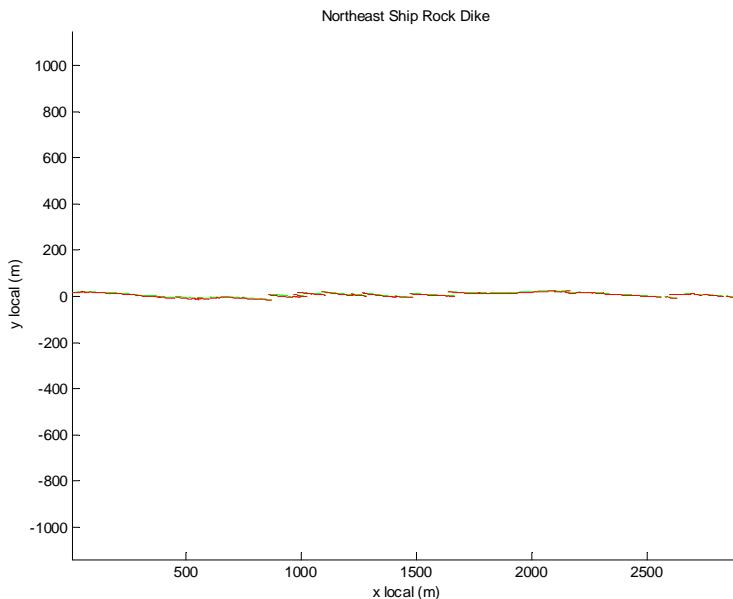


## Exercise Solutions: mapping dikes at Ship Rock

1) Two sets of two-dimensional *position vectors*,  $\mathbf{p}(i)$  and  $\mathbf{q}(i)$ , are used to digitize the contact between the Mancos Shale and the igneous rock of the northeastern dike at Ship Rock with  $\mathbf{p}(i)$  locating the northwestern side of the dike and  $\mathbf{q}(i)$  the southeastern side (Fig. 2.5b). Position vectors for the 2,724 data stations along the dike contact approximate the shapes of the 35 dike segments in map view. These data are given in the tab delimited text file sr\_contact.txt. Read this text file into a data array, parse the data into the vector components for  $\mathbf{p}$  and  $\mathbf{q}$ , and plot these data with equally-scaled local coordinate axes.

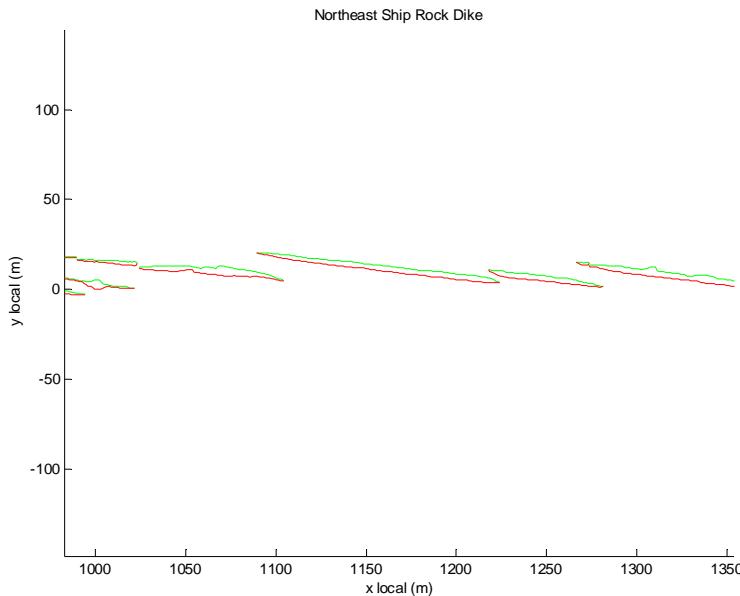
The following Matlab m-script reads the data, parses it into the vector components, and plots the map which is shown below at full scale.

```
%Ship_Rock_map.m
% mapping the dikes at Ship Rock
% reading, parsing, and plotting data
clear all, clf % clear variables and figure
data = dlmread('sr_contact.txt'); % read delimited text file
px = data(:,2); % designate the second column as px
py = data(:,3); % designate the third column as py
qx = data(:,2); % designate the second column as qx, px = qx
qy = data(:,4); % designate the second column as qx
hold on, axis equal
plot(px,py,'g') % plot the NW contact
plot(qx,qy,'r') % plot the SE contact
title('Northeast Ship Rock Dike')
xlabel('x local (m)'), ylabel('y local (m)')
```



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- 2) Zoom in to check the details of your map in comparison to Figure 2.7 which is part of the map from USGS Professional Paper 1202. Describe the characteristic shapes of the dike segments and contacts. Describe the geological features and structures that are found on the USGS map, but not on your map.



The dike segments are tabular (very long relative to their thickness) and typically taper near their ends to a rounded termination. Some segments display local changes in the otherwise nearly planar contact where box-like to circular excursions protrude into the Mancos shale. Many of these local excursions are accompanied by changes in rock type from minette to breccia (shown on the USGS map). Most of the pods of breccia are found lining the contact of the dike segments with the Mancos shale; although in some cases breccias pervade the entire width of the dike. The USGS map also includes strike and dip symbols for beds of the Mancos shale and for joints in the baked shale near the dike contact. Three types of the dike contact are distinguished: contact exposed with minette against shale; contact located within 0.05 m; and contact located within 0.1 m. Two different breccias are distinguished: heterobreccia and monobreccia.

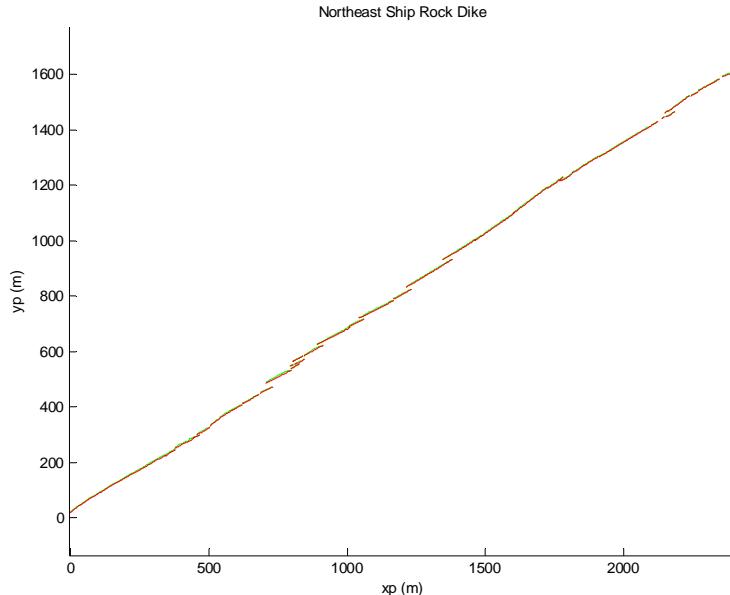
- 3) The azimuth of the local  $x$ -axis for mapping the northeastern dike at Ship Rock is 056 degrees measured clockwise from north in the horizontal plane. Transform the local ( $x$ ,  $y$ ) axes to the UTM (Easting, Northing) axes by a *rotation* about the vertical  $z$ -axis. Plot a new map with equally-scaled local coordinate axes. Note that the  $x$ - and  $y$ -components of position vectors  $\mathbf{p}$  and  $\mathbf{q}$  change under this transformation, but the position vectors themselves are unchanged.

The following Matlab m-script accomplishes the rotation to UTM axes.

```
% rotate map into UTM axis directions
alpha = -34*pi/180; % Define angle of rotation
```

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```
% Define rotation matrix M
M = [cos(alpha) sin(alpha); -sin(alpha) cos(alpha)];
Pp = [px py]*M'; Qp = [qx qy]*M';
pxp = Pp(:,1); pyp = Pp(:,2);
qxp = Qp(:,1); qyp = Qp(:,2);
figure, hold on, axis equal
plot(pxp,pyp,'g') % plot the NW contact
plot(qxp,qyp,'r') % plot the SE contact
title('Northeast Ship Rock Dike')
xlabel('xp (m)'), ylabel('yp (m)')
```

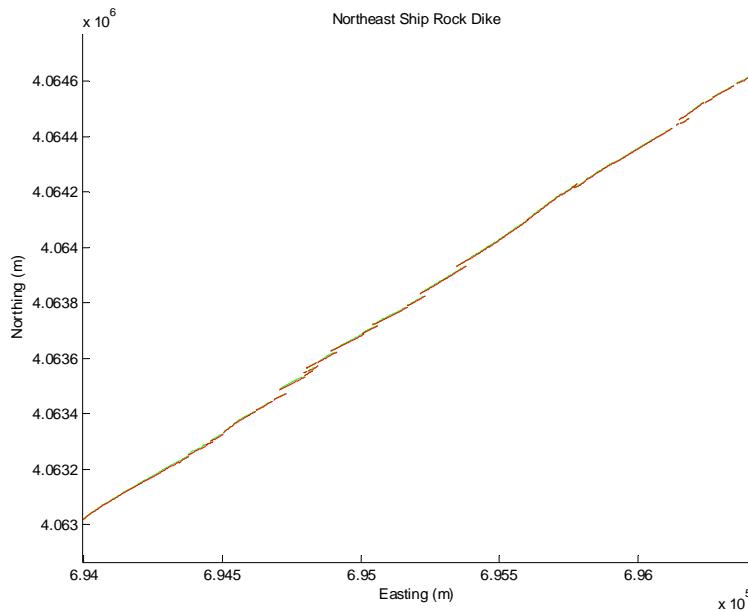


- 4) Transform the origin of the local coordinates by a *translation* to the UTM origin for Zone M12. Plot a map with equally-scaled UTM grid axes. Zoom in to check the details of your map.

The following Matlab m-script accomplishes the translation to the UTM origin.

```
% Translate map to UTM origin for Zone M12
pxutm = pxp + 694000; pyutm = pyp + 4063000;
qxutm = qxp + 694000; qyutm = qyp + 4063000;
figure, hold on, axis equal
plot(pxutm,pyutm,'g')
plot(qxutm,qyutm,'r')
title('Northeast Ship Rock Dike')
xlabel('Easting (m)'), ylabel('Northing (m)')
```

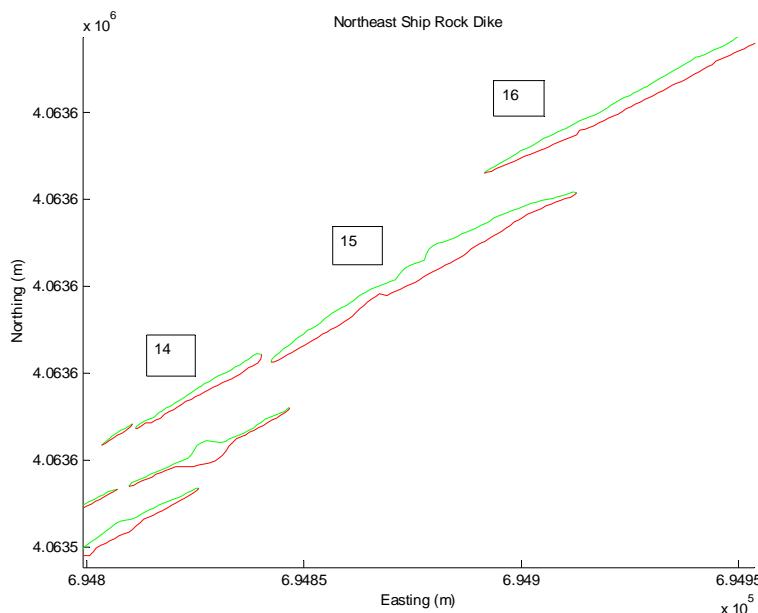
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- 5) The *apparent thickness*,  $t(i)$ , of the northeastern dike at Ship Rock is defined as the distance between the two sides of the dike along a line perpendicular to the local  $x$ -axis:

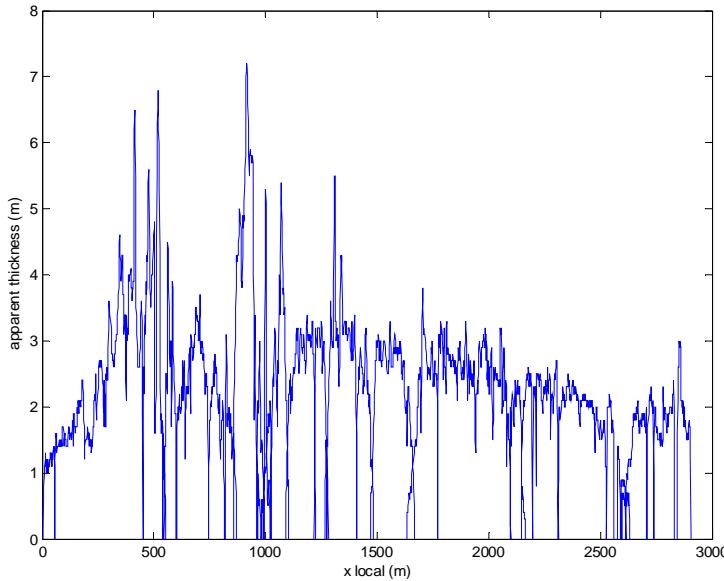
$$t(i) \approx p_y(i) - q_y(i)$$

Plot a graph of apparent thickness versus position,  $x$ , along the entire dike. Note that the thickness goes to zero at the terminations of each dike segment and that a typical thickness near the middle of each segment is 2 to 3 m. Compare and contrast the form of the thickness distributions near terminations for segments that underlap and are essentially co-planar (e.g. #7 - #8, or #14 - #15), with segments that overlap and are arranged in an echelon pattern (e.g. #15 - #16, or #20 - #21).



The following Matlab m-script calculates and plots the apparent thickness.

```
% calculate apparent dike thickness and plot vs. x
ta = py - qy;
figure, plot(px,ta)
xlabel('x local (m)'), ylabel('apparent thickness (m)')
```



Segments that underlap tend to be blunt, whereas segments that overlap in an echelon arrangement tend to be tapered. Both of these shapes are caused by the mechanical interaction of the dike segments. Underlapped and co-planar segments impose a tensile stress on their neighbors thereby enhancing the thickness, while overlapped segments impose a compressive stress on their neighbors thereby diminishing the thickness. See USGS Prof. Paper 1202, Figure 23 for an analysis of these interactions.

- 6) In some localities the thickness is anomalously great, ranging up to about 7 m. Describe the geological phenomena as shown on the USGS map (Figure 2.7) that correlate spatially with thickness anomalies along the northeastern dike. Compare and contrast the two different physical mechanisms that are the major contributors to dike thickness.

The thickness of individual dike segments may be attributed to: 1) fracture dilation (opening) driven by magma pressure and resisted by the remote compressive stress and the elastic stiffness of the Mancos shale; and 2) brecciation of the Mancos shale (presumably by effects such as pore pressure increase and thermal stressing), and erosion of the breccia by viscous drag of the flowing magma.

For isolated segments of the dike the opening would produce an elliptical contact shape in cross section (the map view). The contact shape near the ends of echelon dike

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segments is more tapered than elliptical and the tapering is asymmetric from one side to the other (see USGS Prof. Paper 1202, Figure 23). This is associated with the mechanical interaction of neighboring dike segments: the opening of one segment tends to push the adjacent segment closed. This effect is manifest differently on the side nearest the neighboring segment and the side farthest from that segment.

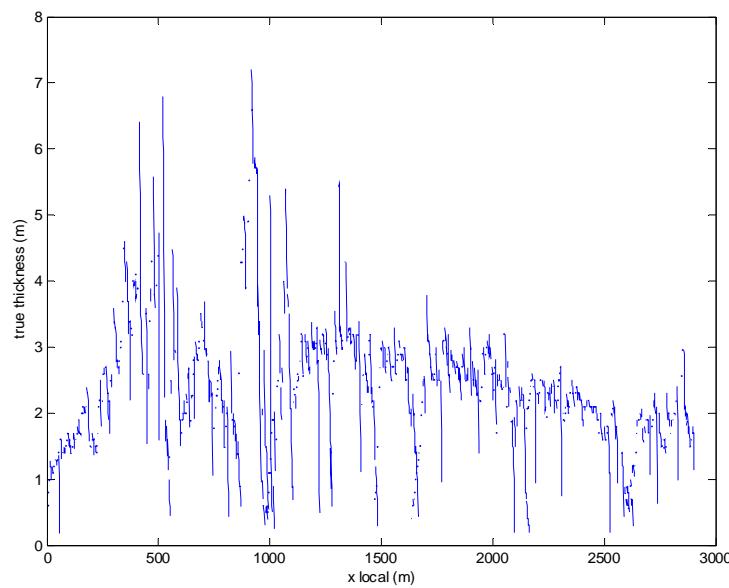
Local excursions of minette into the Mancos shale along the contacts of the dike segments would promote a channeling of flow into these thicker parts of the dike. Heat is lost more readily from the thinner parts of the dike where the ratio of magma volume to dike contact surface area is less. Loss of heat and the concomitant decrease in temperature leads to an increase in viscosity, so the flow rate would decrease. Thicker parts of the dike have a greater ratio of magma volume to contact surface area. There the magma would maintain a higher temperature and therefore a lesser viscosity, so the flow rate would be greater.

7) The *true thickness*,  $T(i)$ , of the northeastern dike at Ship Rock is defined as the distance between the two sides of the dike along a line perpendicular to the local strike of the dike contact. Calculate and plot the true thickness versus position,  $x$ , along the entire dike. Explain how you chose to calculate the local strike. Does it matter which contact you use to determine the local strike? Compare your values  $t(i)$  and  $T(i)$ , describing a few characteristic examples where the apparent thickness is a good approximation to the true thickness, and where it is not.

The following Matlab m-script calculates and plots the true thickness.

```
% calculate dike thickness using a forward difference
for j = 1:2794
    sp(j) = atan2(py(j+1)-py(j),px(j+1)-px(j));
    sq(j) = atan2(qy(j+1)-qy(j),qx(j+1)-qx(j));
    t(j) = ta(j)*cos(sq(j));
end
% eliminate non-parallel sides and plot t vs. x
sp(2795) = NaN; sq(2795) = NaN; t(2795) = NaN;
t(find((sp-sq)>(1*pi/180))) = NaN;
figure, plot(px,t)
xlabel('x local (m)'), ylabel('true thickness (m)')
```

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Here the true thickness is calculated using a forward difference method to determine the orientation of the contact. As the name implies the position vectors for the current point ( $j$ ) and the following point ( $j+1$ ) are used. An alternative would be a central difference method where the previous point ( $j-1$ ) and the following point ( $j+1$ ) are used to calculate the orientation at the current point ( $j$ ). Some of the orientation values for opposite sides of the dike ( $sp(j)$  versus  $sq(j)$ ) are different and these non-parallel sides are eliminated from the calculation if they differ by more than one degree (an arbitrary cut off). Large differences in orientation are likely attributed to erosion of the contact and not to elastic opening of the dike. Discrepancies between true and apparent thickness are greatest where the dike contact is most oblique to the local x-axis of the map.