The following exercises have been chosen for their relative simplicity and realism. Each is an example of a technique or method used extensively in modern stratigraphic work in the petroleum industry.

**PART I:** Fence Diagram of laterally variable facies. The figure on the next page is a map showing the locations of 10 wells. The table below includes the penetrated intervals of four major lithologies encountered in the wells, the depths to the top of Permian and Cambrian strata, and the total depths of the wells.

<table>
<thead>
<tr>
<th>Well #</th>
<th>Coarse Sandstone</th>
<th>Fine Sandstone</th>
<th>Shale</th>
<th>Limestone</th>
<th>Top of Permian</th>
<th>Top of Cambrian</th>
<th>Total Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2000-3250</td>
<td></td>
<td></td>
<td></td>
<td>2000</td>
<td>3250</td>
<td>3700</td>
</tr>
<tr>
<td>2</td>
<td>1900-2650</td>
<td>1600-1900</td>
<td></td>
<td></td>
<td>1600</td>
<td>2650</td>
<td>3700</td>
</tr>
<tr>
<td>3</td>
<td>2100-3600</td>
<td></td>
<td></td>
<td></td>
<td>2100</td>
<td>3600</td>
<td>4300</td>
</tr>
<tr>
<td>4</td>
<td>2100-3100</td>
<td>1450-2100</td>
<td></td>
<td></td>
<td>1450</td>
<td>3100</td>
<td>3550</td>
</tr>
<tr>
<td>5</td>
<td>3650-3800</td>
<td>2020-3650</td>
<td>1300-2020</td>
<td></td>
<td>1300</td>
<td>3800</td>
<td>4100</td>
</tr>
<tr>
<td>6</td>
<td>1850-3250</td>
<td>1400-1850</td>
<td></td>
<td></td>
<td>1400</td>
<td>3250</td>
<td>3700</td>
</tr>
<tr>
<td>7</td>
<td>1950-2200</td>
<td>1100-1950</td>
<td></td>
<td></td>
<td>1100</td>
<td>2200</td>
<td>3180</td>
</tr>
<tr>
<td>8</td>
<td>3180-4200</td>
<td>1600-2100; 2700-3180</td>
<td></td>
<td>2100-2700</td>
<td>1600</td>
<td>4200</td>
<td>4900</td>
</tr>
<tr>
<td>9</td>
<td>1700-2550; 3450-4200</td>
<td></td>
<td></td>
<td>2550-3450</td>
<td>1700</td>
<td>4200</td>
<td>5200</td>
</tr>
<tr>
<td>10</td>
<td>2100-2300</td>
<td>1300-2100</td>
<td></td>
<td></td>
<td>1300</td>
<td>2300</td>
<td>3200</td>
</tr>
</tbody>
</table>

Procedure:

Using a scale of 1' = 2000', extend a vertical line downward from the well locations and plot the total depth of each well. On this line, scale off the intervals of the various lithologies penetrated. The upper limit of the panel represents the unconformity at the top of the Permian (isochronous surface 2). The base of the Permian is marked by an erosional surface (isochronous surface 1). Show these surfaces by wavy lines. Correlate the various lithologic units in the wells and develop panels along the lines connecting the wells on the map. The correlation lines should be drawn so as to demonstrate irregular intertonguing relationships of the various deposits (use gentle zigzags). Work initially in pencil, then ink in the lithologic boundaries, and color, with appropriate symbols, the rock types.

**PART II:** Construction of structure contour, gross isopach and net oil sand map for the Tres Lagos Formation. After graduating from Cornell College and taking a job as a geologist for a large independent petroleum producer in Oklahoma City, OK, you begin your training period for the company. Soon you hear that the next phase of your training will be observing and helping one of the company’s on-site geologists. You are assigned to a field being developed in the Reforma area of Mexico. One of your first assignments
is to create a structure contour map, gross isopach map and a net oil sand map for the oil-bearing formation being drilled. The senior geologist gives you the electric logs of the sixteen wells completed and their base map coordinates:

<table>
<thead>
<tr>
<th>Well #</th>
<th>Elevation</th>
<th>Easting</th>
<th>Northing</th>
<th>Top of Zone</th>
<th>Bottom of Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>63</td>
<td>2.875</td>
<td>3.75</td>
<td>5535</td>
<td>5693</td>
</tr>
<tr>
<td>2</td>
<td>66</td>
<td>2</td>
<td>4.34375</td>
<td>5720</td>
<td>5761</td>
</tr>
<tr>
<td>3</td>
<td>63</td>
<td>3.21875</td>
<td>2.96875</td>
<td>5520</td>
<td>5687</td>
</tr>
<tr>
<td>4</td>
<td>77</td>
<td>2.3125</td>
<td>2.03125</td>
<td>5738</td>
<td>5786</td>
</tr>
<tr>
<td>5</td>
<td>26</td>
<td>4.90625</td>
<td>5.15625</td>
<td>5744</td>
<td>5800</td>
</tr>
<tr>
<td>6</td>
<td>24</td>
<td>4.9375</td>
<td>2.5</td>
<td>5854</td>
<td>5873</td>
</tr>
<tr>
<td>7</td>
<td>123</td>
<td>2.46875</td>
<td>1.40625</td>
<td>5836</td>
<td>6005</td>
</tr>
<tr>
<td>8</td>
<td>27</td>
<td>3.90625</td>
<td>1.96875</td>
<td>5612</td>
<td>5739</td>
</tr>
<tr>
<td>9</td>
<td>22</td>
<td>4.375</td>
<td>3.5625</td>
<td>5596</td>
<td>5651</td>
</tr>
<tr>
<td>10</td>
<td>122</td>
<td>1.6875</td>
<td>2.8125</td>
<td>5729</td>
<td>5884</td>
</tr>
<tr>
<td>11</td>
<td>24</td>
<td>3.6875</td>
<td>0.71875</td>
<td>5854</td>
<td>5969</td>
</tr>
<tr>
<td>12</td>
<td>24</td>
<td>4.1875</td>
<td>2.78125</td>
<td>5540</td>
<td>5694</td>
</tr>
<tr>
<td>13</td>
<td>41</td>
<td>3</td>
<td>5.53125</td>
<td>5941</td>
<td>6001</td>
</tr>
<tr>
<td>14</td>
<td>31</td>
<td>3.90625</td>
<td>3.28125</td>
<td>5556</td>
<td>5652</td>
</tr>
<tr>
<td>15</td>
<td>29</td>
<td>4.09375</td>
<td>4.1875</td>
<td>5964</td>
<td>6069</td>
</tr>
<tr>
<td>16</td>
<td>48</td>
<td>3.3125</td>
<td>4.75</td>
<td>5722</td>
<td>5767</td>
</tr>
</tbody>
</table>

Procedure:
- Open a new data file and template file in Rockworks. Under “New,” select “both data file and template”, then “Oil and Gas” and then “Formation Tops”
- Enter the data provided (elevation is placed in the “collar” column, the well # in the “Well ID” column). Change Fm1 etc., to the following columns: “top of zone”, “bottom of zone”,“zone thickness”, “oil level”, and “wet wells”.
- Use the thickness function on the “Edit” drop-down menu to calculate the thickness of the formation (obviously you should place the result in you “zone thickness” column).
- The water/oil contact is at -5700 feet. Enter this in the “oil level” column
- I will leave figuring out which are “wet” (producing) wells up to you, but hint that it involves using the thickness function again, and reading part C, below.
- This is all the information you need to produce the following maps (see the instructions included with this lab).

A. Gross isopach map – This relates the thickness of a particular rock unit by plotting the thickness measured in the wells on a base map. The map coordinates (easting and northing) are supplied in the data table above. To construct the map, use the thickness calculated for each well on your spreadsheet.

B. Structure contour map – A structure contour map shows the contour, or topography, of the surface of an underground formation at depths determined by correlation “picks” on
the well’s electric logs or drilling sample cuttings of the wells drilled into the formation. Construct a structure contour map of the top of the formation, and use a contour interval of 100’.

C. Net Oil Sand Map – The net oil sand is that portion of the gross sand that is saturated with hydrocarbons and is above the oil/water contact. For this oil field the oil/water contact iw at −5700 feet (below sea level). Define whether each well is an oil-producing well (greater than 5 feet of “pay” – oil in the sandstone) or a dry hole. In reality, a dry hole (well) means a non-producing well with all of its sand below the oil/water contact. A dry hole may be saturated with saltwater, encounter a non-porous or non-permeable zone, or may not be drilled deep enough.

For this portion of the lab you should turn in a gross isopach map, structure contour map with the producing wells labeled, and answer the following questions:

1. The hydrocarbon trap in this oil field is the result of which of the following: and anticline, a syncline, a normal fault, a nonconformity, or a permeability barrier?

2. Where would you suggest drilling Well #17.

Remember, this is your first assignment for your new company. Your performance rating, future promotion and job security depend on your work. Moreover, well #17 will cost approximately $3 million to drill; don’t miss!

PART III: Putting it all together: An application of fence diagrams and isopach maps to the future mining activities at Linwood Mine, Davenport Iowa. Linwood Mining and Minerals Co. extracts limestone from the Davenport and Otis Members of the Wapsipinicon Formation. Mining activities occur in a “room and pillar” configuration, in which the material is removed producing “rooms” that have thick “pillars” of undisturbed bedrock that support the ceiling. Limestones of the Cedar Valley Formation immediately overlie the Davenport. These limestones are, in turn, overlain by poorly-indurated sandstones of Pennsylvanian age. Mining operations can be conducted safely only where the resulting rooms and pillars are overlain by relatively thick packages of the Cedar Valley Formation. The limestone has the structural integrity to serve as a “roof” for the mine. The poorly indurated sandstones do not possess this integrity and hence cannot support the weight of overlying bedrock and Quaternary sediments once the underlying limestones are removed.

In 1998, the mining company hired Paul Garvin to assess the disposition of the bedrock geology within the mine property boundary (indicated by the stippled and green patterns on the attached map). Specifically, mine managers were interested whether it was feasible to extend room and pillar operations into un-mined land owned by the company (i.e., from the area with the stippled pattern into the area indicated in green on the
attached map). Beginning in the summer of 1998 and continuing until his retirement in 2005, Paul worked with several geology majors logging cores obtained from several wells drilled on Linwood property. The wells were placed along six traverses across the property – the traverses are labeled A-A’, B-B’, etc., on the attached map. The wells are marked by dots on the map, and are labeled beginning with “LMM” followed by a series of numbers. I have loaded the cumulative data into the Rockworks program for analysis.

Procedure:

Using the Rockworks Program, generate a series of fence diagrams that illustrate the relationships of the Otis, Kenwood, Davenport, Cedar Valley and Pennsylvanian units. You should also produce an isopach map for the units that are mined, as well as one for the important “ceiling former”, the Cedar Valley limestones. Compare your results to the map on the next page and prepare a written report to the management of the company. In this report you will identify whether mining can continue on the property owned by the company. If so, in which direction, within the mine land holdings, mining operations should continue, and why (i.e., include the relevant fence diagram(s) and an explanation of them). Should the mine exercise their lease option on the additional land (indicated in green)? Remember, the safety of human beings and profitability of the company are in your hands!
Create a column-based isopach map.

Estimated time: 3 minutes.

In this first pass, we will show you how to:

Use the data sheet tools to compute the thickness of a stratigraphic unit (Edit / Columns / Thickness).

Create a grid model and a contour map of this column of thickness values (Map / Grid-Based Map).

Compute the volume of the thickness grid (Grid / Grid Statistics).

1. Please be sure that you have restored the program defaults and opened the Stratos1 data and template files (as discussed earlier in this section) before continuing.

Compute the thickness.

With the main RockWorks data sheet in front of you, orient yourself for a minute with what's contained in the data columns. To the right of the drill hole location information (Easting and Northing) are listed the elevations at the top of ten stratigraphic units, from the Surface down to the Total Depth (TD). We will compute the thickness of the Coal unit simply by subtracting the Shale elevations from the Coal elevations, storing the computed differences in another column in the data sheet.

2. Select the Edit option from the main RockWorks menu.

3. Select the Columns item from the menu, and the Thickness command from its pop-up list.

4. Enter the requested data column information:

   The name of the currently-selected column is displayed next to each prompt. To change a column name for any of the prompts simply click on the small down-arrow and select another column name.

To view the entire dialog box, click on its title bar are move it to the left so that both the tutorial screen and the dialog box are visible.

Or, you can drag this tutorial window out of the way, minimize it, or turn off its always-on-top status; click here for more information.

Data Columns (Input):

   Upper Surface: Select the column named "Coal". This is the unit for which the thickness is to be computed.

   Lower Surface: Select the column named "Shale". This is the column down to which the thickness is to be computed.

   The Shale unit lies below the Coal unit.

Data Column (Output):

   Calculated Thickness: Select the column named "CoalThick". (You'll need to scroll down the listing a ways to find this name.) This is the column in the data sheet into which the computed thickness of the Coal unit will be stored.

5. Click OK at the bottom of the Compute Thickness window.

The program will compute the difference between the elevation at the top of the Coal formation and the elevation at the top of the Shale formation for each drill hole, storing the computed values in the CoalThick column.
Set up the thickness grid.

6. Select the Grid-Based Map command from the Map menu.

7. Click in the Create New Grid button. This tells the program to create a new grid model for the thickness data rather than creating a map from an existing grid model.

8. Click on the Data Columns button to define how the data is laid out.
    Click in the Spreadsheet button.
    Define the names of the columns in the data sheet that contain the requested information.
    The name of the currently-selected column is displayed next to each prompt. To change a column name for any of the prompts simply click on the small down-arrow and select another column name.
    X (Easting): This column should be set to the data column named "Easting". This column contains the X or Easting coordinates for the drill holes.
    Y (Northing): This should be set to the column named "Northing." This column contains the Y or Northing coordinates for the drill holes.
    Z (Elevation): This should be set to the column "CoalThick" so that the contour map we build will represent the thickness we just computed.
    Symbols: This should be set to the "Symbols" column. The program will use the symbols displayed in this column to overlay points on the map.
    Point Labels: This should be set to the "ID" column; the information in the ID column will be used for the symbol labels in the map.

9. Click on the Modeling Method button to define how the grid model is to be computed.
    Be sure this is set to Triangulation with Declustering and Polyenhancement turned off.

? If you click the Help button at the bottom of the window, you can get more information under the "Select the Grid Modeling Method" topic.

10. Click on the Model Dimensions button to define how dense the grid model is to be.
    Be sure this is set to Medium density.

11. Click on the Grid Model Name button to define a name for this model.
    Click on the large file name button. Be sure the "Samples" folder is the current folder shown at the top of the window. Into the File Name prompt, type in the name: coal-thickness-1.grd and click the Save button.

Set up the isopach map.

12. Click in the Create Diagram button to tell the program you want to create a map at this time.

13. Click in the 2-Dimensional radio button to tell the program you want to create a 2D (flat) map.
14. Now click on the rectangular 2-Dimensional button to select the "Visible Layers" to be included in this map.

Insert a check in the Symbols check-box.

![Symbols](check_box)

Now, click on the Symbols button (">") to view the symbol settings. These should be set to Fixed size (all symbols will be plotted at the same size) and a size of "3" displayed on the Size button.

Insert a check in the Labels check-box.

![Labels](check_box)

Click on the Labels button (">") to view the label settings. Since you restored the factory defaults earlier, you shouldn't need to make any adjustments of the label placement, size, or color.

Insert a check in the Contours check-box.

![Contours](check_box)

Click on the Contours button (">") if you want to view the contour settings.

Insert a check in the Color Intervals check-box, and click on the Color Intervals button (">") if you want to view the color-filled interval settings.

![Colorfill](check_box)

Insert a check in the Borders check-box, and click on its button to view its settings.

![Border](check_box)

Now, create the map.

15. Click OK at the bottom of the Grid-Based Map window.

The program will scan the data sheet, determine the location coordinates for each drill hole, and build a grid model of the coal thickness data using the Triangulation gridding method. The grid model will be saved on disk under the name "coal-thickness-1.grd." It will then start to build the map, creating line contours and color-filled contour intervals to represent the thickness values stored in the grid model. It will overlay point symbols and labels to illustrate the drill hole locations. The completed map will be displayed in a new "RockPlot" window on the screen.

RockPlot is the plotting program for RockWorks. It displays completed maps and diagrams and offers many graphic tools. See the RockPlot tutorial for more information.

16. Save this map on disk by choosing RockPlot's File menu, Save As command. In the displayed prompt, type in the name: coal-thickness-1.rkw and click the Save button.

17. Resize this map window to occupy 1/3 or 1/2 of your screen by grabbing the window's lower-right corner and dragging to the right size. As necessary, you can move the entire window by grabbing the title bar at its top.

18. Re-draw the map within the newly-sized window by clicking on the Best-Fit toolbar button, shown above.

We will compare this map to the one created in a following lesson.

19. Click in the main RockWorks window to continue.