

Exercise: kinematics of faulting at Chimney Rock

Reading: Fundamentals of Structural Geology, Ch. 2, p. 49 – 61
Maerten, L., 2000, Variation in slip on intersecting normal faults:
implications for paleostress inversion, J. Geophysical Research, v.
105, p. 25,553 – 25,565

In this exercise we consider the kinematics of faulting at Chimney Rock, Utah (Figure 1). Kinematics is an important part of a complete mechanics that focuses on the motion (displacement) and relative motion (strain) of rock particles. We use the slickenlines on exposed fault surfaces to indicate the direction of slip and investigate how these directions vary along a particular fault. We use structure contours to identify the offset of particular sedimentary layers across the faults and to measure the magnitude of slip.



Figure 1. Laurent Maerten and Scott Young discuss exposures of the Carmel formation at Chimney Rock, Utah. The tops of the ledge-forming limestone beds were mapped using GPS and provide the data for this exercise.

Although slip directions may be studied on a stereographic projection we emphasize here that such projections neglect the spatial information that tie each slickenline direction to a position on a fault, and that slip magnitude can not be represented on a stereonet. The broader term 'slip distribution' refers to the positions, magnitudes, and directions of the slip vector field on the fault surface. The slip distribution plays an important role in understanding the three dimensional kinematics of faulting which is closely related to the physical mechanisms operating as the fault evolves in space and time. Associated with fault slip, the nearby sedimentary strata are deformed and this deformation is characterized using a structure contour map.

1) Consider the slip distribution for the Blueberry fault by first investigating how the slip direction varies along the fault trace. GPS data were gathered in the Chimney Rock region (Fig. 2.29) using a data dictionary that prompted the geologist to record the following information for each data station along the fault traces:

Easting Northing Elevation strike dip rake quality size formation (1)

There are 92 data stations along the Blueberry fault. Use the rake data for the Blueberry fault from the text data file blueberry.txt and devise a 3D plotting method to visualize the slip directions. Is the variation in slip direction with position on the fault systematic? If so, describe the variation.

2) Plot slip magnitude and rake versus position along the trace of the Blueberry fault. Decimate the data selecting only those data stations with a quality rating of 'good' and re-plot. Discuss the criteria used to eliminate data and address the issue of whether the decimated data or the complete data should be presented. Describe the variation in slip direction with position on the fault. Suggest an explanation for this variation based upon your knowledge of the geology at Chimney Rock.

3) GPS data from Chimney Rock include data stations on four 'marker' horizons that crop out throughout the area. The stratigraphic section for the area (Fig. 2.28) indicates the tops of three prominent, ledge-forming limestone layers and the top of the Navajo formation as distinctive horizons. Coordinate data were gathered for each data station along these horizons as:

Easting Northing Elevation (2)

Four tab-delimited text files contain these data for the following layers (numbers in parentheses are the number of data stations):

carmel1.txt	(9479)
carmel2.txt	(653)
carmel3.txt	(726)
navajo.txt	(2284)

Plot a map of these data stations using the (Easting, Northing) UTM coordinates. Use different colors for the different layers. Zoom in to key areas that display the relationships among the horizons and infer which data set corresponds to the Blue-gray limestone, the Gray limestone, and the Reddish limestone as identified in the stratigraphic section.

4) Construct a topographic map of the Chimney Rock area. You will have to do a two-dimensional interpolation of the data and construct a regular grid in Northing and Easting. Describe the topography including the drainage direction, shapes of the drainage basins, and shapes of the ridges between the canyons. Describe the relationships among the topography and the stratigraphic horizons recalling that the horizons, on average, dip very gently to the east.

Fundamentals of Structural Geology
Exercise: kinematics of faulting at Chimney Rock

- 5) Use the thickness data from the stratigraphic section (Fig. 2.28) to project the locations of the data stations from the Carmel2, Carmel3, and Navajo horizons onto Carmel1. With this combined data set construct a structure contour map on Carmel1. Describe the geometry of the surface represented by your contour map giving a value for the average strike and dip of the entire surface. Compare your contour map to the map of faults and describe how the faults affect the shape of the surface.
- 6) Structure contour maps reveal breaks in slope where faults intersect the mapped horizon. Devise an automated way to identify and locate these fault traces. Vary the parameters in your numerical method to test the sensitivity of the outcome to these parameters. Compare your results to the map of faults in the Chimney Rock region and explain why your method works well in some areas and badly in others.
- 7) Recall from calculus that the second derivative of a plane curve is related to the curvature. In three dimensions the Laplacian is related to the curvature of a surface; it is positive for functions shaped like $i^2 + j^2$ and negative for functions shaped like $-(i^2 + j^2)$. The MatLab function `del2.m` computes the discrete Laplacian of a matrix of values. Use the `del2.m` function and contour the resulting values. Vary the grid spacing and the threshold to find those that best define the fault traces. Compare your results to the map of faults in the Chimney Rock region and explain why this method works well in some areas and badly in others.