Project 6-2: Deriving trend surfaces of simple folds using LiDAR data in Raplee Ridge, Utah, USA

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1. Introduction

Geologists use two different compass bearings, strike and dip, to define the orientation of rock strata in three-dimensional space. The intersection between a dipping rock layer and an imaginary horizontal place is a line. Strike is the compass bearing (relative to north) of the intersection line, while dip is the direction of maximum inclination down from strike, and is always perpendicular to strike. An angular measurement, dip magnitude, is the smaller of two angles formed by the intersection of an imaginary horizontal plane and a dipping rock layer. The three-dimensional orientation of rock layers and simple folds can be represented by trend surfaces.

A trend surface is a smooth surface defined by a mathematical function (a polynomial) that fits the input sample points using the least-squares fitting. The first-order, second-order, and third-order trend surfaces are defined by the following equations:

First-order:

$$f(x, y) = c_0 + c_1 x + c_2 y \qquad (6\text{-}1)$$

Second-order:

$$f(x, y) = c_0 + c_1 x + c_2 y + c_3 x^2 + c_4 xy + c_5 y^2 \quad (6\text{-}2)$$

Third-order:

$$f(x, y) = c_0 + c_1 x + c_2 y + c_3 x^2 + c_4 xy + c_5 y^2 + c_6 x^3 + c_7 x^2 y + c_8 xy^2 + c_9 y^3 \quad (6\text{-}3)$$

where x and y are the (x, y) coordinates of input points, c_0 ~ c_9 are coefficients obtained by solving a set of simultaneous linear equations, and $f(x, y)$ is the output z value at (x, y). A first-order trend surface is a flat or tilted plane without any bending; a second-order trend surface is a concave or convex surface, and a third-order trend surface has two bends. For simple rock layers and folds, the above equations should be enough to capture general trends of the surfaces.

The basic idea of this project is to create a point shapefile and add points to the shapefile along the outcrops of a rock layer, then use the points to extract elevations (z values) from the DEM. Finally, a trend surface representing the orientation of the rock layer can be created from the (x, y, z) points.

2. Data

In this project, LiDAR data collected from Raplee Ridge, Utah, USA on February 24, 2005 is used to derive trend surfaces of rock layers and simple folds. LiDAR data acquisition and processing was completed by the National Center for Airborne Laser Mapping (NCALM). NCALM funding was provided by National Science Foundation's Division of Earth Sciences, Instrumentation and Facilities Program. EAR-1043051. The LiDAR point density is about 2.15

points/m^2. The horizontal coordinate system is UTM z12 N NAD83 (CORS96) [EPSG: 26912], vertical coordinate system NAVD88 (Geoid 03) [EPSG: 5703].

3. Project Steps

(1) Open an empty Word document so that you can copy any results from the following steps to the document. To copy the whole screen to your Word document, press the PrtSc (print screen) key on your keyboard, then open your Word document and click the “Paste” button or press Ctrl+v to paste the content into your document. To copy an active window to your Word document, press Alt+PrtSc, then paste the content into your document.

(2) Add DEM data. Open ArcMap, turn on the Spatial Analyst extension, then add raster “dem.tif” from the project folder (Figure 6.43).

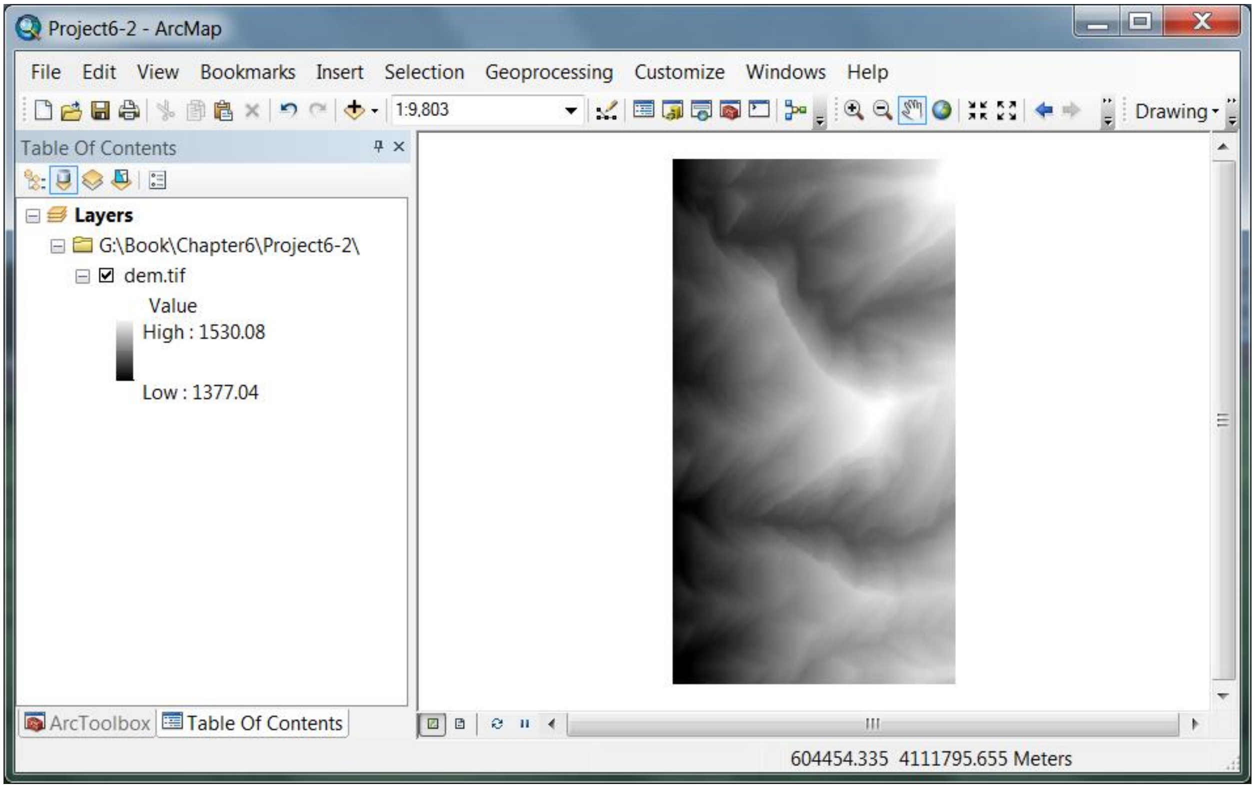

Figure 6.43. LiDAR-derived DEM (1 m by 1 m cell size) of a study area in Raplee Ridge, Utah, USA.

(3) Create hillshaded DEM. Open ArcToolbox → Spatial Analyst Tools →Surface → Hillshade. Use the hillshade tool (Figure 6.44) to created a hillshaded DEM (Figure 6.45) to help interpret topographic features of the study area.

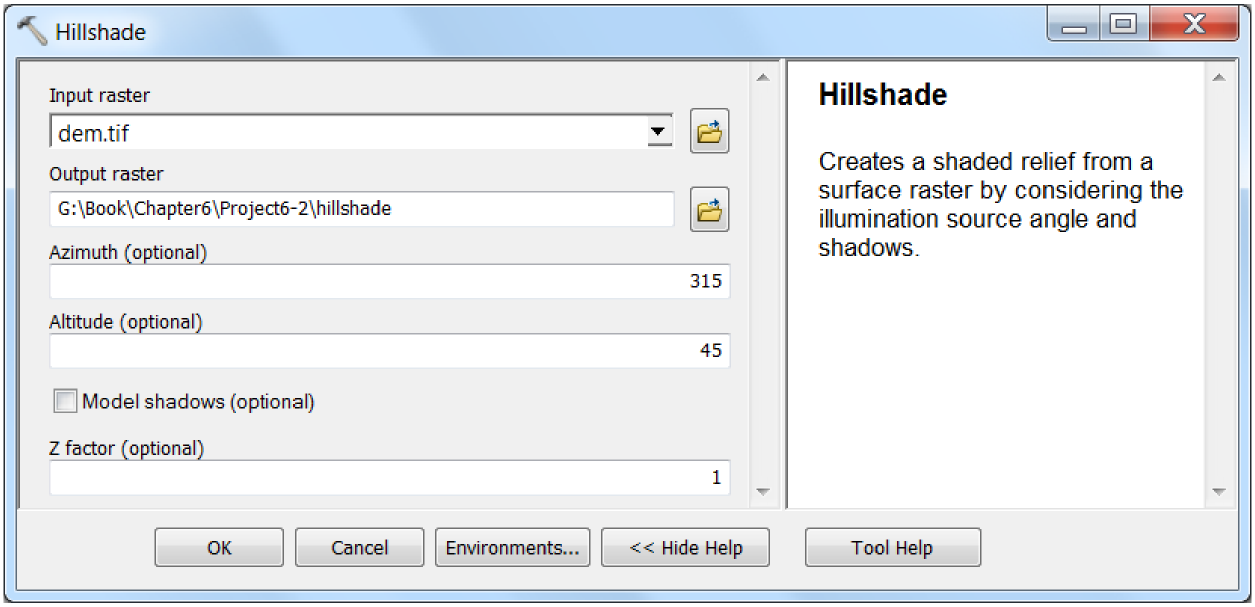

Figure 6.44. Hillshade tool in ArcGIS.

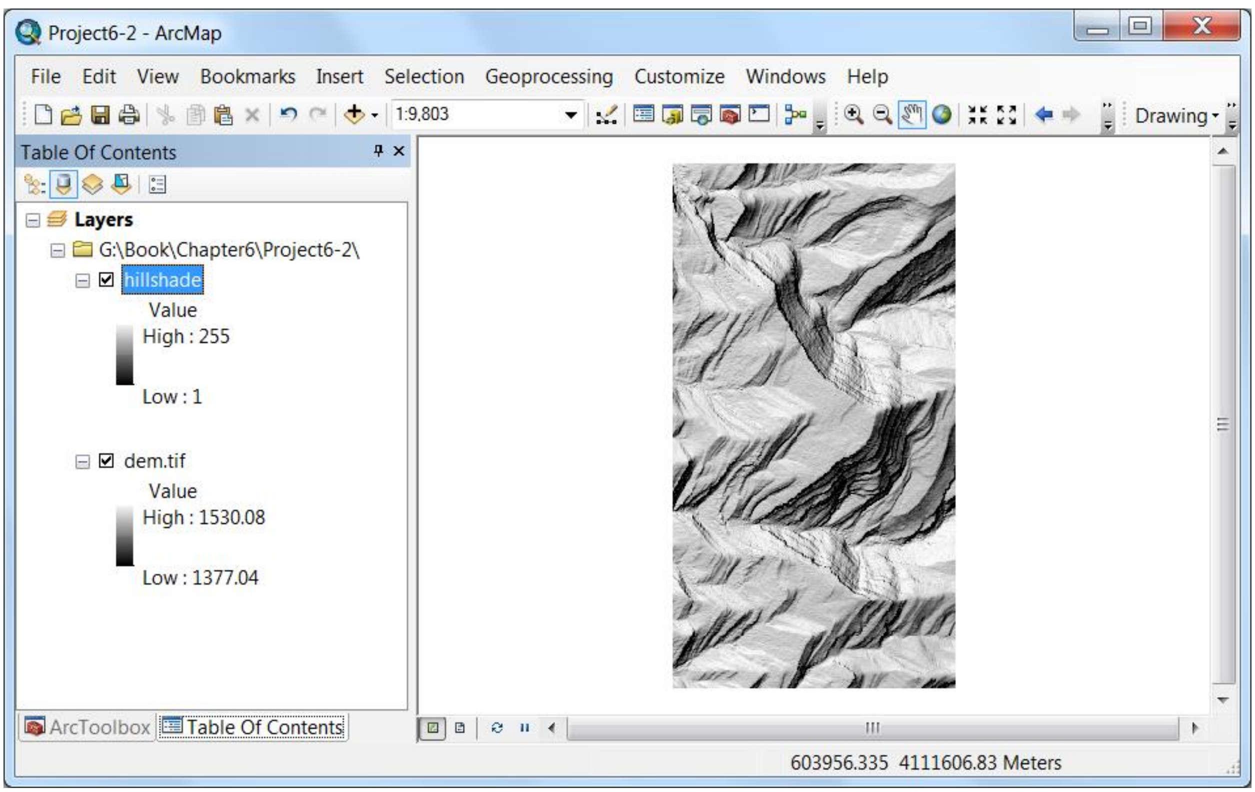

Figure 6.45. Hillshade raster created from the DEM in Figure 6.20.

(4) Create slope raster. Open ArcToolbox → Spatial Analyst Tools →Surface → Slope, and use dem.tif as the input raster to a slope “slope” (Figure 6.46). Due to the differences in the *resistance* of the rock layers to the *weathering* processes, outcrops of some rock layers may show relatively steep slopes (bright tones in Figure 6.46).

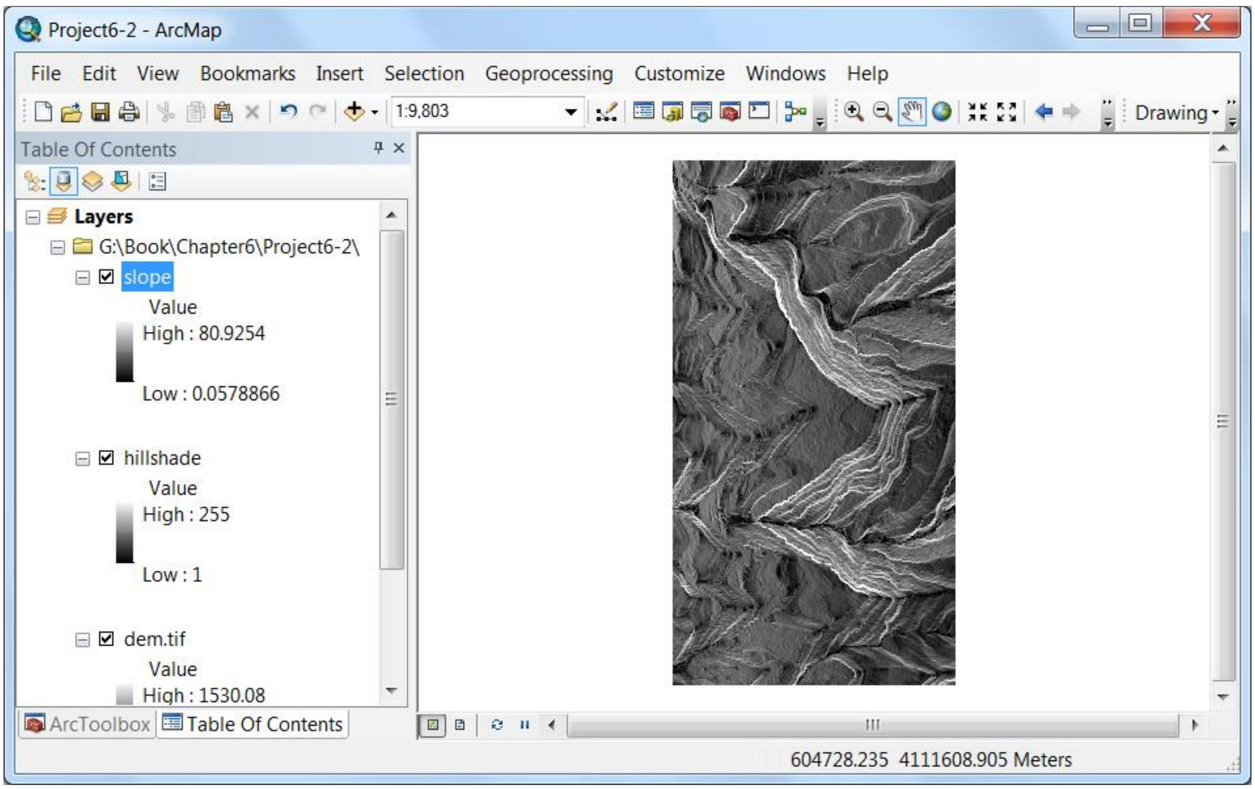

Figure 6.46. Slope raster created from the DEM in Figure 6.20.

(5) Create new shapefile for sample points. Open ArcCatalog and select the project folder for Project6-2, then right click the ArcCatalog window and select “New” → “Shapefile…” to create a point shapefile “samples.shp”. To define the spatial reference of samples.shp, click the “Edit” button and import the spatial reference properties of the DEM raster “dem.tif”.

(6) Add sample points to shapefile. Add the empty point shapefile “samples.shp” to ArcMap and change the symbol of the shapefile to red cross or any other point symbol. Load the Editor toolbar, and select “Start Editing” in the dropdown menu “Editor”, then select “Editing Windows” → “Create Features”. In the “Create Features” window on the right side of ArcMap, click “samples”, then click “Point” in the “Construction Tools” window on the lower-right corner of ArcMap (Figure 6.47). Now you can zoom in to a rock layer (a bright feature in the slope raster), and start adding sample points along the feature. If a high-resolution remotely sensed image such as IKONOS or GeoEye is available and co-registered to the LiDAR-derived DEM, the image can be added to ArcMap and used as reference when adding the sample points. To complete the editing process, select “Stop Editing” in the dropdown menu “Editor”, and save the edits.

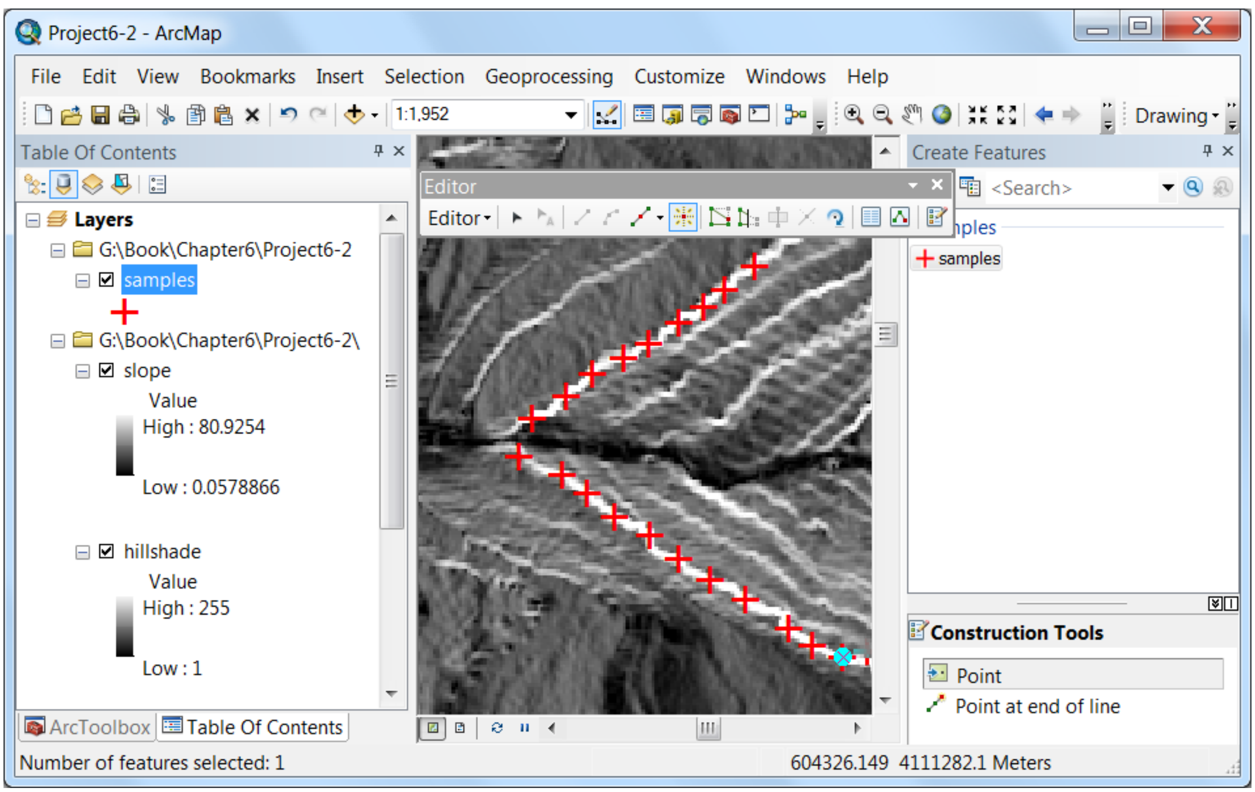

Figure 6.47. Adding sample points along a rock layer based on the slope raster.

(7) Extract elevations using sample points. The point shapefile “samples.shp” created in Step (6) can be used to extract elevations at individual sample locations from the DEM. Open ArcToolbox → Spatial Analyst Tools → Extraction → Extract Values to Points, and extract z values to a new point shapefile “pnt-elevations.shp” where z values are saved in the RASTERVALU field (Figure 6.48).

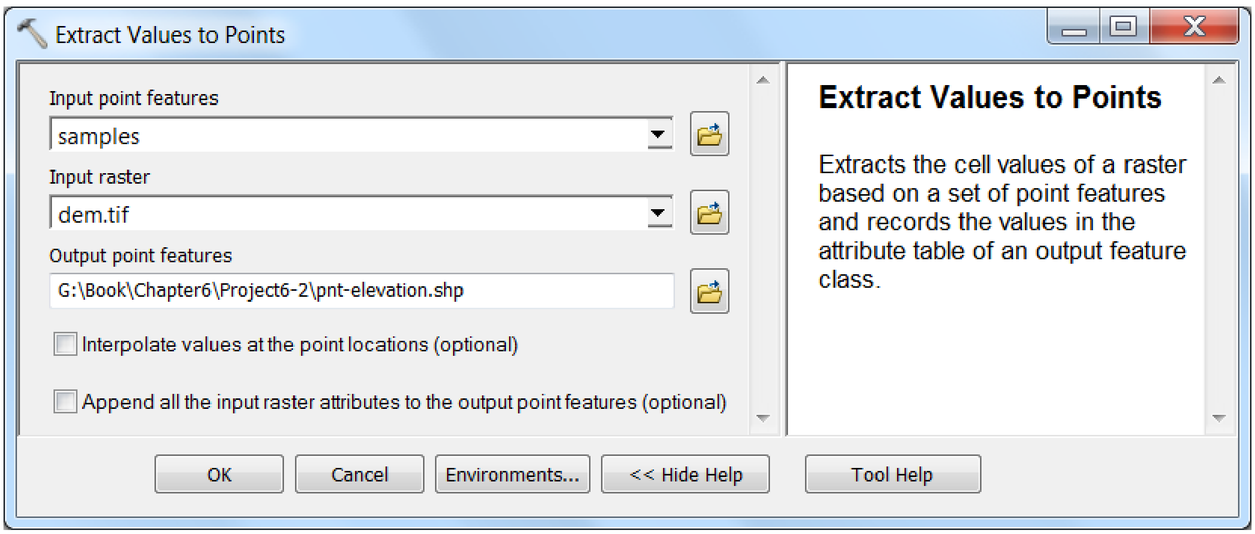

Figure 6.48. Extracting elevation values to points.

(8) Create trend surfaces. Open ArcToolbox → Spatial Analyst Tools → Interpolation → Trend, and set the parameters as in Figure 6.49 to create a second-order trend surface from sample points in pnt-elevation.shp. Similarly, first-order and third-order trend surfaces can also be created using the Trend tool. Table 6-1 lists the coefficients, RMS errors, and Chi-square values for the first-order, second-order, and third-order trend surfaces created from the 35 points in Figure 6.29. Since the rock layer used in this project is part of an anticline, the first-

order trend surface may not be the best option for representing the orientation of the rock layer, as indicated in the RMS error and Chi-square values in Table 6-1.

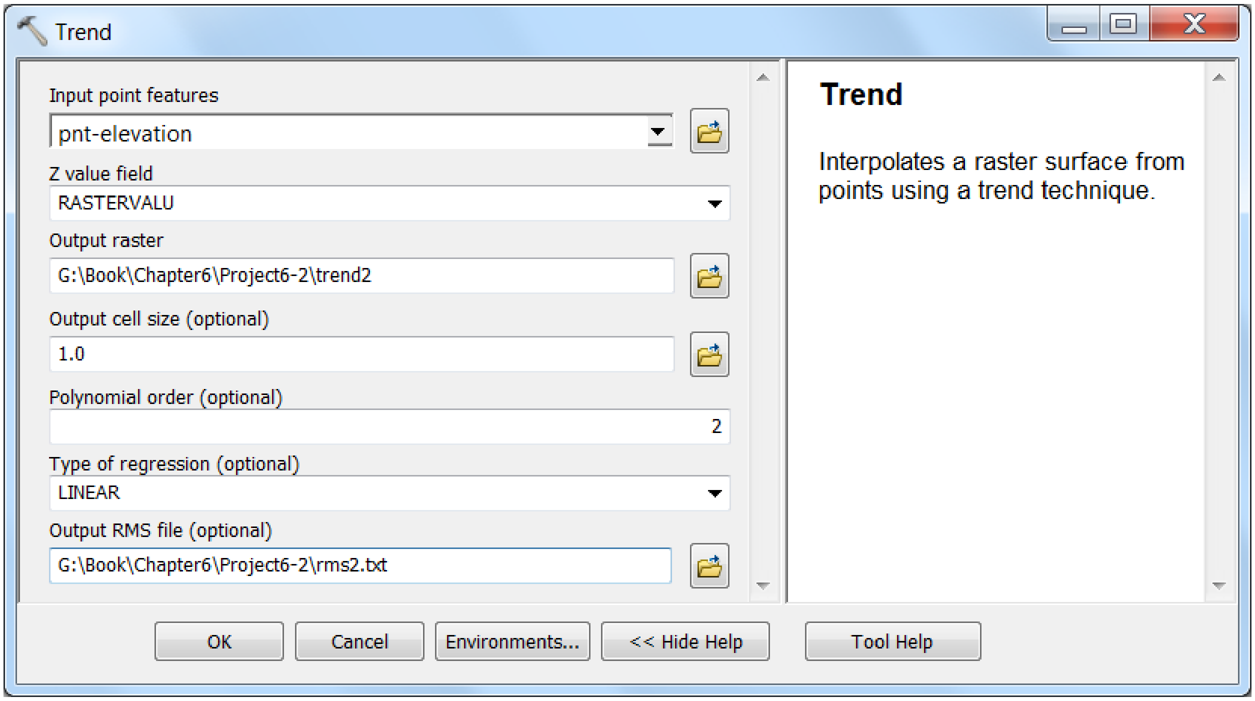

Figure 6.49. Generating a second-order trend surface from sample points.

Table 6-1. Coefficients, RMS errors, and Chi-square values of three trend surfaces

Order of polynomial	First-order	Second-order	Third-order
Coefficients	c_0 = -559588.0989 c_1 = 0.5203 c_2 = 0.0599	c_0 = -330290248.7063 c_1 = 871.4967 c_2 = 32.4302 c_3 = -0.0009 c_4 = 4.7504e-005 c_5 = -7.4263e-006	c_0 = -141724654.4038 c_1 = 170.9755 c_2 = -2.1991 c_3 = 0.0003 c_4 = 4.4767e-005 c_5 = 1.1979e-006 c_6 = -6.2593e-010 c_7 = -8.2176e-012 c_8 = 1.5412e-012 c_9 = -7.7478e-013
RMS Error	5.1103	3.1367	3.1367
Chi-Square	914.04785	344.3583	344.3589

(9) Three-dimensional (3D) visualization. To create 3D visualization of the DEM, sample points, and trend surfaces, open ArcScene and add the DEM raster "dem.tif", the second-order trend surface raster "trend2", and the sample points "pnt-elevation.shp" as scene layers. You can change the background color of the scene, and symbology or transparency of each scene layer as desired. It is important to set the base height property for each layer to obtain a 3D view. For raster scene layers, open the Layer Properties form and select the Base Heights tab, select "Floating on a custom surface", then select the corresponding raster for the raster scene layer and click "Apply" (Figure 6.50). You can also change raster resolution (Figure 6.50). For vector scene layers, select "Use a constant value or expression" in the Base Heights tab (Figure 6.51), and click the expression builder button to select a field for z values (field [RASTERVALU] in this case). The DEM, sample points, and second-order trend surface are shown in ArcScene in Figure 6.52.

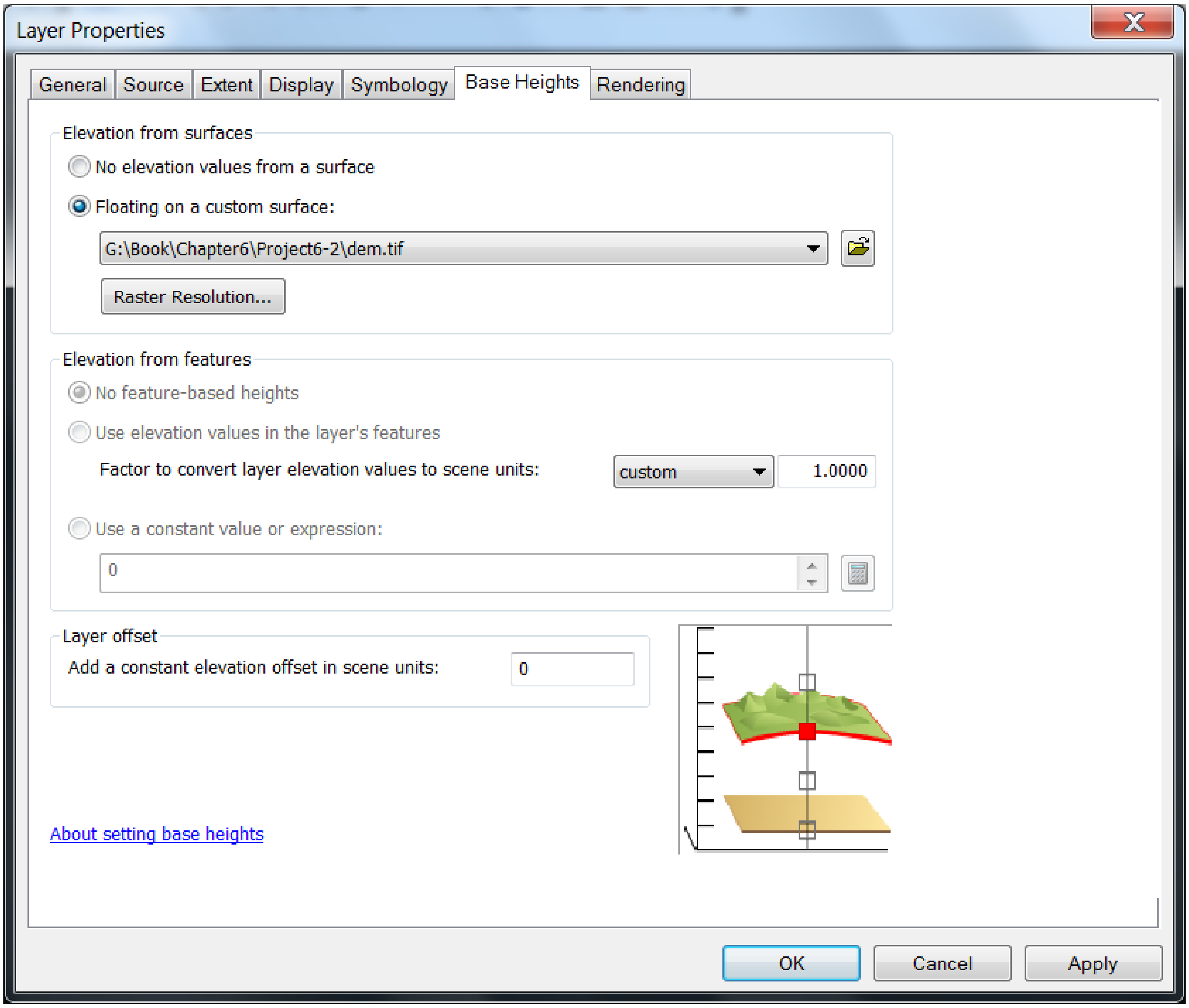

Figure 6.50. Setting base heights for a raster scene layer.

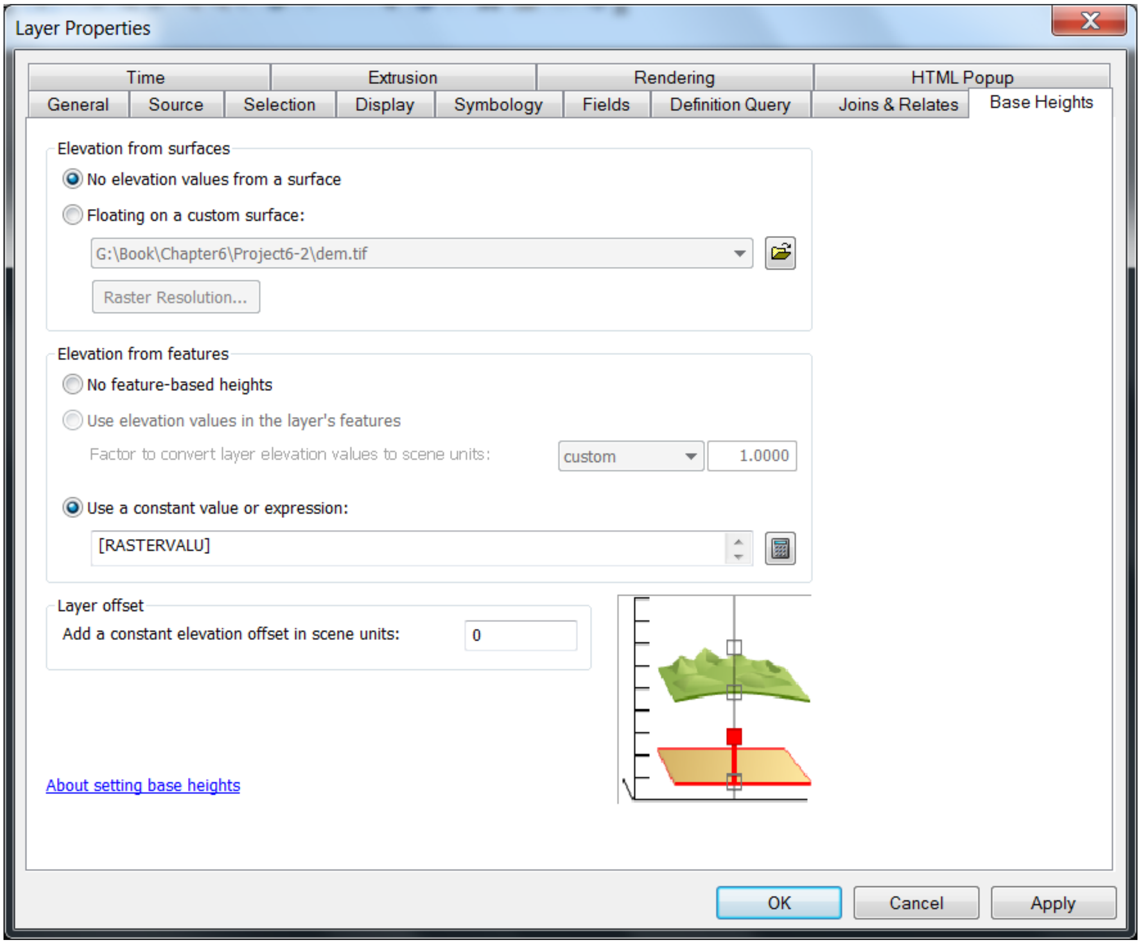

Figure 6.51. Setting base heights for a point scene layer.

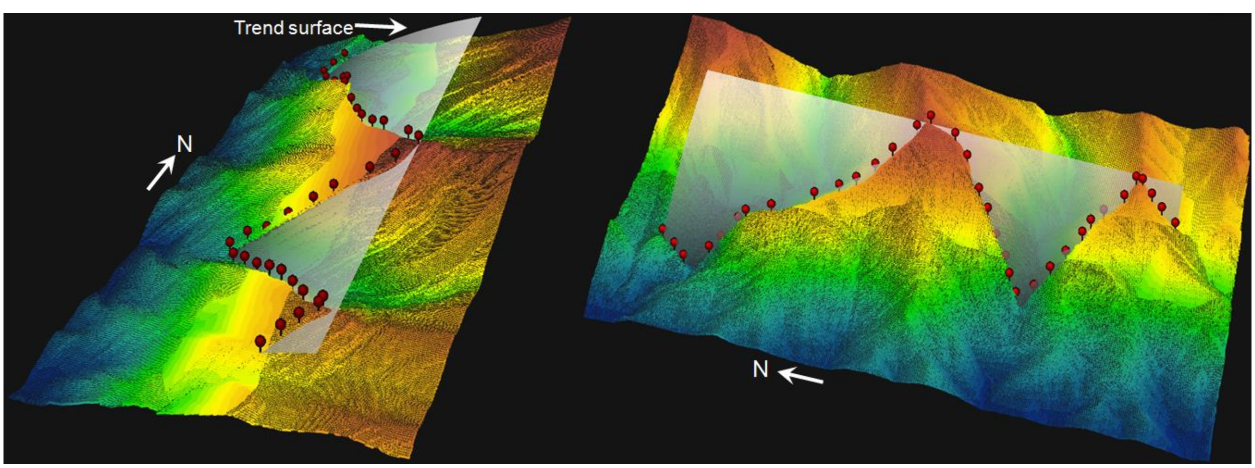

Figure 6.52. A mosaic of ArcScene visualization of DEM, sample points, and second-order trend surface.

(10) Save your ArcMap and ArcScene projects.

(11) Questions: (a) Suppose the above second-order trend surface can be used for representing the orientation of the rock layer, how can you calculate the dip direction, dip magnitude, and strike at any location of the rock layer using ArcGIS? (b) If two parallel rock layers are represented by two first-order trend surfaces L_1 and L_2 (Figure 6.53), how can you calculate the distance T between the two layers in ArcGIS? Note: If L_1 is the top and L_2 is the bottom of a rock layer, T is the true thickness of the rock layer. (Hint: Extract z values (elevations) z_1 and z_2 from the two surfaces using a single point, and get ΔZ as the first step.)

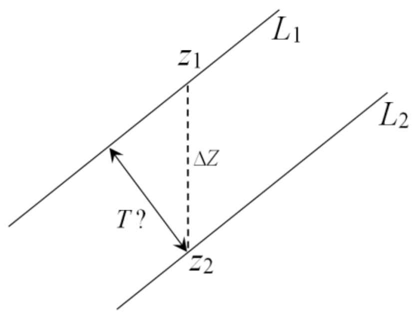

Figure 6.53. Two first-order trend surfaces L_1 and L_2 for two parallel rock layers.