standard deviations to provide a 95 percent confidence interval. This assumes the error is random and follows a normal distribution. The cliff retreat rates vary substantially and range from 12 ± 7 cm/yr in study section 1 (fig. 4*A*) to a high of 25 ± 5 cm/yr in study section 3 (fig. 4*C*), near the town of Big Sur. In section 3 the average rate is higher because of an episodic failure along a very small (< 50 m) part of the cliff. Cliff retreat rates are presented in this study as yearly averages. While average values are often very useful for long-term management planning, the actual processes of cliff retreat are highly episodic; a large retreat event during a series of storms may account for most of the retreat in any given area. With the exception of study section 8 (fig. 4*H*), in which the retreat is relatively evenly distributed, most areas have one or two erosion hotspots that account for much of the average cliff retreat rate.

The cliff retreat rates are correlated to the variable geology of the area (fig. 5) to assess the relation between lithology and cliff retreat. For descriptions of the geology of the study sections, see Hapke and others (2004). There is a general trend that suggests the stronger granitic rocks have lower cliff retreat rates, and the weaker materials (mélange of the Franciscan Complex) have higher rates. However, study sections 3, 4, and 5 have the highest retreat rates, respectively, and are associated with cliffs in the stronger granitic rocks (study section 4) and sedimentary units of the Franciscan Complex (study sections 3 and 5). These results imply that there are parameters in addition to material strength that influence how rapidly the cliffs are retreating along the Big Sur coast. While it is beyond the scope of this study to explore these factors, such parameters may include prior history of slope disturbance (natural or anthropogenic), distribution and density of geologic structure, hydrologic conditions, and protection (or lack thereof) at the base of the slope such as beaches or debris fans.

SUMMARY

Coast Highway 1 along the Big Sur coast is regularly subjected to damage from coastal cliff retreat, because the steep slopes experience both high amounts of precipitation and high wave energy during the winter months. This study provides coastal cliff retreat rates along nine discontinuous study sections of the Big Sur coast. Three-dimensional stereo models from a previous study (Hapke and others, 2004) were used to digitize cliff edges, and the retreat rates were calculated for a 52-year time period from 1942 to 1994. The average cliff retreat rate was 18 ± 6 cm/yr along the total 45 km of coast measured in this study. The lowest retreat rates (12 ± 7 cm/yr) are associated with the stronger granitic rocks, located primarily in the northern part of the Big Sur coast (study sections 1 and 2). The highest rate (25 ±5 cm/yr) is along the coast just south of the town of Big Sur where it appears a large promontory on the slope completely eroded away or collapsed during the time period of the analysis (1942 to 1994).

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Wills, C.J., Manson, M.W., Brown, K.D. Davenport, C.W., and Domrose, C.J., 2001, Landslides in the Highway 1 Corridor: Geology and slope stability along the Big Sur Coast; Report to the Coast Highway Management Plan Caltrans District 5, 29 p.

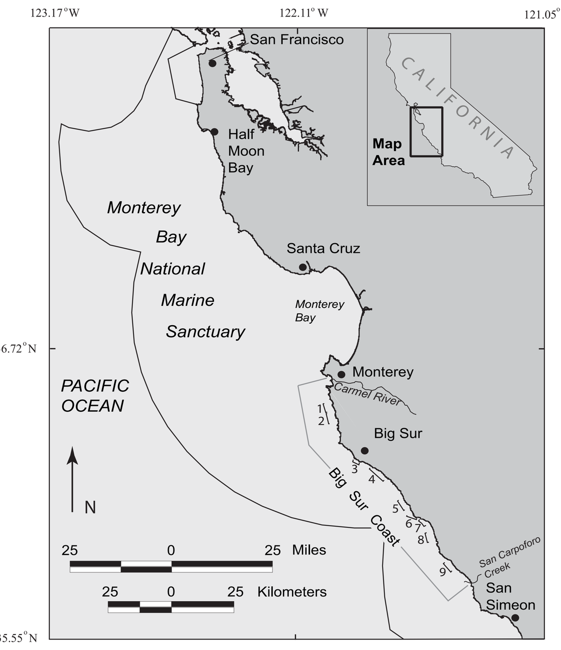

Figure 1. Map showing location of the Monterey Bay National Marine Sanctuary and the Big Sur coast in central California. Numbers 1-9 shown on the map correspond to the specific study sections shown in figure 4.

Table 1. Coastal cliff retreat rates for the nine study sections shown in figure 4 from 1942-1994

Study section No.	Post Mile*	Along-coast length, km	Retreat Rate, cm/yr
1	63.1-66.0	4.5	12±7
2	59.5-63.0	5.5	12±7
3	45.6-46.6	2.5	25±5
4	36.8-41.5	7.3	22±7
5	26.0-29.2	5.3	21±6
6	21.3-24.1	5.0	17±6
7	19.4-21.2	3.0	17±6
8	14.0-17.4	8.0	20±6
9	73.0(SLO)-3.5	5.0	20±7

*All post miles are in Monterey County unless otherwise denoted; SLO, San Luis Obisbo County.

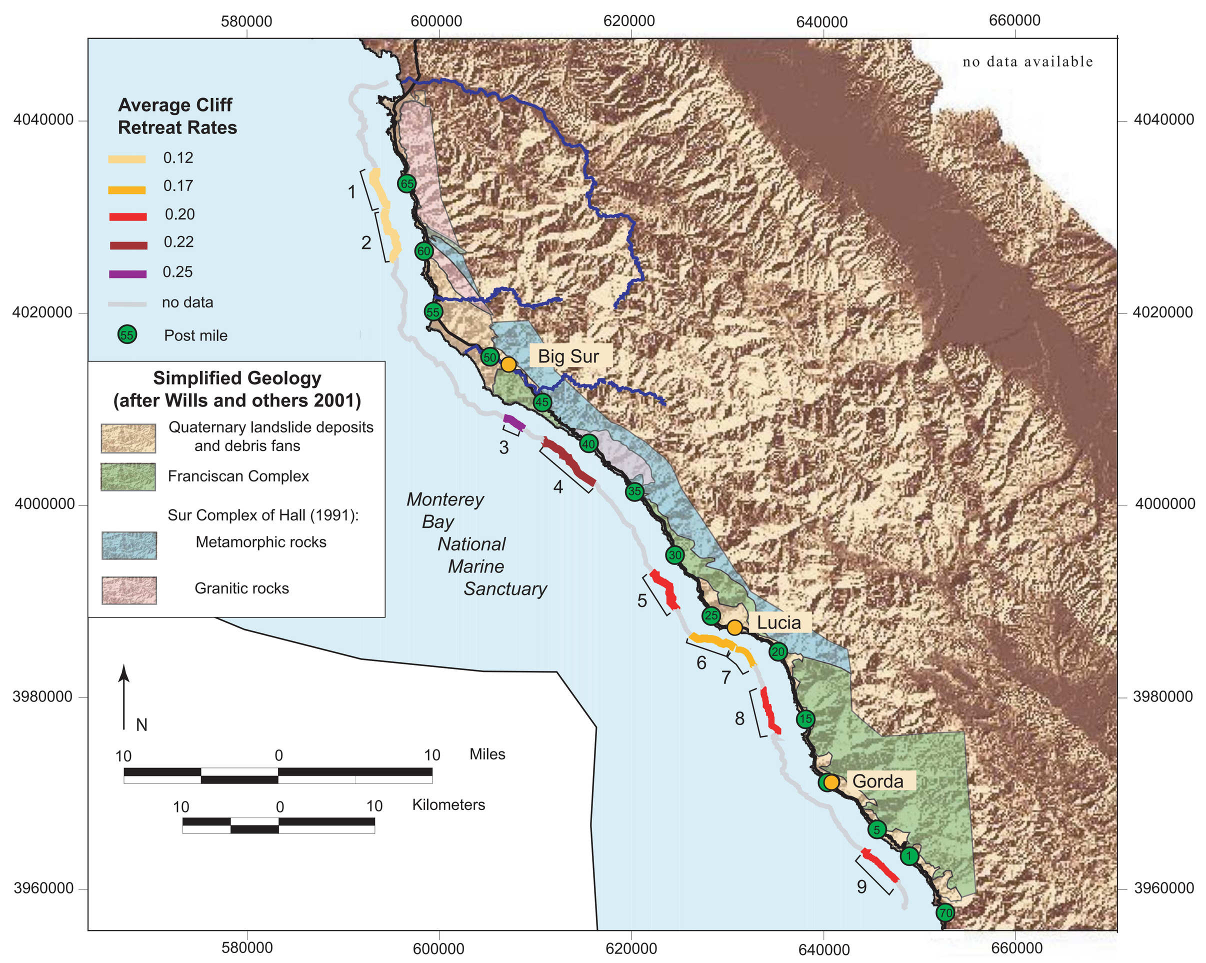

Figure 2. Map showing locations of the nine study sections of coast near Big Sur, California, and the average cliff retreat rates associated with each study section .

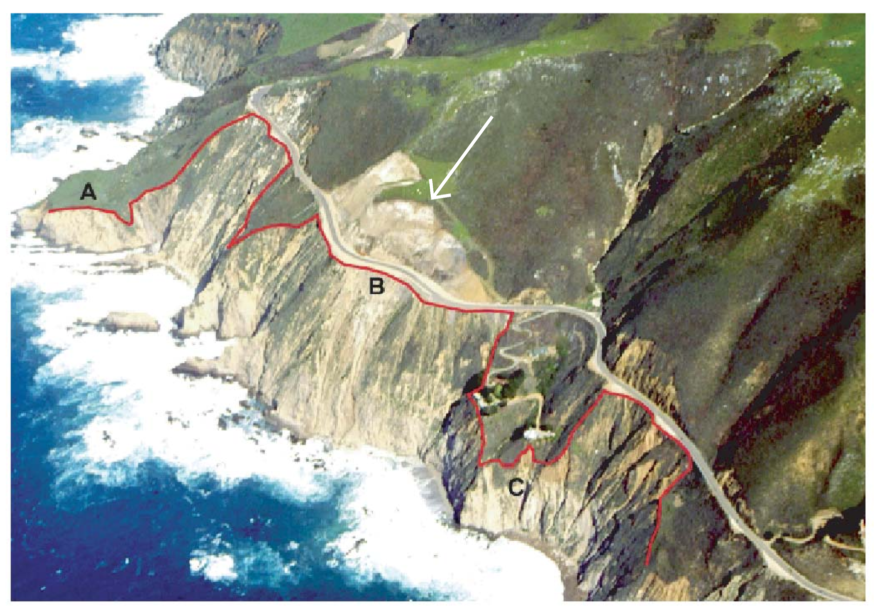

Figure 3. Oblique aerial photograph of Big Sur coast. Red line shows feature digitized as cliff edge. Letters A, B, and C represent different morphologies of the cliff edge. A, sharp cliff; B, active slope extending to road grade; C, active slope not visibly active to road grade. White arrow shows an engineered slope above road.

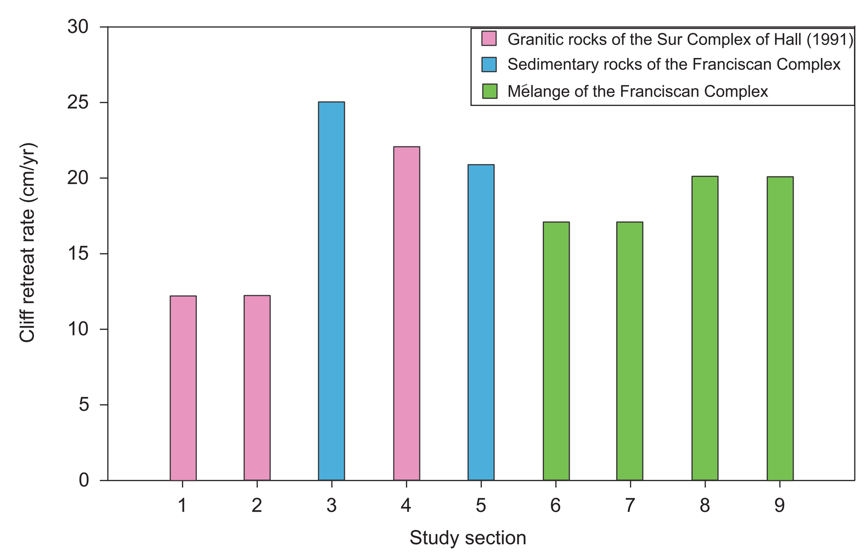

Figure 5. Relation between lithology and cliff retreat rates for the nine study sections of coast near Big Sur, California.

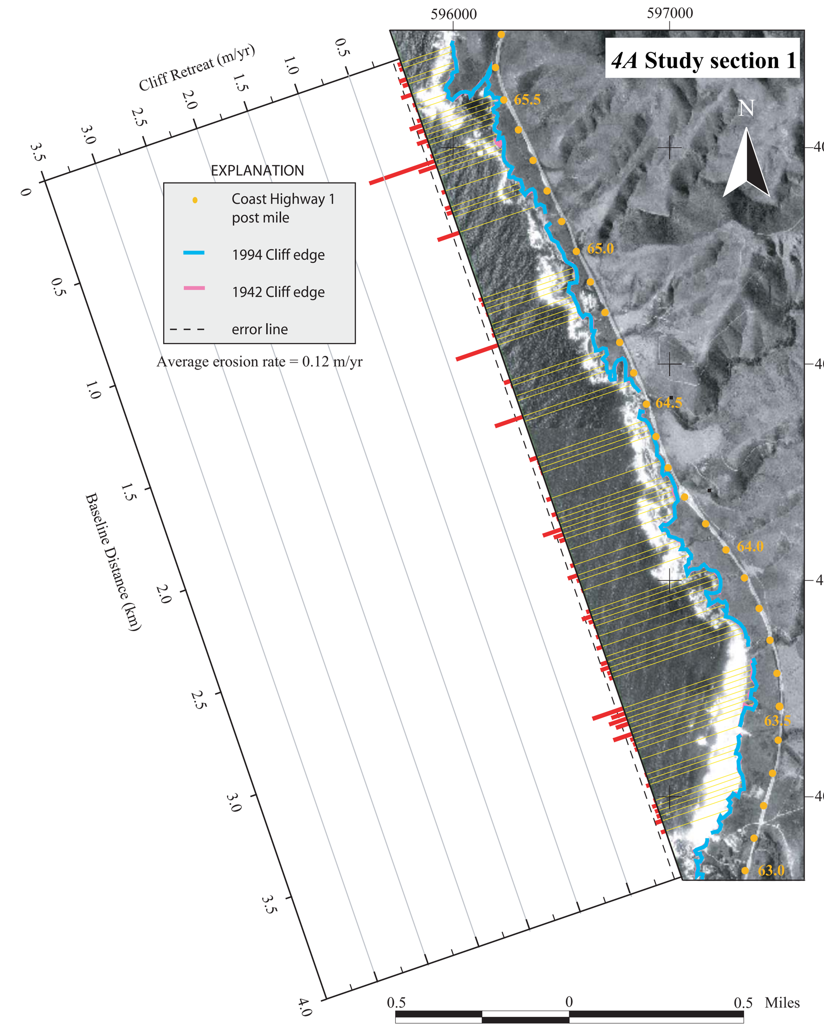

Figure 4A. Cliff retreat rates for study section 1 of the Big Sur coast.

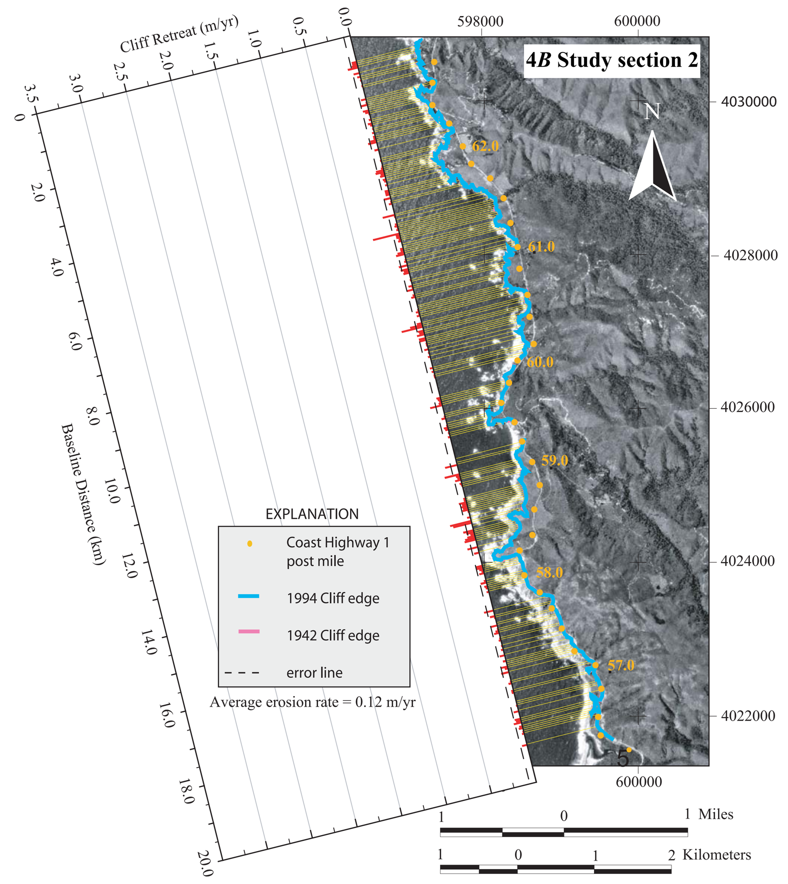

Figure 4B. Cliff retreat rates for study section 2 of the Big Sur coast.

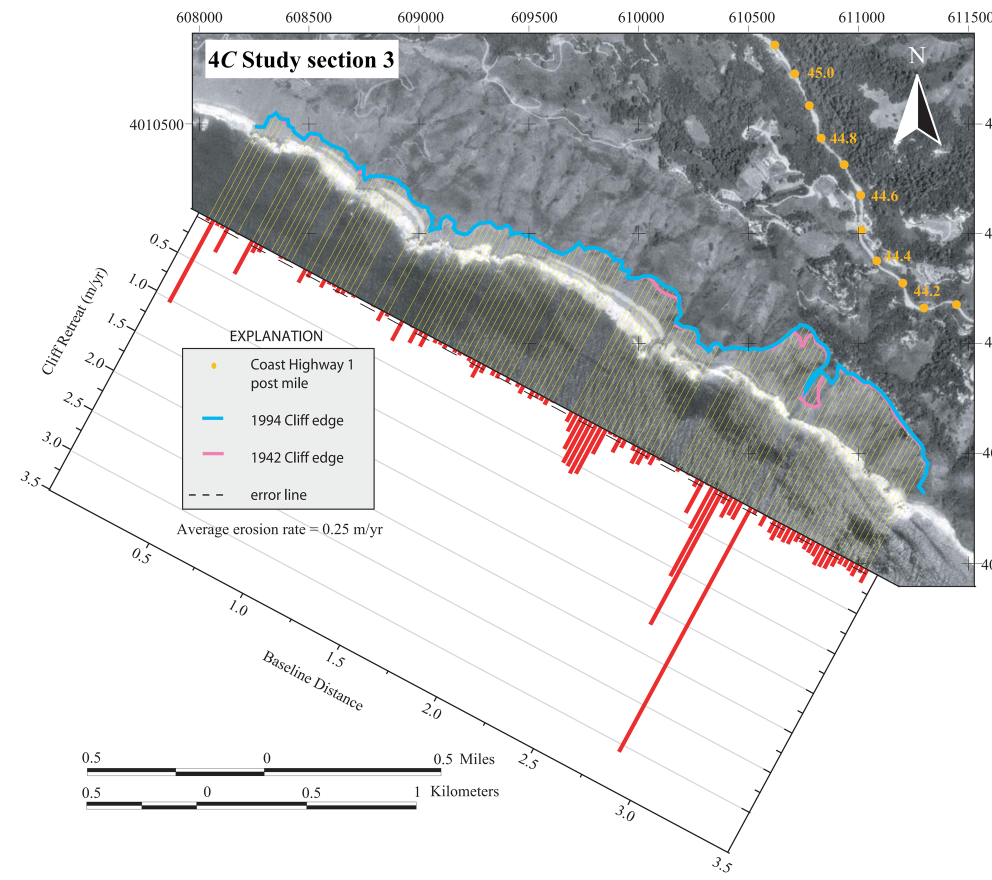

Figure 4C. Cliff retreat rates for study section 3 of the Big Sur coast.

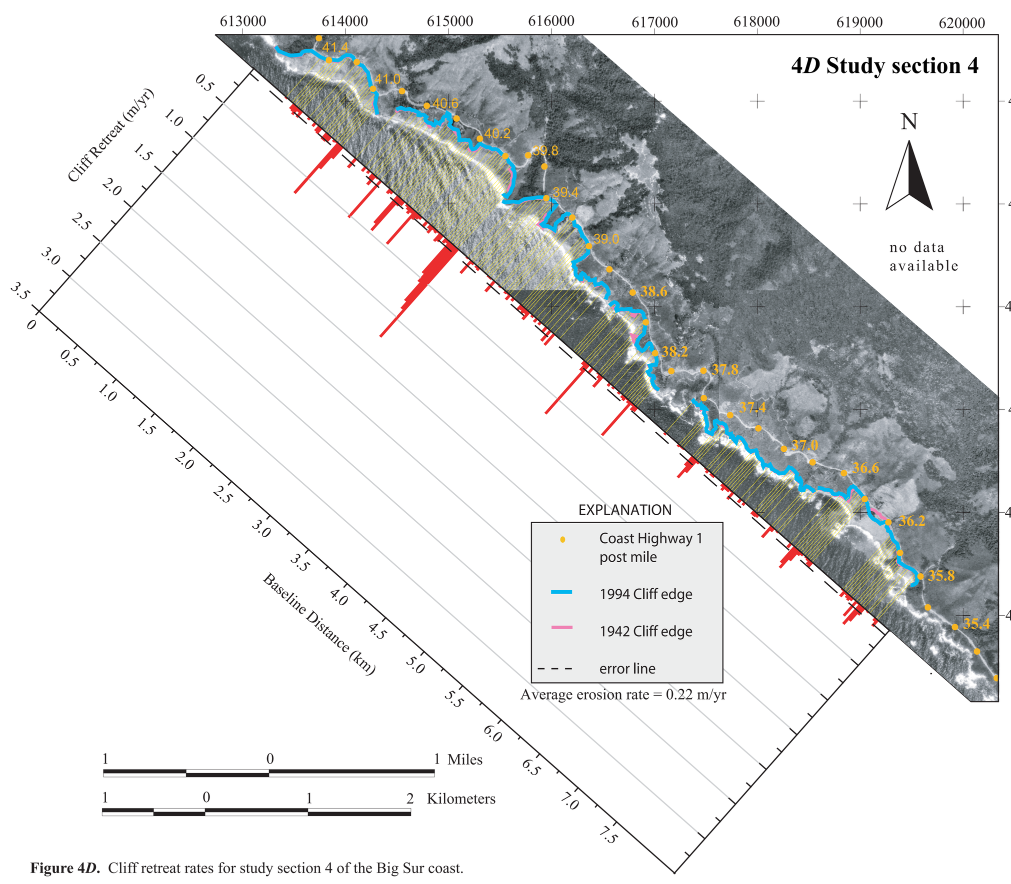

Figure 4D. Cliff retreat rates for study section 4 of the Big Sur coast.

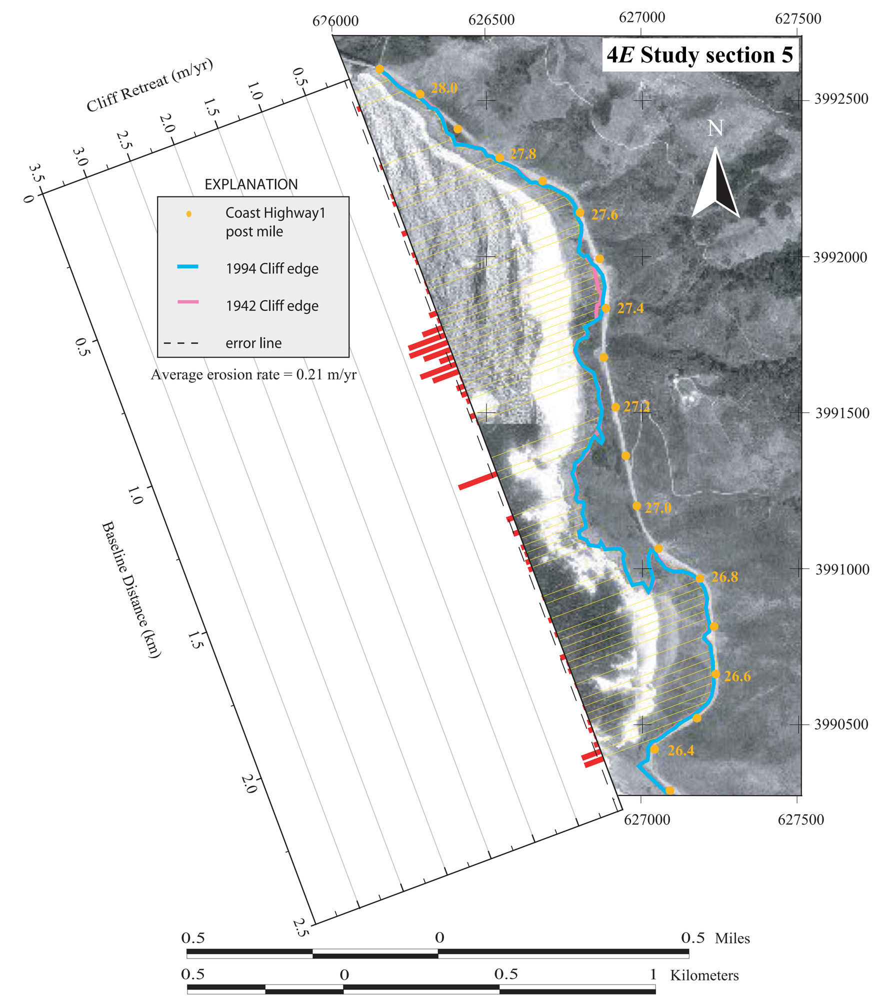

Figure 4E. Cliff retreat rates for study section 5 of the Big Sur coast.

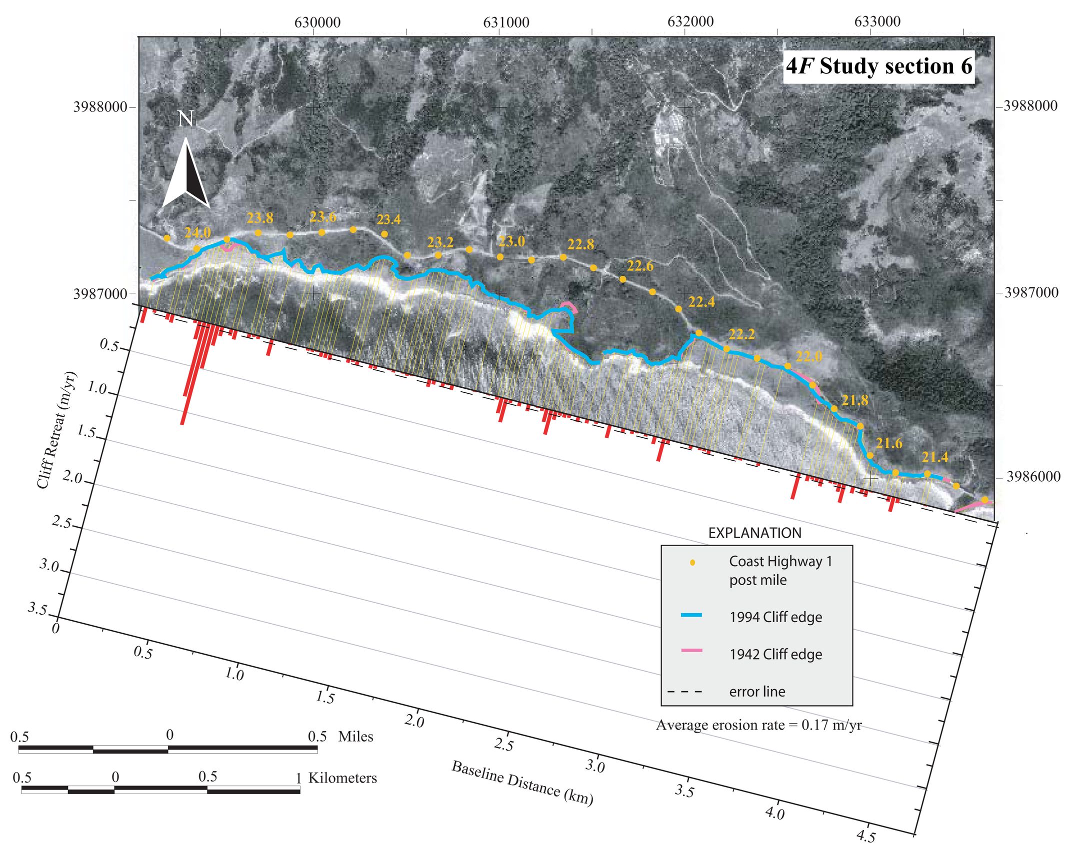

Figure 4F. Cliff retreat rates for study section 6 of the Big Sur coast.

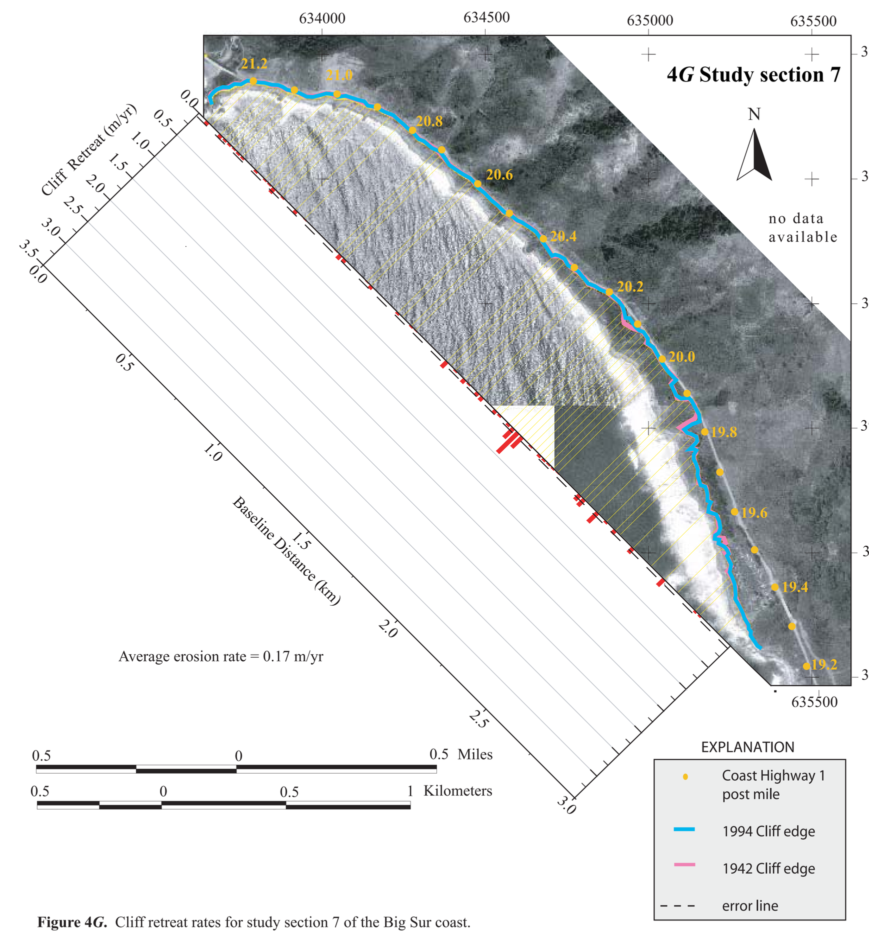

Figure 4G. Cliff retreat rates for study section 7 of the Big Sur coast.

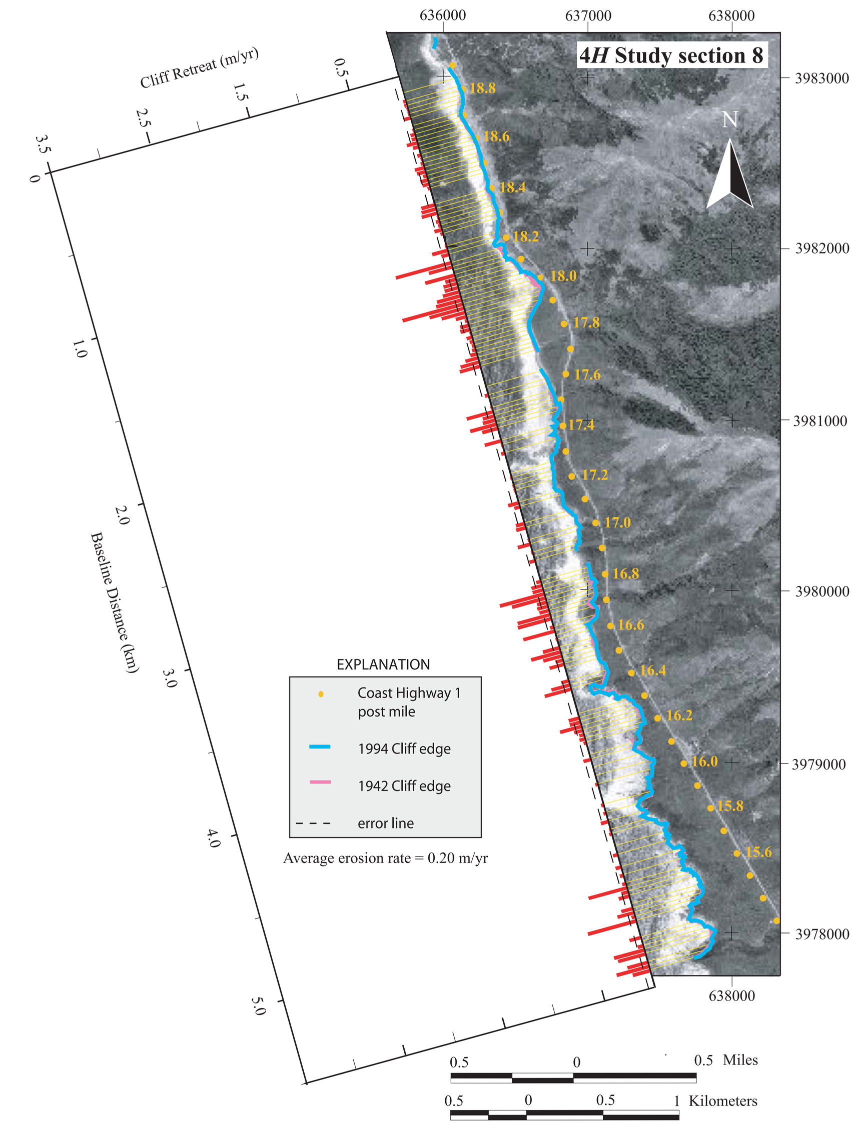

Figure 4H. Cliff retreat rates for study section 8 of the Big Sur coast.

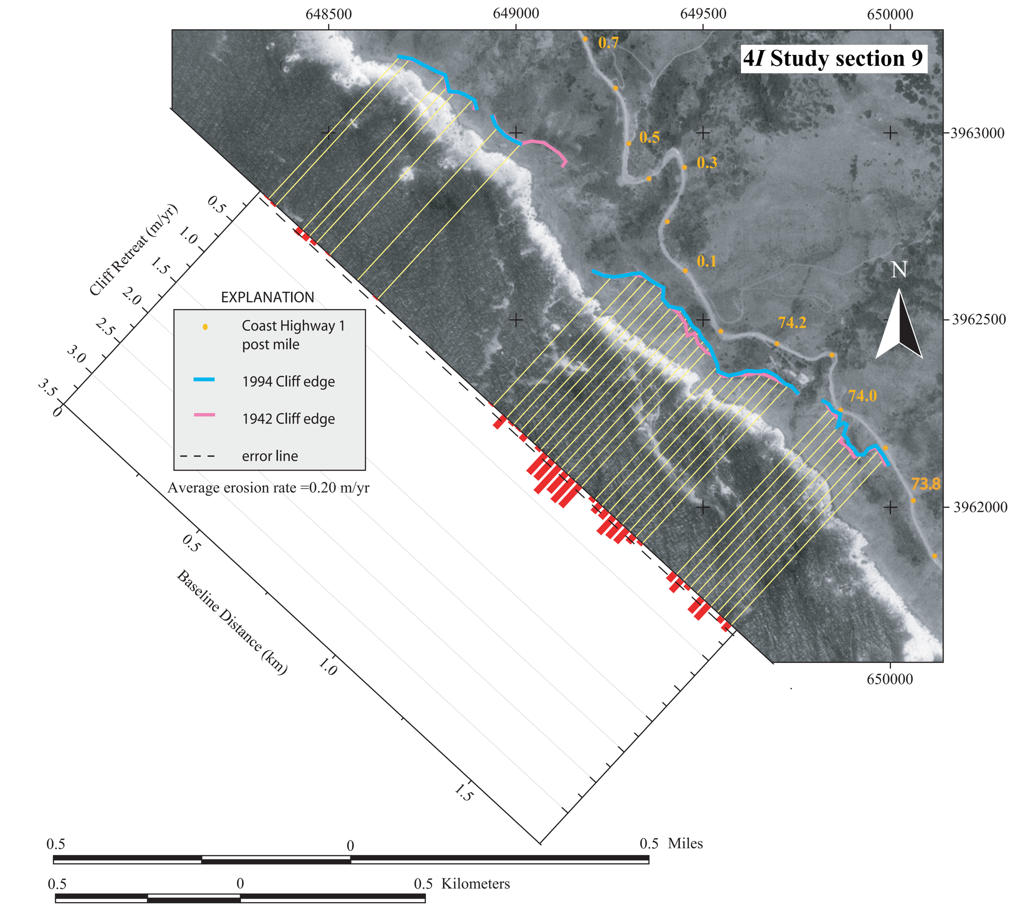

Figure 4I. Cliff retreat rates for study section 9 of the Big Sur coast.

Maps Showing Coastal Cliff Retreat Rates Along the Big Sur Coast, Monterey and San Luis Obispo Counties, California

By
Cheryl J. Hapke and Krystal R. Green

2004

Orthophotographs from U.S. Geological Survey DOQ, UTM Zone 10, NAD 83.
Transects and erosion rates were generated using the Digital Shoreline Analysis System (DSAS).
Cliff edges were derived from 1994 and 1942 topographic models generated from stereo aerial photographs by Cheryl Hapke, 2003.

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