Moss Beach Project

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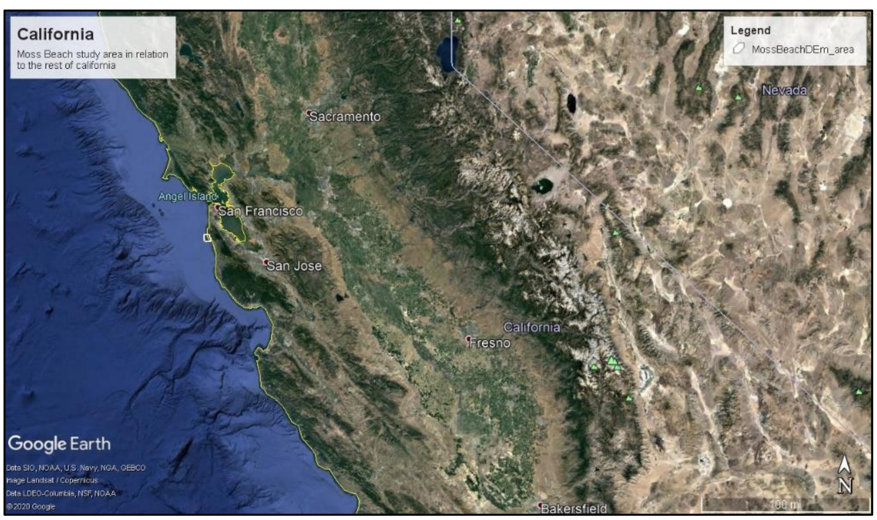
contents

Introduction

Moss beach is a somewhat densely populated area in California that is cut by the San Gregoria fault. It is located near many structural and geomorphological features and is subject to many hazards. With so many local residents and businesses that inhabit this area, are these features and hazards a cause for concern? When did the San Gregoria fault slip last and is it still active? Is the area currently experiencing uplift, and if so, how quickly is it occurring? A description of the risks associated with the geomorphology as well as a description of the structural geology of the area will be created and interpreted using open source GIS software as well as a free drafting program to draw geologic cross sections, a program to create stereonets and google earth for satellite imagery. All of the data will be created by digitizing features seen from a given digital elevation model. The resulting maps in conjunction with age data will be used to calculate uplift rates as well as display the structural and geomorphological features in the study area.

Geologic Setting

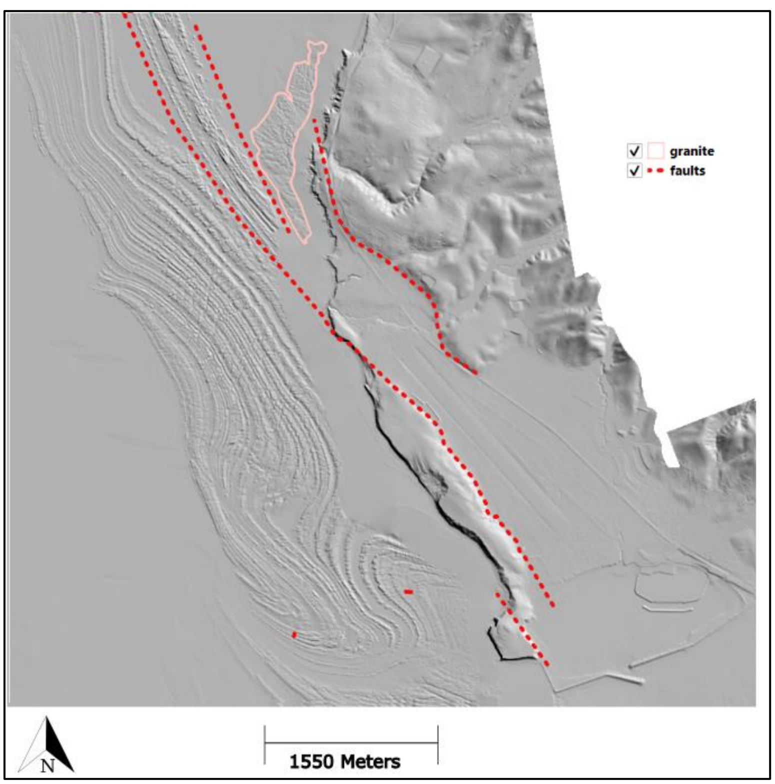
Moss beach is located on the Western coast of California, south west of San Francisco (Fig.1 and Fig.2) and is cut by the San Gregoria fault. The San Gregorio is a right lateral strike slip fault that is the westernmost part of the San Andreas fault system and is by definition active. It was discovered using paleoseismologic techniques and recent historical records that the most recent slipping event occurred between 800 and 300 years ago (Simpson et al. 1997). The area we are studying is 35 square kilometers in size and includes the region offshore that displays a series of large folds as well as smaller scale faults, joints and fractures. The San Gregorio fault can be traced on land cutting roughly parallel to the coast and continuing offshore to the north. The other faults in the area have similar orientations, also running north west to south east. To the west of our study area is the boundary of the Pacific plate and North American plate. This plate boundary is special since it is not just a subduction zone. Since there is a spreading center on the Pacific plate, as it subducted it also creates a right lateral fault system where the plates meet.



(Fig.1) An area map of the study area in relation to the rest of California.

(Fig.2) A closer image of the study area and a polygon representing the DEM used for subsequent GIS interpretations.

The lithology is comprised of clastic sedimentary rocks which make up the Purisima Formation. These layers lie on top of a granitic batholith called the Montara Mountain Granite and form an unconformable contact. The clastic rocks are all quaternary in age and range from coarse sandstone to fine mudstone and from alluvial fans, stream deposits and marine terrace deposits which cap the bluff. Offshore, the Purisima formation can be seen in the folds from Figure 1. The resistant layers are made of sandstone, which can be seen as ridges in the DEM and the less resistant layers can be seen as smooth flat lying layers between the ridges. The Montara granite can also be seen offshore to the northwest of the bluff (Fig.3).



(Fig.3) A polygon outlining where the Montara Granite can be seen offshore in relation to the San Gregoria Fault.

The main feature on land in the study area is a bluff. The bluff ranges in height from about 100 feet to 180 feet above sea level and only has an area of one square kilometer. The flat top to the bluff is not a manmade feature, it is a marine terrace which formed naturally due to erosion and as such is also an unconformity (Fig.4). Based on Figure 4, we can see that it is an angular unconformity. There are two possibilities on how this bluff became exposed. Either sea level fell, or the area was uplifted. Since we know that sea level has been rising in recent history, the likely answer is that the area has been uplifted. The uplift most likely occurred due to the geometry of the San Gregorio fault. Since the fault is a right lateral strike slip fault that is not perfectly straight, it can experience compression and in turn, uplift. Along the outer edge of the bluff collapse features such as landslides and fault scarps can be seen. These features, along with the faults themselves present the most cause for concern for people who live in the area.

(Fig.4) Google earth imagery demonstrating an angular unconformity in an outcrop of the bluff

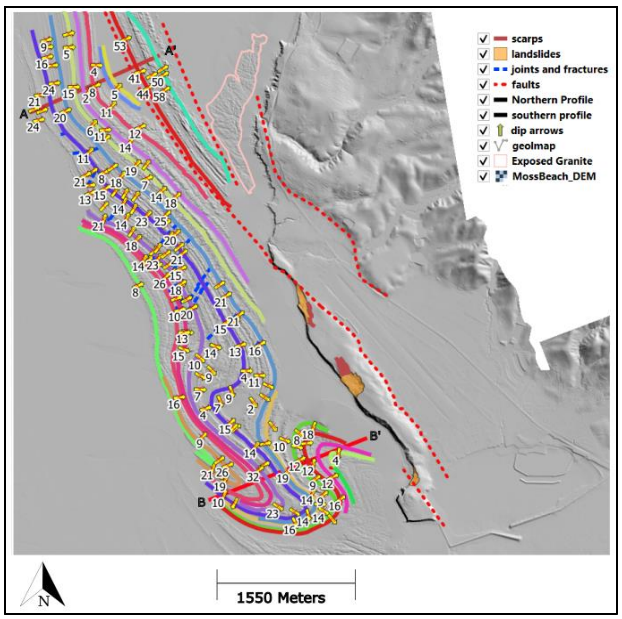
Also visible in figure 4 is a reverse fault. It is kind of difficult to see, so it was digitized to make it clearer (Fig. 4a). If the outcrop were followed further to the east, another reverse fault could also be seen. The faults are present because the San Gregorio fault is experiencing compression as well as being a strike slip fault.

(Fig. 4a) a reverse fault seen in an outcrop of the bluff in the moss beach study area.

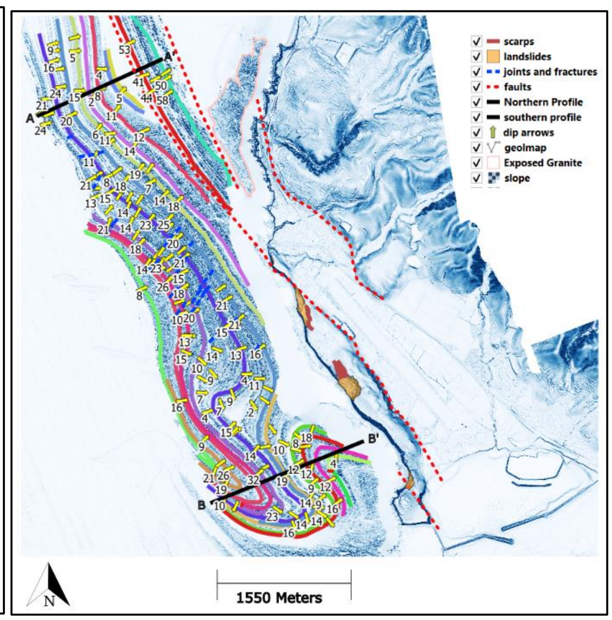
Moss Beach Geomorphology and Structure

All of the analysis was done using only a provided Digital elevation model. Using the DEM faults, folds, dip, dip direction, landslides, scarps, joints, geologic layers and geologic cross sections were digitized and analyzed. Through the rest of this section, these data will be displayed over top of the given DEM and occasionally over a slope raster grid. The slope raster grid was created using the QGIS toolbox slope tool and used to create the dip and dip direction arrows. The slope raster grid shows high slope values in dark blue and low slope values in light blue. The following two figures will display all of the digitized data at once over the two respective grids (Fig.6 and Fig.7). For the remainder of this section and subsequent sections, only relevant data will be displayed to reduce clutter and allow the layouts to remain more easily interpretable.

There is a problem with the digital elevation model that was used. The DEM does not display useful information between the folded layers and the shore. This is because the DEM was created using two types of imaging: sonar for the area underwater and lidar for the land. These two imaging results were combined to create the DEM, but they did not completely overlap, so there is missing information in the area near the coast. This causes a slight issue for the interpretation of the southern cross section but did not affect anything else.

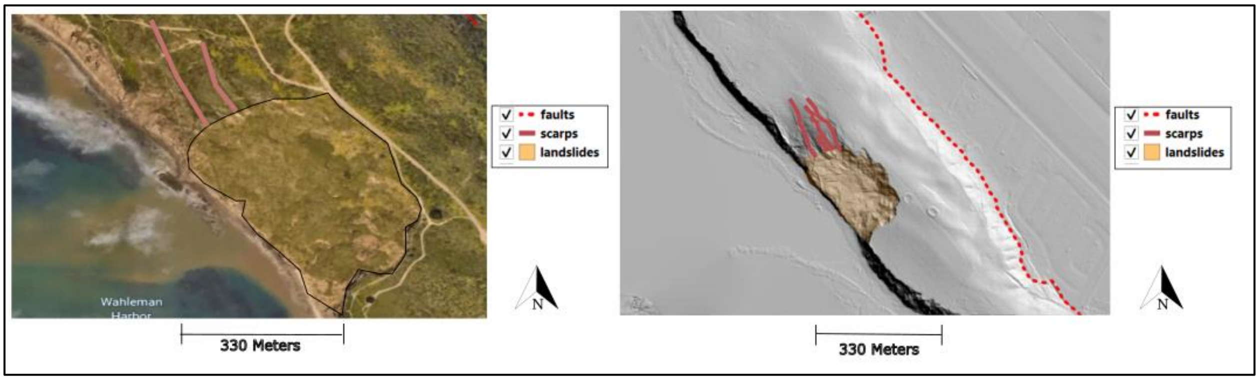


(Fig. 6) A map with all the data displayed using a DEM base map.

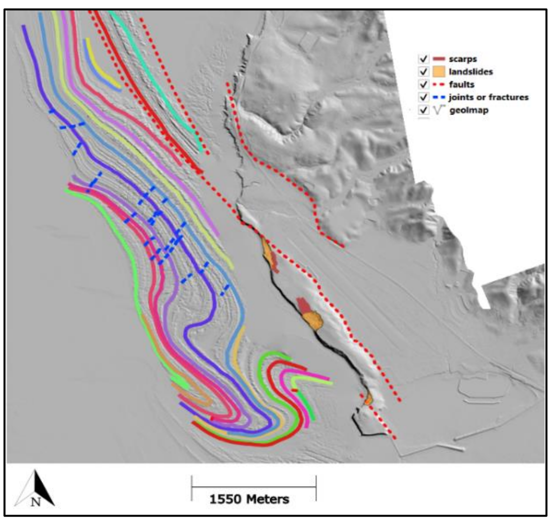


(Fig. 7) A map with all the data displayed using a slope base map.

The main cause for concern for the residents of the moss beach region are the faults, landslides and fault scarps. Landslides with their accompanying scarps can be easily seen in the DEM (fig. 8). Many landslides were large enough to be seen in the DEM, but only the three largest were mapped, the largest one forming in the center portion of the bluff and the other two being in the north and south portions of the bluff. These landslides pose the most threat to residents who live on the western side of the bluff, as that’s where they occur. The southern and central mapped landslides are too far away from any buildings or roads to cause damage, but the effects of the northern one can be seen in satellite imagery. This landslide caused enough damage to a road that it had to be shut down (Fig. 9).At the end of that road is someone’s house, which is starting to fall off the edge of the sea cliff. Another issue is that many neighborhoods and houses are built directly over the San Gregorio fault. While the San Gregorio fault is not creeping, if it were to slip again, any of the structures that were built on it on it would be destroyed. The last time the fault slipped it caused an earthquake with a magnitude of 7.0 to 7.25 (Simpson et al. 1997). An earthquake of that magnitude would cause much destruction now that the area is so densely populated.



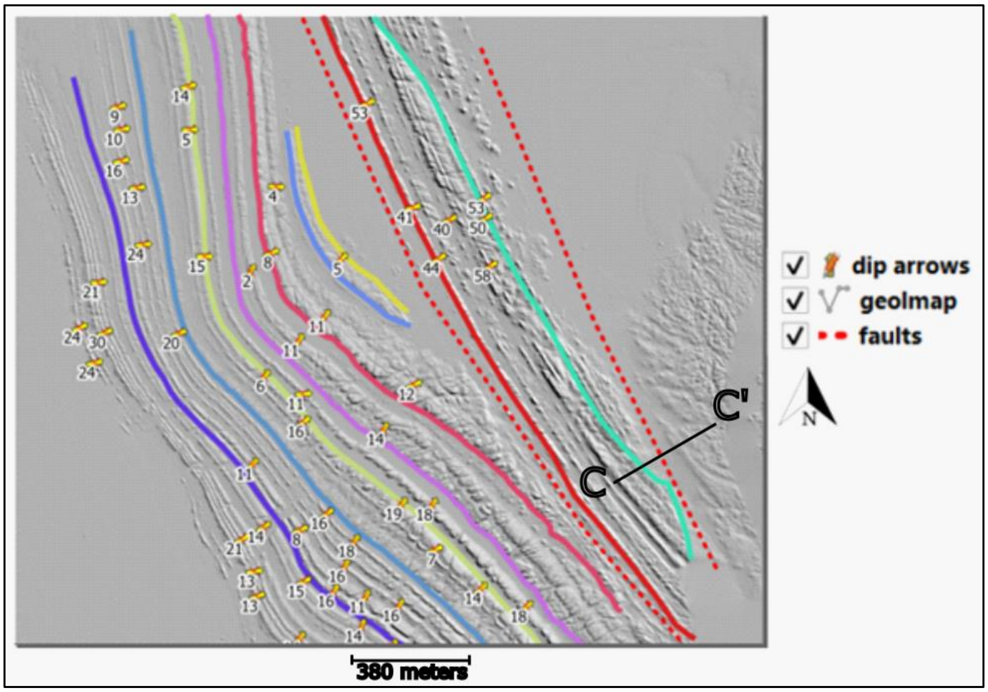
(Fig. 8) Satellite imagery and a digital elevation model with the same landslide and faults scarps mapped on each to show how the DEM displays these features more clearly.



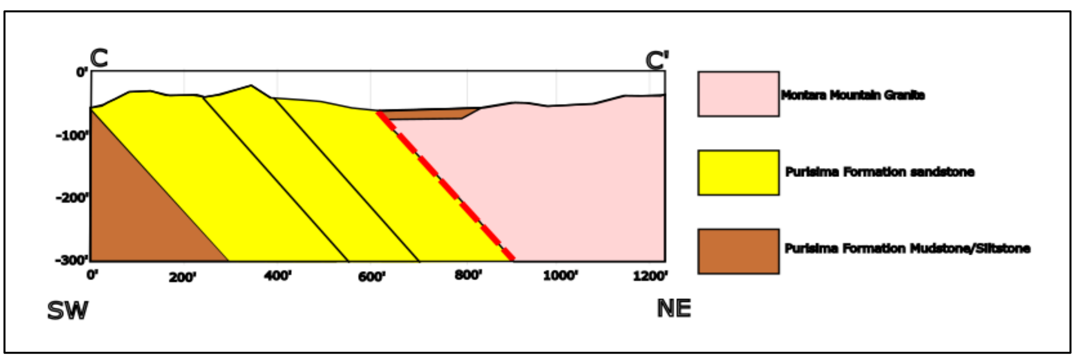
(Fig. 8a) An area map displaying geologic layers as well as some faults, fault scarps and landslides.

(Fig. 9) Satellite imagery of a road that was damaged and shut down due to land slide

All of the mapped faults can be seen in Fig. 8a, but this map is not comprehensive. Even though there are more faults in the study area, only the faults that could be seen or interpreted with the given DEM were mapped. Two of the more notable faults are seen surrounding the bluff in the central eastern portion of the map. The fault on the eastern side of the bluff is the San Gregorio fault, it also continues farther north off land. This fault was easily interpreted as the resistant layers of sandstone to the west are folded and dipping at a low angle and the layers to the west are not folded and have a steep dip (Fig.11). Off shore to the north east there is another fault that does not connect to the land. This fault was interpreted by looking at the surrounding lithologies. To the west of this fault all the lithology is dominated by clastic sedimentary rocks such as sandstones and mudstones, this is the Purisima Formation. To the east of this fault we can see the Montara Mountain Granite. In contrast to what we see on land, it is unlikely that this is an unconformable contact. That would imply the area was overturned since the sedimentary layers are dipping under the granitic layers (Fig. 11a) and it is known that the Purisima formation is younger than the Montara Granite. The north eastern fault that is on land was interpreted by looking at the elevation of the surrounding area. The western side of that fault is relatively flat and low elevation until it reaches the fault along the bluff. This stark contrast of the elevation suggests that there has to be some structural features on both edges of the flat area, in this case, it is a fault.

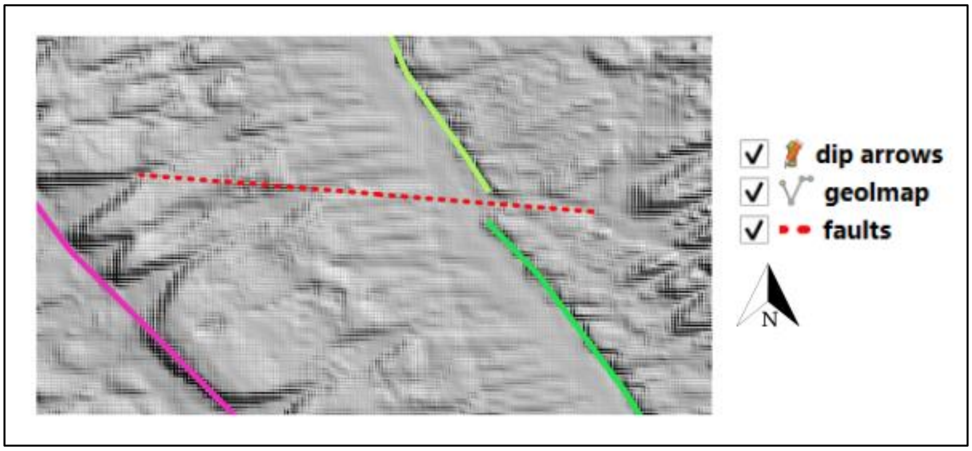


(Fig. 11) A map showing the dip and dip direction of resistant layers to demonstrate a fault. As well as the profile for the cross section C to C'

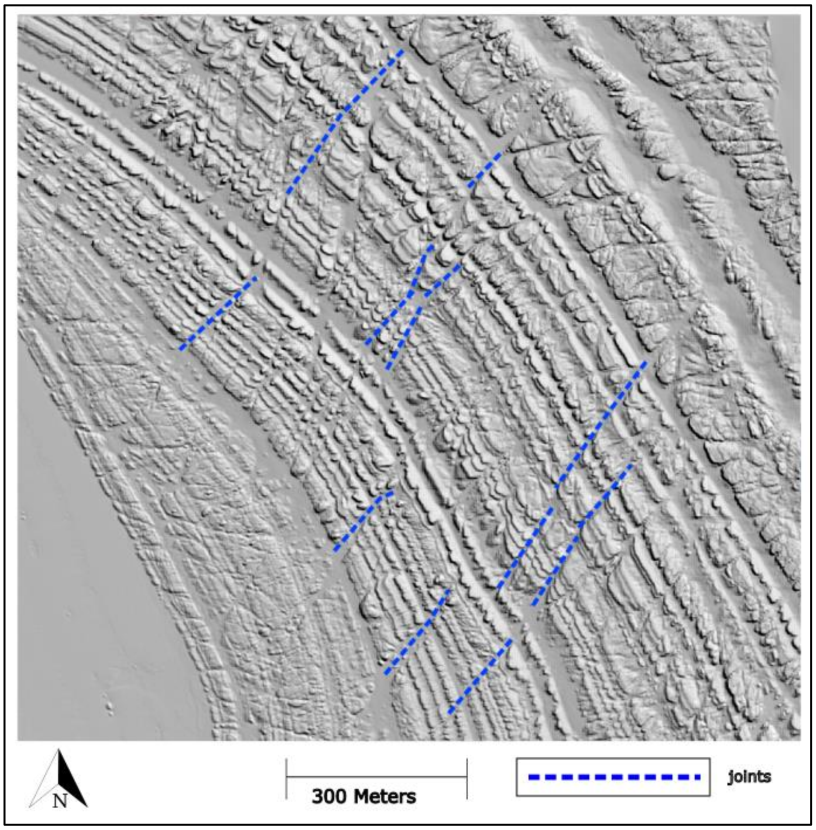


(Fig. 11a) A cross section demonstrating the fault between the Purisima formation and the Montara Granite

The offshore region of Moss Beach also has smaller scale faults (Fig. 12) and joints or fractures (Fig.13) present. The small-scale faults were found by looking for offsets of the resistive sandstone layers. Across the entire study area, I was only able to find 3 cases of this. The faults range from 50 to 150 meters in length and don't seem to have a preferred orientation in which they form. There are more joints than small scale faults, so many that not all of them were mapped to decrease the clutter of the map layout. They vary in size and are more common in the northern portion of the study area. The joints demonstrate a preferred orientation of south west to north east.

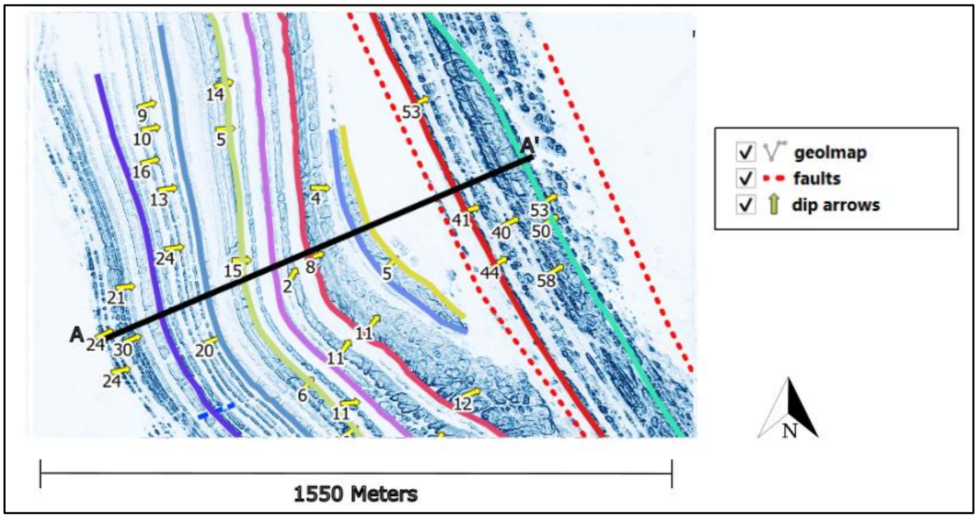


(Fig. 12) A small scale fault seen displacing a resistive layer of sandstone.

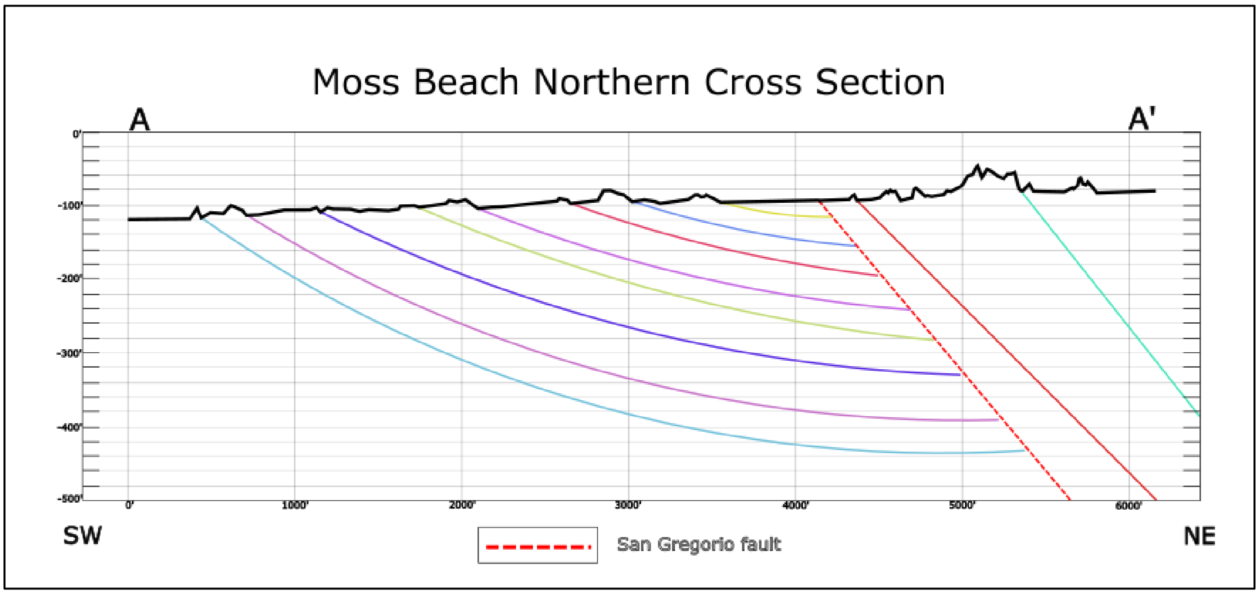


(Fig. 13) A field of joints offshore to the north of the anticline and syncline

Two more cross sections were made using the mapped geologic layers, one in the north displaying the San Gregorio fault (Fig. 15) and one in the south displaying the plunging anticlines and synclines (Fig.17). As previously stated, these geologic layers were digitized using the digital elevation model and was drawn using the resistive sand stone beds from the Purisima formation. All of the lines are symbolized using a categorical color scheme, but they are all the same lithology. The colors were used to make it easier to correlate the layers into the cross sections. These cross sections were created using dip and dip direction, which were interpreted from the slope layer. So, the area maps display the slope layer for the base map imagery.



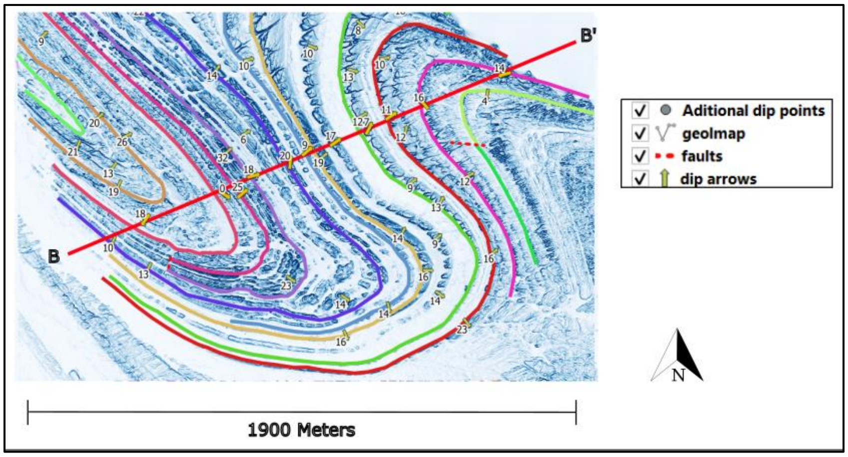
(Fig. 14) An area map showing the location of the A to A' cross section.



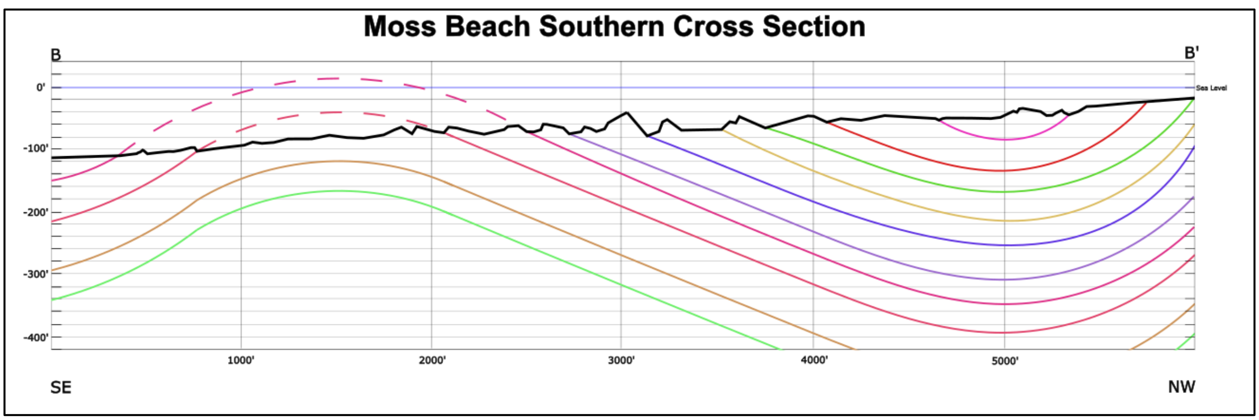
(Fig. 15) A cross section for the A to A' profile displaying the folded layers being cut by the San Gregorio fault.

Figure 14 and Figure 15 show a cross section of the northern offshore portion of the study area. To the west of the A to A' profile, the resistive sandstone layers are folded and are dipping to the north east with low dip values ranging from 5 to 33. Since these layers are folded, the layers were interpreted to be curved under the surface to match the surface geometry. The north eastern portion of the cross section has layers that still dip in the same direction, but they are not folded and have much larger dip values, ranging from 40 to 53. Since these layers do not appear to be folded, they were interpreted to be strait lines under the surface to match this geometry as well.

The contrast in dip angle and layer geometry suggests that there has to be a fault cutting the folded layers. This fault happens to be the San Gregorio fault. There is some question to whether or not the fault should be displayed as dipping or perfectly vertical, since it is a strike slip fault. I decided to symbolize it as dipping since it has already been established that the San Gregorio fault is not a perfectly straight strike slip fault and the surrounding layers are dipping as well.



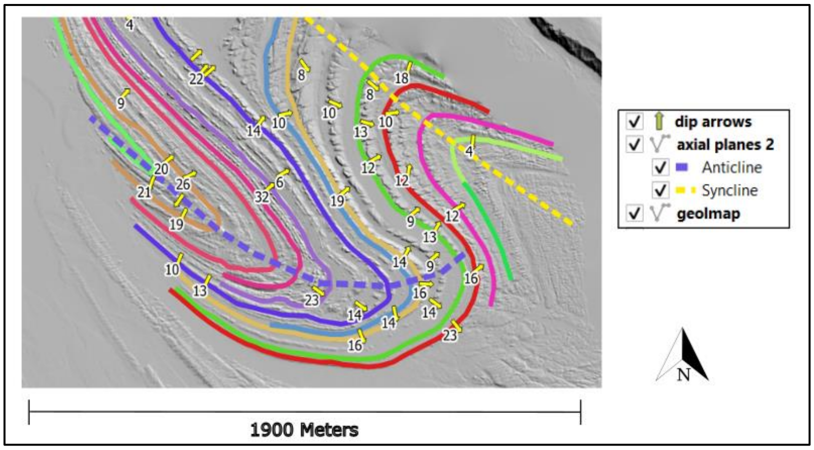
(Fig. 16) An area map showing the location of the B to B' cross section.



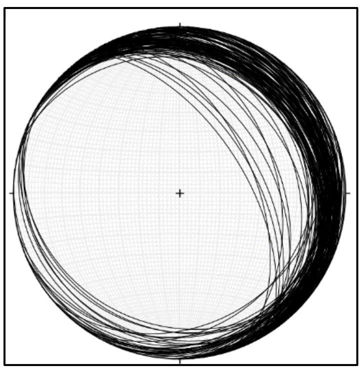
(Fig. 17) A cross section for the B to B' profile displaying the plunging syncline and anticline pair in the southern portion of the study area

Figure 16 and Figure 17 show a cross section of the southern offshore portion of the study area which has a plunging anticline and syncline system. While the geometry looks more complex, there are no faults cutting through the area and offsetting the layers. Similar to the northern cross section, all of the digitized geologic layers are the same lithology and are symbolized with a categorical color scheme. The south eastern portion of the profile is a plunging anticline and the north eastern portion of the profile is a plunging syncline. In the cross section, the bottom two layers were interpreted based off the remaining layers that were not intersected by the profile line. The cross section could have continued to the north west, but the DEM did not have appropriate data for the area between the folds and the bluff. While it can be interpreted that the folds would continue past the end of my cross section, it was not included since there was no imagery data to base it off of.

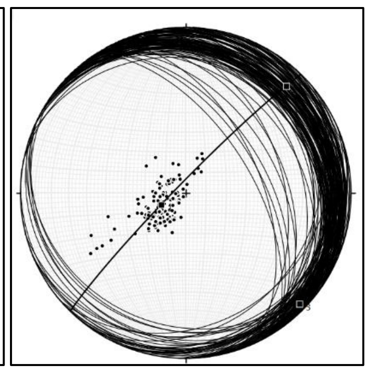
Another important piece of information for the syncline and anticline is the orientation of their fold axes. Digitized lines of their respective fold axes are seen in Figure 18. As previously stated, these folds are plunging, but more specifically, they are plunging to the south east. This is known since the "v" of a plunging anticline points in the same direction as the plunge of the fold. The dip and dip directions of each point were saved in a CSV file and imported into a stereonet software which plotted the data as planes (Fig. 19). Then poles were plotted to these planes, and finally a great circle of best fit was plotted through the poles (Fig. 20). Then a final pole was plotted to this great circle (Fig.21), the trend and plunge of this pole is the axis for the folds.



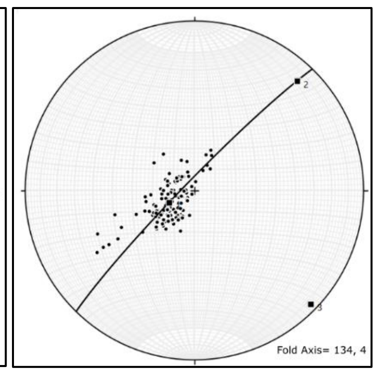
(Fig. 18) A map displaying the fold axes of the syncline and anticline



(Fig.19) A stereonet of the dip and dip direction plotted as planes.



(Fig. 20) A great circle of best fit plotted through the poles generated from figure 16.



(Fig. 21) a pole plotted to the great circle of best fit at pt. 3

So, the trend and plunge of the fold axis is 134,4. This means that the overall orientation of the axes are 134 degrees, or roughly south east and they are plunging by 4 degrees.

Since the San Gregorio fault is a strike slip fault that is also has an aspect of compression, the area is experiencing uplift. This can be most clearly seen by the bluff that the San Gregorio fault runs parallel to. The bluff has a higher elevation than the land to the east, and ranges from 100 to 200 feet above sea level. As discussed in the geologic setting portion of this paper, the bluff is relatively flat due to wave action cutting it and creating a marine terrace. The marine terrace can be used to identify the uplift rate of the area.

To find the uplift rate, three variables are needed: elevation of the terrace above the current sea level, the time when the terrace was formed and the sea level at that time expressed in reference to current sea level (Keller and Pinter 2002). The time the feature formed is the age of the marine terrace. Since a marine terrace forms as waves cut a surface, the age is when the formation uplifts to a point where it is no longer in contact with the water. The sea level at the time of formation can be expressed as a positive or a negative number depending on its relationship to the current sea level. If the number is positive, that means the sea level is lower now than it was at the time of formation. If it is negative, that means the sea level is higher now (Keller and Pinter 2002).

The age of the marine terrace was calculated to be 11.41 ± 1.54 thousand years old using luminescence dating techniques (Washburn et. Al., 2020). Using this in conjunction with a graph that displays historic sea level from *Active Tectonics Earthquakes, Uplift and Landscape* (Keller and Pinter 2002), it is found that the sea level at that time is 45 meters lower than the current sea level. Then, the current elevation above sea level was acquired by querying the DEM at a point near where the age was calculated. The equation to calculate uplift rate is as follows: $uplift\ rate = \frac{elevation - sea\ level}{time}$. The values used for this calculation and the result can be seen in Figure. 22.

Uplift rate (meters/year)	elevation of terrace above sea level (meters)	historic sea level (meters)	time (years)
0.0084	51.7	-45	11410.00

(Fig. 22) A table showing the calculation of the uplift rate in the Moss Beach study area.

This calculation shows that the uplift rate in the study area is 8.4 millimeters per year, or 8.4 meters every thousand years with an error of plus or minus 1 meter per thousand years. This value seems high and possibly inaccurate as it is almost 8 times larger than the calculated uplift rate of other marine terraces in the area. For comparison, other marine terraces near Santa Cruz California were measured to have an uplift rate of 1.1 meters every thousand years (Perg et al. 2001). Using the given error with the calculated age of the marine terrace reduces the uplift to 7.4 meters per thousand years. Another possible source of error is not choosing the correct point in the DEM for the current elevation above sea level, using the lowest elevation in the area changes the calculation to result in an uplift rate value of 5.8 meters per thousand years.

Summary and Conclusions

The moss Beach area of California is exposed to many structural and geomorphological hazards such as faults, landslides, earth quakes and sea cliff collapse. While there are many faults in the area, the main fault is the San Gregorio fault which is an active portion of the San Andreas fault system that last slipped between 800 and 300 years ago (Simpson et al. 1997). This fault is a transgressional strike slip fault, and as such experiences compression which leads to an uplift ranging from 1.1mm/year (Perg et al. 2001) to 8.4 mm/year. The area offshore is home to more structural features such as a syncline anticline system, more faults including a continuation of the San Gregorio fault, some smaller scale faults, joints and fractures. These features were useful in determining where other faults were located and understanding how the San Gregorio fault interacted with the surrounding area. Many residential neighborhoods and local businesses are built directly on top of or near the San Gregorio fault. Local roads and buildings have seen the effects of the fault system and collapse features such as landslides and have been destroyed or needed to be shut down.

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