ERCB/AGS Information Series 136

Digital Mapping and 3D Visualization/ Modelling of Subsurface Geology Using ArcGIS 9.2 and Well Log Data

Energy Resources Conservation Board

ERCB/AGS Information Series 136

Digital Mapping and 3D Visualization/Modelling of Subsurface Geology Using ArcGIS 9.2 and Well Log Data

S. Mei

Energy Resources Conversation Board
Alberta Geological Survey

March 2008

ISBN 978-0-7785-6944-2

Published March 2008 by
Energy Resources Conservation Board
Alberta Geological Survey
4th Floor, Twin Atria Building
4999 – 98th Avenue
Edmonton, Alberta
T6B 2X3
Canada

Tel: (780) 422-1927
Fax: (780) 422-1918
E-mail: EUB.AGS-Infosales@gov.ab.ca
Website: www.ags.gov.ab.ca

Contents

Figures

Acknowledgments

The author thanks Dianne Haley, Cristina Pana and other colleagues who expressed strong interest at the ERCB GIS Seminar for the author to write this manual. Kirk McKay went through the exercise and provided valuable comments. Glen Prior and Gisela Hippolt-Squair are thanked for editorial review.

The Landsat 7 image used is created from a subset clipped from the Alberta mosaic of Landsat 7 Enhanced Thematic Mapper Plus (ETM+) image, which was produced by Photosat Information Ltd, by fusing it with the sunshade relief image of SRTM DEM. The SRTM DEM is obtained from USGS website http://seamless.usgs.gov/. The base maps, including roads and rivers, were obtained from Geomatics Canada, Department of Natural Resources Canada.

Abstract

This is a step-by-step instruction manual of digital mapping and 3D visualization/modelling of subsurface geology using ESRI ArcGIS software and well log data. ArcGIS makes it possible to derive almost all of the building blocks for 3D visualization/modelling, including 3D wellbores, geological surfaces, cross-sections, fence diagrams, block diagrams, faults and geological solids, from a single shapefile with well log data, including well locations (x and y coordinates) and picks for geological formation tops (z value). The ArcGIS components involved include ArcMap, ArcScene and ArcCatalog applications, and extensions including 3D Analyst, Spatial Analyst and a third-party extension called XTools Pro that was developed by Data East, LLC of Russia. Simulated well log data, including formation picks and interpolated surfaces, derived from the Peace River Arch region in the northwestern Alberta, are provided to assist with using this manual. Base map data, including rivers, roads, urban areas and a satellite image are also included for the exercise.

1 Introduction

In 2004, the Alberta Geological Survey (AGS) studied the geology, metallurgy and economics of the Clear Hills (Peace River) ooidal ironstone deposits within the Upper Cretaceous Bad Heart Formation. The Clear Hills ironstone deposits overlap the well-known Peace River Arch (PRA) region, which is characterized by a long-lived zone of structural disturbance in the Western Canada Sedimentary Basin (WCSB) that affected sedimentation and the resulting subsurface stratigraphy. One component of this project was to detect and map subsurface structures/faults using well log data and geostatistical analysis (Mei, 2006, 2007). The result is a significant update to the structural framework of the Peace River Arch region, which has been the focus of structural study for decades. Lineaments have been identified from 14 formation tops (including the Precambrian top) and traced through most of the sedimentary cover in this region. In 2007, AGS initiated a multiyear project to produce a digital atlas of shallow and surficial geology of Alberta. It requires 3D digital mapping and visualization of subsurface geology. As a result, a pilot project was carried out to explore and develop the methodology for digital mapping and 3D visualization/modelling of subsurface geology using data obtained from the structure mapping of the Peace River Arch region. This has resulted in a prototype 3D model of subsurface geology for the Peace River Arch region (Mei, 2007). Figure 1 demonstrates the concepts we learned from this process about 3D digital mapping. 3D digital mapping of subsurface geology starts with a table containing the x, y and z coordinates of the basic geological entity; e.g., wellbores with formation top picks. Other geological entities can be derived from the coordinates of the basic entity. For example, Mei (2006) demonstrated how faults can be detected and mapped from well log data using geostatistical analysis.

A 3D model comprises several basic types of geological objects. They are block diagrams, fence diagrams, cross-sections, faults, geological solids and wellbores. These objects can all be derived from the well log data with formation picks. Figures 2 to 5 show some snapshot pictures of the 3D visualization/modelling of subsurface geology for the Peace River Arch region (Mei, 2007).

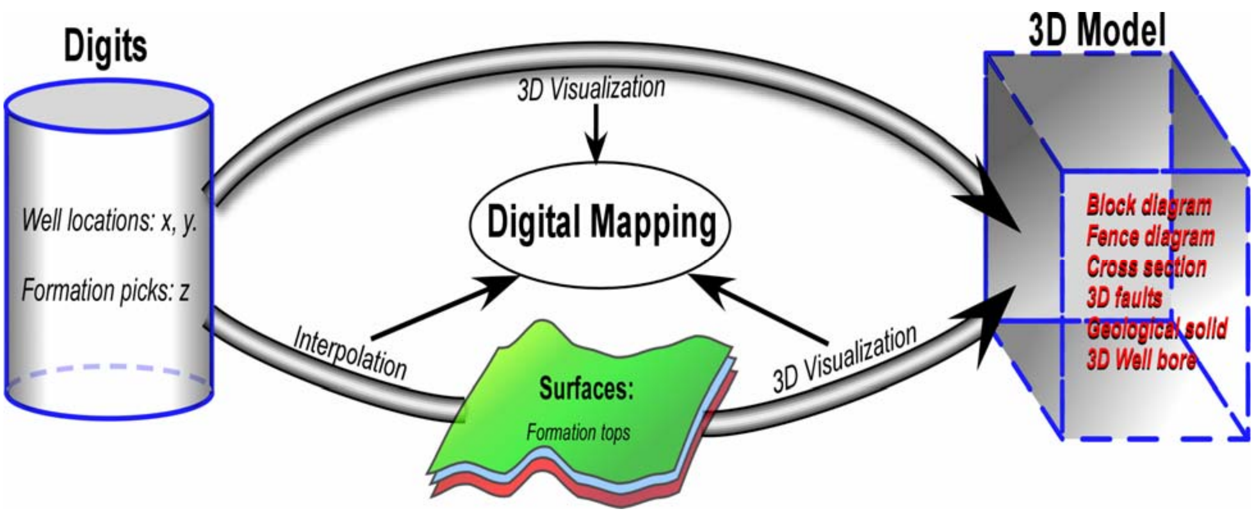

Figure 1. Illustrating the concept of digital mapping and 3D visualization/modelling.

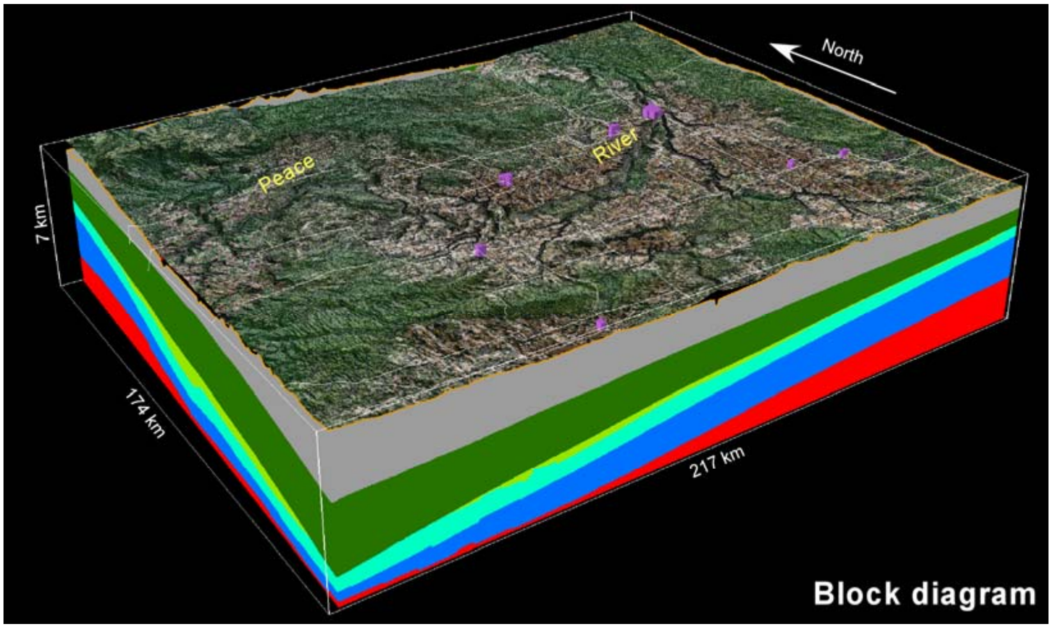

Figure 2. An example of a block diagram.

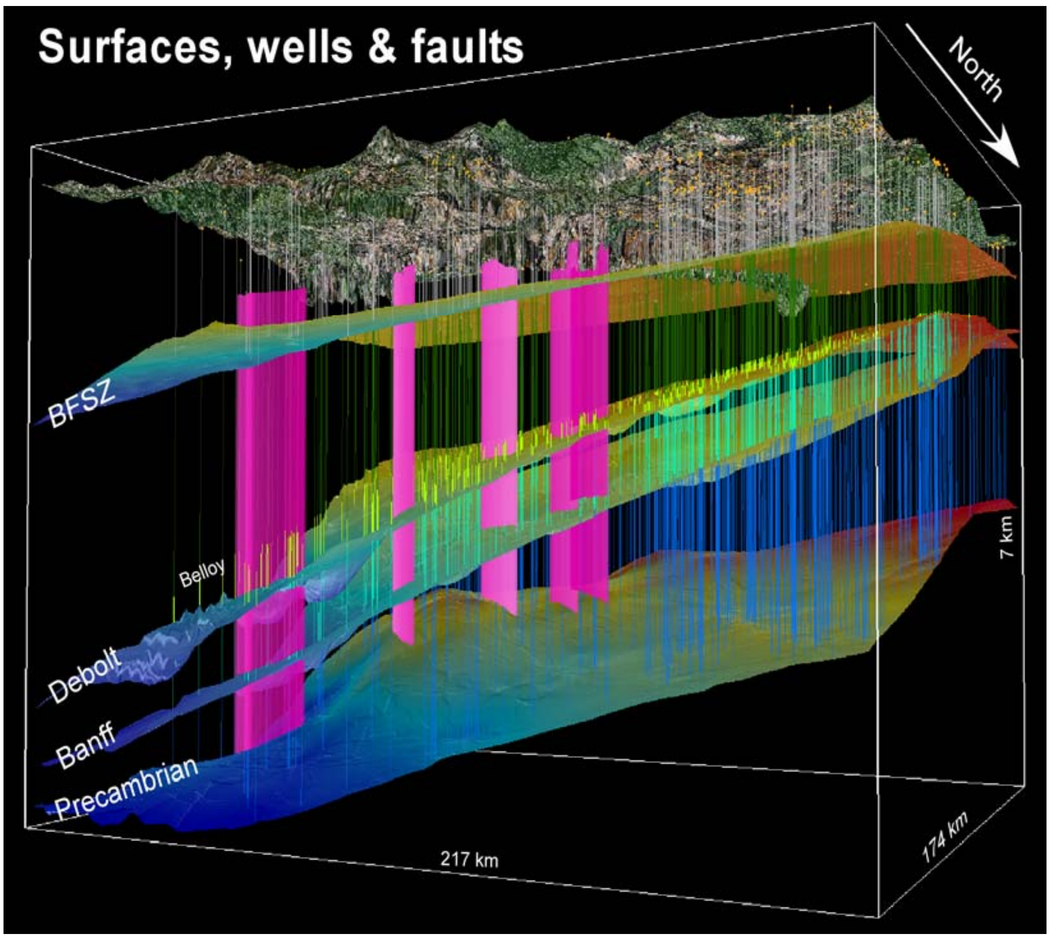

Figure 3. 3D display of geological surfaces, wellbores and faults.

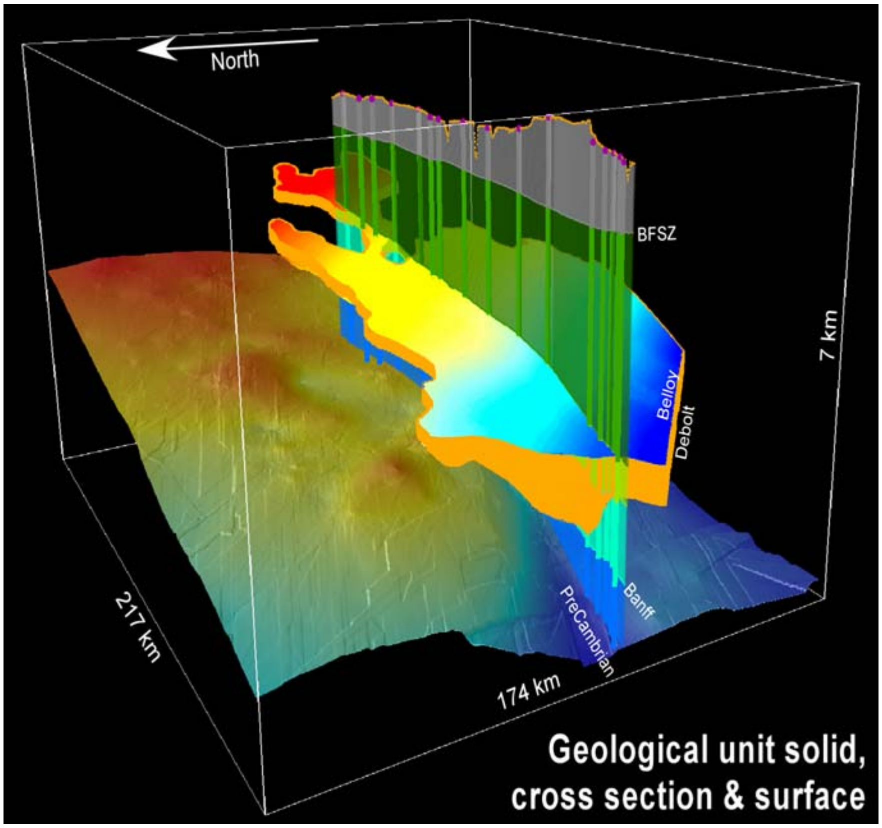

Figure 4. 3D display of a geological solid, cross-section and geological surfaces.

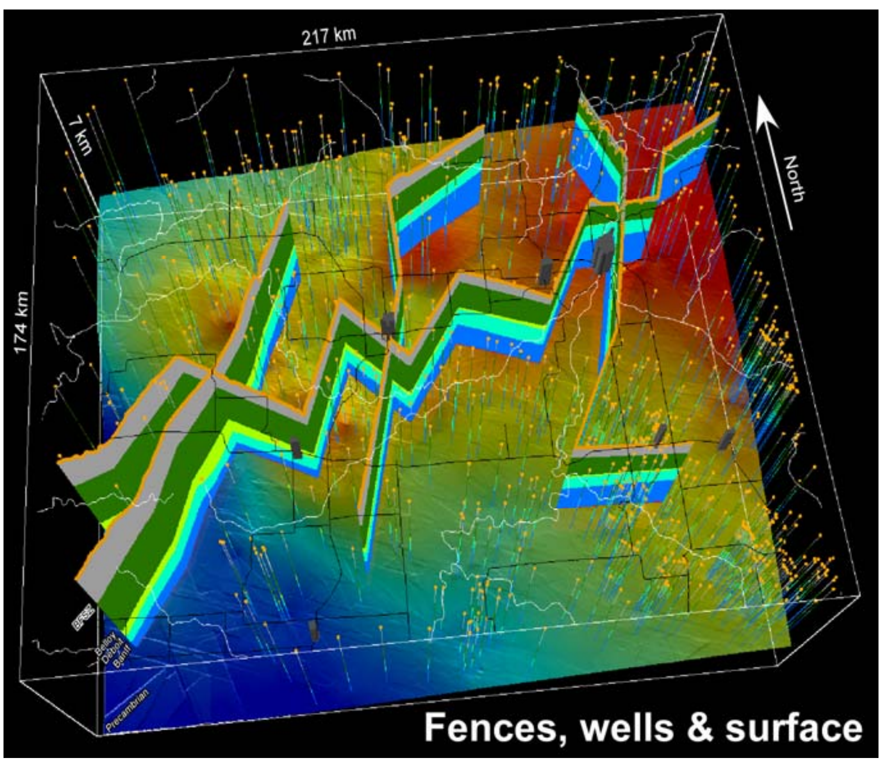

Figure 5. 3D display of fences, wellbores and a geological surface.

This report is a step-by-step manual of 3D digital mapping and visualization of subsurface geology using ESRI ArcGIS 9.2 software, including ArcMap and ArcScene, its extensions including 3D Analyst and Spatial Analyst, and a third-party extension named XTools Pro for ArcGIS desktop developed by Data East, LLC. Tutorial data, which are modified from the data used in Mei (2006), are provided for use with this manual. After successfully finishing these exercises, you will be able to create cross-sections, fence diagrams, block diagrams, geological solids, 3D faults and 3D wellbores using well log data, including formation picks. These instructions are based on ArcGIS 9.2 and XTools Pro 4.2 and may not work as shown for other versions. Nevertheless, the workflow serves as a useful reference for creating 3D visualization/modelling of subsurface geology using well log data and ArcGIS.

Familiarization with ArcGIS, including its three components: ArcMap, ArcScene and ArcCatalog, is required to use this manual. Understanding the concept of shapefiles and some experience editing shapefiles in ArcMap using the Editor toolbar are also necessary. Experience using 3D analyst and Spatial Analyst would be very helpful.

2 Tutorial Data

The following files/data, derived from the Peace River Arch region (Mei, 2006), are provided for this manual. These data are either in public domain or were specifically created or modified for the tutorial. They should only be used with this manual.

1) Shapefiles with well locations, formation picks and fault locations

   - *wells_all_picks_u11.shp*: a shapefile containing simulated well locations and formation picks extracted from interpolated surfaces for the top of Precambrian, the top of Banff Formation, the top of Debolt Formation, the top of Belloy Formation, the Basal Fish Scale Zone (BFSZ) and ground surface
   - *interpreted_faults_BFSZ.shp*: a shapefile from Mei (2006) containing faults interpreted from the surface of Basal Fish Scale Zone (BFSZ)
   - *interpreted_faults_Precam.shp*: a shapefile from Mei (2006) containing faults interpreted from the surface of the top of Precambrian

2) Interpolated surfaces (from Mei, 2006):
   - *precamb_surface_u11.tif*: interpolated surface for the top of Precambrian
   - *banff_surface_u11.tif*: interpolated surface for the top of Banff Formation
   - *debolt_surface_u11.tif*: interpolated surface for the top of Debolt Formation
   - *belloy_surface_u11.tif*: interpolated surface for the top of Belloy Formation
   - *BFSZ_surface_u11.tif*: interpolated surface for Basal Fish Scale Zone
   - *ground_surface_u11.tif*: Shuttle Radar Topography Mission (SRTM) DEM

3) Base maps including
   - *river_u11.shp*: shapefile for rivers clipped from the data provided by Geomatics Canada, Department of Natural Resources Canada
   - *road_u11.shp*: shapefile for roads clipped from the data provided by Geomatics Canada, Department of Natural Resources Canada
   - *urban_u11.shp*: shapefile for urban areas created by digitizing the outlines of the towns of Peace River, Fairview and Sexsmith from the base map provided by Alberta Sustainable Resource Development

- *landsat_image_u11.tif*: colour image of the ground surface created for the Peace River Arch region by fusing a Landsat 7 Enhanced Thematic Mapper Plus (ETM+) image with a sunshade relief image of SRTM.

In reality, a project usually starts with a table with well locations and formation picks. All other data needed for the digital mapping and 3D visualization/modelling, except for the base maps, can be derived from the well locations and formation picks contained in the table. The complete workflow for deriving surfaces and faults from well log data is

1. Convert the table of formation picks into a shapefile and display the shapefile in ArcMap.
2. Interpolate the geological surfaces from the shapefile with the formation picks.
3. Interpret the faults from the geological surfaces.

For details of this workflow, you are referred to Mei (2006). It is unlikely each of the wells would have the complete set of formation picks for all surfaces, as in the case of *wells_all_picks_u11.shp*. In case some wells are missing the picks for some of the surfaces, interpolation is required to extract the missing picks needed for 3D visualization/modelling. It is also important to include the most accurate surfaces in the 3D model. For generating the best geological surfaces using well log data, you are referred to Mei (2006).

3 Manual

Step-by-step instructions are provided for 3D visualization/modelling of subsurface geology. In the instructions, multiple menu selections are bolded and separated by the | symbol; text input required by the user is displayed with a different font; e.g., **`text input`**.

3.1 How to Create a 3D Framework for Display

A 3D framework enhances the 3D effect for visualizing the geology.

To Create a 3D Framework

1. Open ArcMap, add base maps and wells with formation picks (*wells_all_picks_u11.shp*) for the study area, and save the project as 2D.mxd.
2. If the Draw toolbar is not displayed in ArcMap, click the View menu, point to Toolbars and select Draw.
   - Click the dropdown arrow for drawing tools on the Draw toolbar and select **New Rectangle.**
   - Draw a rectangle on the map area of ArcMap for the extent to be displayed in 3D modelling. Click the XTools Pro dropdown arrow and select **Feature Conversions | Convert Graphics to Shapes**.
   - In the Convert Graphics to Shapes window, select the proper file path in the Output Storage box and name the output shapefile *frame_outline.shp*.
   - Click OK. The shapefile *frame_outline.shp* will be created and automatically loaded onto the map.
   - Delete the rectangle created by the New Rectangle tool.

3. Make sure the *frame_outline* layer is selected.

   - Click the XTools Pro dropdown arrow.
   - Select **Feature Conversions | Convert Features to Points**.
   - In the Convert Features to Points window, select the proper file path in the Output Storage box and name the output shapefile *frame_points.shp*.
   - Click OK. The shapefile *frame_points.shp* will be created and automatically loaded onto the map.

4. Open ArcScene.

   - Change the default data frame name from Scene layers to 3D in the Table of Contents window by clicking once on the name Scene layers so it is highlighted, then type ***3D*.**
   - Add *frame_points.shp* to the data frame 3D.
   - Right click the *frame_points* layer and select **Properties**.
   - In the Layer Properties window, click the **Base Heights** tab.
   - Select **Use a Constant Value or Expression to Set Heights for Layer** and type ***-4000*** in the box.
   - Click the **Extrusion** tab.
   - Select **Extrusion Value or Expression** option and type ***7000*** in the **Extrusion value or expression** box.
   - Select **Adding it to Each Feature's Base Height** from the dropdown list for the **Apply Extrusion By** box.
   - Click OK.

5. Add *frame_outline.shp* to ArcScene.

   - Right click the *frame_outline* layer and select **Copy.**
   - Right click the data frame 3D in the Table of Contents window and select **Paste Layer(s)**. A second copy of the *frame_outline* layer is added to the data frame 3D.
   - Right click one of the two *frame_outline* layers and select **Properties**.
   - In the Layer Properties window, click the **Base Heights** tab.
   - Select **Use a Constant Value or Expression to Set Heights for Layer** and type ***-4000*** in the box below. Repeat this for the second *frame_outline* layer and set its base height to ***3000***.
   - Right click the data frame 3D and click **Scene Properties**.
   - In the Scene Properties window, change the background colour to black and change the vertical exaggeration to ***20.***
   - Click OK

6. Change all three layers for the frame in ArcScene to white to contrast against the black background.
   - Click the symbol of the layer in the Table of Contents window to open the Symbol Selector window.
   - Click the dropdown arrow for the Colour option to open the colour palette window.
   - Select white.
   - Click OK.
   - Repeat for all three layers.
7. It is good practice to group all three layers for the frame and manage them as one item.
   - Select all three layers for the frame.
   - Right click one of them and select **Group**. A new group of layers is created with the default name New Group Layer.
   - Right click the name New Group Layer. Click the **Properties** to open the Layer Properties window.
   - Select the **General** tab. Type ***`3D Frame`*** in the Layer name box and click OK. The layer group name will now be changed to 3D Frame.
   - Click the collapsing box to the left of the 3D Frame layer group to collapse it.
8. Save the ArcScene project as 3D.sxd.

Congratulations! You have successfully created a 3D frame for 3D visualization.

3.2 How to Display Wells with Multiple Formation Tops in 3D

The shapefile (*wells_all_picks_u11.shp*) used for this exercise is prepared so each well has picks for the complete set of surfaces. For those who wish to prepare such a shapefile, interpolation is required if some of the wells are missing the picks for some of the surfaces. For an example of how to interpolate a surface using formation picks, please refer to Section 3.3. After a surface is interpolated, the missing picks can be extracted from the interpolated surface at the well locations. For details on how to extract picks from a surface, refer to Section 3.4.

1. Open 3D.sxd with ArcScene. Add *wells_all_picks_u11.shp* to ArcScene and examine its attribute table by right clicking the layer *wells_all_picks_u11* and selecting Open Attribute Table to ensure it contains picks for all surfaces. In the attribute table you should see, in ascending order of stratigraphy, the formation picks for the top of Precambrian, the top of Banff Formation, the top of Debolt Formation, the top of Belloy Formation, Basal Fish Scale Zone (BFSZ) and the ground surface, under the columns/fields of Precamb, Banff, Debolt, Belloy, BFSZ and Ground, respectively.
2. Right click the layer *wells_all_picks_u11*. Select **Copy**.
   - Right click the data frame 3D. Select **Paste Layer(s)**. A second copy of the layer *wells_all_picks_u11* is added to the data frame 3D.
   - Repeat this for n-1 times where n is the total number of surfaces including the ground surface.

3. The following process creates a 3D display of the wells for the interval from an elevation of -4000 metres to the top of the Precambrian.

    - Right click one of the copies of the layer *wells_all_picks_u11*. Click **Properties.**
    - In the Layer Properties window, click the **Base Heights** tab.
    - Select **Use a Constant Value or Expression to Set Heights for Layer** and type ***-4000*** in the box below.
    - Click the **Extrusion** tab.
    - Select **Extrusion Value or Expression** and click the **Expression Builder** tool beside the Extrusion value or expression box.
    - In the Expression Builder window, form an expression like ***[Precamb]+4000*** and click OK to close the Expression Builder window.
    - In the Layer Properties window, select **Adding it to Each Feature's Base Height** in the Apply Extrusion By box.
    - Click OK.

4. Next is to create a 3D display of the wells for the interval from the top of the Precambrian to the top of the Banff formation.

    - Right click a second copy of the layer *wells_all_picks_u11* in ArcScene.
    - Click **Properties** | **Base Heights** tab.
    - Select **Use a Constant Value or Expression to Set Heights for Layer** and click the Expression Builder tool beside the text box to open the Expression Builder window.
    - Form an expression, such as Precamb, by clicking the Precamb field in the Fields box.
    - Click OK to return to the Layer Properties window.
    - Select the Extrusion tab.
    - Select **Extrusion Value or Expression** and click the Expression Builder tool beside the Extrusion value or expression box to open the Expression Builder window.
    - Form an expression, such as [Banff]-[Precamb].
    - Click OK to return to the Layer Properties window.
    - Select **Adding it to Each Feature's Base Height** in the Apply Extrusion By box.
    - Click OK.

    Repeat this for the remaining copies of the layer *wells_all_picks_u11* and ensure to assign the correct surface for the base of the interval to be displayed and the correct expression for the top of the interval to extrude to, as demonstrated above.

5. Change the layer colours for the intervals between the formation tops for easier viewing. This exercise changed the interval below the top of Precambrian to red, between the Precambrian top and the Banff Formation top to blue, between the Banff formation top and the Debolt formation top to cyan, the interval between the Debolt Formation top and the Belloy Formation top to yellowish green, the interval between the Belloy Formation top and the BFSZ surface to dark green and the interval between the BFSZ surface to the ground to grey.

- Click the symbol of the layer in the Table of Contents window to open the Symbol Selector window.
- Click the dropdown arrow for the colour option to open the Colour Palette window.
- Select the colour you want.
- Click OK. Repeat for all layers.

6. It is a good practice to group all well layers and manage them as one item, labelled Wells.

    - Select all layers for the wells.
    - Right click one of them.
    - Select Group. A new group of layers is created with the default name New Group Layer.
    - Right click the layer group name New Group Layer.
    - Click **Properties | General** tab and type ***`Wells`*** in the Layer name box.
    - Click OK. The layer group name will be changed to Wells. Click the collapsing box to the left of the layer group Wells to collapse it.

7. Save the ArcScene project.

Congratulations! You have successfully displayed wells with multiple formation tops in 3D.

3.3 How to Generate and Render Geological Surfaces

A continuous geological surface can be generated from the formation picks of each well for this geological surface using interpolation techniques. A variety of interpolation techniques is available, including using expert's experience, hand contouring, Triangular Irregular Network (TIN), Inverse Distance Weighted averaging (IDW), Spline, Trend/Polynomial, Natural Neighbours, hydrologically correct interpolation and Kriging.

To select the proper interpolation tool and generate the best geological surface using well log/formation picks data, refer to Mei (2006). Step-by-step instructions for generating a surface using IDW are provided here as an example only for demonstrating how to interpolate a geological surface using formation picks. Several geological surfaces, interpolated from the picks used in the previous section, have been provided for this exercise. They are *precamb_surface_u11.tif, banff_surface_u11.tif, debolt_surface_u11.tif, belloy_surface_u11.tif, BFSZ_surface_u11.tif* and *ground_surface_u11.tif*, in ascending order of stratigraphy.

1. Open 2D.mxd with ArcMap.

    - Examine the attribute table of *wells_all_picks_u11.shp* by right clicking the layer *wells_all_picks_u11* and selecting Open Attribute Table.
    - In the table, you will see, in ascending order of stratigraphy, the formation picks for the tops of Precambrian, Banff Formation, Debolt Formation, Belloy Formation, Basal Fish Scale Zone (BFSZ) and the ground surface. You can generate a geological surface for each of the formation tops by its associated picks. This exercise will generate the surface for the Precambrian top using.

2. Ensure Spatial Analyst is open.
   - Click **Tools | Extensions** and check the Spatial Analyst box.
   - Click Close.
   - Click **View | Toolbars | Spatial Analyst** to turn it on.

3. Next, we will create an interpolated surface for the top of the Precambrian and add it to the map.
   - Click the Spatial Analyst dropdown arrow and select Interpolate to Raster.
   - Click Inverse Distance Weighted and select the layer *wells_all_picks_u11* from the Input Points dropdown list.
   - Select Precamb from the Z value field dropdown list.
   - Accept the defaults for other inputs and click OK.

   This demonstrates that a geological surface can be generated from the formation picks and you can experiment by generating other surfaces using the picks under other columns/fields in the table of *wells_all_picks_u11.shp*. However, these geological surfaces (e.g., *precamb_surface_u11.tif, banff_surface_u11.tif, debolt_surface_u11.tif, belloy_surface_u11.tif, BFSZ_surface_u11.tif*) and a SRTM DEM (*ground_surface_u11.tif*) have already been generated for you to use in the steps that follow. They were generated with the more advanced interpolation technique called Kriging using the extension Geostatistical Analyst (for details see Mei, 2006).

4. Add a surface, e.g., *precamb_surface_u11.tif*, to ArcScene.
   - Right click the layer *precamb_surface_u11*.
   - Select **Layer Properties | Base Heights**.
   - In the **Height** section, select **Obtain Heights for Layer from Surface** and select *precamb_surface_u11.tif* from the drop down list.
   - Click the **Symbology** tab and select the Red to Blue colour ramp from the drop drown list for the Colour Ramp box.
   - Check the Invert box.
   - Click OK.

5. Repeat Step 3 for the remaining geological surfaces *banff_surface_u11.tif, debolt_surface_u11.tif, belloy_surface_u11.tif, BFSZ_surface_u11.tif.*

6. For the ground surface, add both the ground surface (*ground_surface_u11.tif*) and the Landsat image (*landsat_image_u11.tif*) to ArcScene.
   - Right click the *Landsat_image_u11* layer and select **Layer Properties**.
   - Click the **Base Heights** tab.
   - In the **Height** section, select **Obtain Heights for Layer from Surface** and select *ground_surface_u11.tif* from the drop down list.
   - Click OK.
   - Check off the layer *ground_surface_u11.tif* to have it display properly.

7. It is a good practice to group layers and manage them as one item.
   - Select all layers for the Surfaces.
   - Right click one of them and select **Group**. A new group of layers is created with the default name New Group Layer.
   - Right click the name New Group Layer. Click **Properties,** select the **General** tab and type ***`Surfaces`*** in the Layer name box.
   - Click OK. The layer group name will be changed to Surfaces.
   - Click the collapsing box to the left of the layer group Surfaces to collapse it.
8. Save the ArcScene project.

Congratulations! You have successfully displayed geological surfaces and ground surface image in the 3D geological model.

3.4 How to Create a Cross-Section

After the geological surfaces are generated, cross-sections can be made in any direction. This involves extracting the picks for each surface along the cross-section line. To create a cross-section, follow the below steps.

1. Open 2D.mxd in ArcMap. If the Draw toolbar is not displayed, click **View | Toolbars | Draw** to open it.
2. Click the dropdown arrow for drawing tools on the Draw toolbar and select New Line.
3. Draw a line by clicking along the intended path of the cross-section on the ArcMap map area. Double-click at the endpoint to finish drawing the line.
4. Make sure the cross-section line is selected.
   - Click the XTools Pro dropdown arrow.
   - Select **Feature Conversions | Convert Graphics to Shapes**.
   - Select the file path in the Output Storage box and name the output shapefile **`cross_line.shp`**.
   - Click OK.
   - The shapefile *cross_line.shp* will be created and automatically loaded onto the map.
   - Delete the original line you created.
5. Make sure the *cross_line* layer is selected.
   - Click the XTools Pro dropdown arrow.
   - Select **Point to Feature Conversions | Convert Features to Points**.
   - Select the file path in the Output Storage box and name the output shapefile **`cross_points.shp`**.
   - Select the **Equidistant points (fixed interval)** option in the **Points** section.

- Enter `100` in the Interval box.
- Click OK.

The shapefile cross_points.shp will be created and automatically loaded onto the map

6. Make sure 3D Analyst is open.

- Click **Tools | Extensions** and check the 3D Analyst box.
- Click the Close button to exit the Extensions window.
- Click **View | Toolbars | 3D Analyst**.

3D Analyst will be turned on.

7. Click the 3D Analyst dropdown arrow.

- Select **Convert | Features to 3D**.
- Click the dropdown arrow for the Input features box and select *cross_points* from the dropdown list.
- In the Output features box, name the output file `cross_points_precamb.shp`.
- Click OK.

The shapefile *cross_points_precamb.shp* will be created and automatically added on the map.

8. Click the XTools Pro dropdown arrow.

- Point to **Table Operations | Add X, Y, Z Coordinates**.
- Select *cross_points_precamb* from the list in the Layers box.
- Check the Add Z Coordinate box and the Only for 3D Shapes box in the section to the right of the Layers box and uncheck the other checkboxes.
- Enter `Precamb` in the Field name box.
- Click OK.

9. In ArcMap, open the attribute table of the *cross_points_precamb* layer by right clicking it and selecting Open Attribute Table. You will see a column with the picks extracted from the top of Precambrian (*precamb_surface_u11.tif*) for each point along the cross-section line.

10. Repeat the previous three steps for each surface from *banff_surface_u11.tif, debolt_surface_u11.tif, belloy_surface_u11.tif, BFSZ_surface_u11.tif* and *ground_surface_u11.tif*. Make sure you select the right layer and enter the right field name for the picks for each surface. Five shapefiles result from this process and they are, in ascending order of stratigraphic horizon, *cross_points_banff.shp, cross_points_debolt.shp, cross_points_belloy.shp, cross_points_BFSZ.shp* and *cross_points_ground.shp*.

11. Join the table of *cross_points.shp* with each of the shapefiles created in the last four steps.

- Right click the *cross_points* layer.
- Select **Joins and Relates | Join**.

- In the Join Data window, select the proper field (FID in this case) for the join to base on, and select one shapefile with picks of a specific surface.
- Click OK to finish joining to the table of one of the shapefiles.
- Repeat for all remaining shapefiles.

12. Open the attribute table of the layer *cross_points* by right clicking it and selecting **Open Attribute Table.** You will see all of the columns created from the shapefiles for each surface.

    - Turn off all fields that do not contain picks by right clicking the title of the field and selecting **Turn Field Off**. Only leave the columns Fid, Shape and those with picks for different surfaces.
    - Right click the layer *cross_points.*
    - Select **Data | Export Data** and name the output shapefile **`cross_points_all_picks.shp.`**
    - Click OK.

    The *shapefile cross_points_all_picks.shp* will be created and automatically loaded on the map. Open the attribute table and ensure it has all of the columns with picks for all surfaces, including the ground surface.

13. Open ArcScene (3D.sxd) and check off the layer groups Wells and Surfaces to save memory for a fast display and add *cross_points_all_picks.shp*.

    - Right click the layer *cross_points_all_picks.*
    - Select **Copy**.
    - Right click the data frame 3D and select **Paste Layer(s).** A second copy of the layer *cross_points_all_picks* is added to the data frame 3D.
    - Repeat this for n-1 times where n is the total number of surfaces including the ground surface.

14. Next, we will create a 3D display of the cross-section for the interval from an elevation of -4000 m to the top of Precambrian.

    - Right click one of the copies of the layer *cross_points_all_picks.*
    - Select **Properties** and click the **Base Heights** tab.
    - Select **Use a Constant Value or Expression to Set Heights for Layer** and enter **`-4000`** in the box.
    - Click the **Extrusion** tab and select **Extrusion Value or Expression**.
    - Click the Expression Builder tool beside the Extrusion value or expression box to open the Expression Builder window.
    - Form an expression such as **`[Precamb]+4000`**.
    - Click OK button to return to the Layer Properties window.
    - Select **Adding it to Each Feature's Base Height** in the Apply Extrusion box.
    - Click OK.

15. This following process creates a 3D display of the cross-section for the interval from the top of Precambrian to the top of Banff formation.

    - Right click a second copy of the layers of *cross_points_all_picks.*
    - Click **Properties** and select the **Base Heights** tab.
    - Select the **Use a Constant Value or Expression to Set Heights for Layer** option and click the Expression Builder tool beside the text box to open the Expression Builder window.
    - Form an expression like [`Precamb]`by clicking the Precamb field in the Fields box.
    - Click OK to exit the Expression Builder window and return to the Layer Properties window.
    - Click the **Extrusion** tab.
    - Select the **Extrusion Value or Expression** option and click the Expression Builder tool beside the Extrusion Value or Expression box.
    - Form an expression like `[Banff]-[Precamb].`
    - Click OK to return to the Layer Properties window.
    - Select **Adding it to Each Feature's Base Height** in the Apply Extrusion By box and click OK to finish.
    - Repeat this for the remaining copies of the layer *cross_points_all_picks* and make sure to assign the correct surface for the base of the interval to be displayed and the correct expression for the top of the interval to extrude to, as demonstrated above.

16. Change the layer colour for the interval below the top of Precambrian to red, the interval between the Precambrian top and the Banff Formation top to blue, the interval between the Banff formation top and the Debolt formation top to cyan, the interval between the Debolt Formation top and the Belloy Formation top to yellowish green, the interval between the Belloy Formation top and the BFSZ surface to dark green and the interval between the BFSZ surface to the ground to grey.

    - Click the symbol of the layer in the Table of Contents window to open the Symbol Selector.
    - Click the dropdown arrow for the Colour option to open the Colour Palette window.
    - Select the colour you want.
    - Click OK to finish.
    - Repeat all layers.

17. It is a good practice to group all layers for the cross-section and manage them as one item

    - Select all layers for the cross-section
    - Right click one of them and select the **Group** tool.
    - A new group of layers is created with the default name New Group Layer.
    - Right click the name New Group Layer, select **Properties** and click the **General** tab.
    - Type `Cross-Section` in the Layer name box.
    - Click OK.
    - The layer group name will be changed to Cross-Section. Click the collapsing box to the left of the layer group Cross-Section to collapse it.

18. Save the ArcScene project.

Congratulations! You have successfully created a cross-section in 3D.

3.5 How to Create a Fence Diagram

The process for creating a fence diagram is the same as creating a cross-section, except that a fence diagram is composed of several cross-sections.

1. Open 2D.mxd in ArcMap.
    - If the Draw toolbar is not displayed in ArcMap, click **View | Toolbars | Draw** to open it.
    - Click the dropdown arrow for drawing tools on the Draw toolbar and select **New Line.**
    - Draw several lines to form a fence on the ArcMap map area.
    - Double click the endpoint to finish drawing each line.
2. Make sure all the lines for the fence are selected.
    - Click the XTools Pro dropdown arrow and select **Feature Conversions | Convert Graphics to Shapes.**
    - Select the file path in the Output Storage box and name the output shapefile *fence_line.shp.*
    - Click OK.
    - The shapefile *fence_line.shp* will be created and automatically loaded onto the map.
    - Delete the line created using the **New Line** tool.
3. Make sure the *fence_line* layer is selected.
    - Click the XTools Pro dropdown arrow and select **Feature Conversions** | **Convert Features to Points**.
    - Select the file path in the Output Storage box and name the output shapefile *fence_points.shp*.
    - Select **Equidistant Points (Fixed Interval)** in the **Points** section.
    - Type **`100`** in the Interval box.
    - Click OK.
    - The shapefile *fence_points.shp* will be created and automatically loaded onto the map
4. Make sure 3D Analyst is open.
    - Click **Tools | Extensions.**
    - Check the **3D Analyst** box.
    - Click the Close button to exit the Extensions window.
    - Click **View | Toolbars | 3D Analyst**.
    - 3D Analyst should be available for use.

5. Next create the shapefile *fence_points_precamb.shp* and add it to the map.
   - Click the 3D Analyst dropdown arrow.
   - Select **Convert | Features to 3D.**
   - Click the dropdown arrow for the Input features box and select *fence_points* from the dropdown list.
   - Click the dropdown arrow for the Raster or TIN Surface box and select *precamb_surface_u11.tif* from the dropdown list.
   - In the Output features box, name the output file **`fence_points_precamb.shp`**.
   - Click OK.
6. Click the XTools Pro dropdown arrow.
   - Point to **Table Operations | Add X, Y, Z Coordinates.**
   - Select *fence_points_precamb* from the list in the Layers box.
   - Check the Add Z Coordinate box and the Only for 3D Shapes box and uncheck other boxes in the section to the right of the Layers box.
   - Type **`Precamb`** in the Field Name box.
   - Click OK.
7. In ArcMap, open the attribute table of the *fence_points_precamb* layer by right clicking it and selecting **Open Attribute Table**. You will see a column with the picks, extracted from the top of Precambrian (*precamb_surface_u11.tif*), for each point along the fence lines.
8. Repeat Steps 5 to 7 for each surface by using *banff_surface_u11.tif, debolt_surface_u11.tif, belloy_surface_u11.tif, BFSZ_surface_u11.tif* and *ground_surface_u11.tif*, respectively. Make sure you select the correct layer and type in the correct field names for the picks for each surface. Five shapefiles result from this process and they are, in ascending order of stratigraphic horizon, *fence_points_banff.shp*, *fence_points_debolt.shp*, *fence_points_belloy.shp*, *fence_points_BFSZ.shp* and *fence_points_ground.shp*.
9. Join the table of *fence_points.shp* with each of the shapefiles created in the previous four steps.
   - Right click the *fence_points* layer and select **Joins and Relates | Join.**
   - In the Join Data window, select the correct field for the join to base on, and select one shapefile with picks of a specific surface.
   - Click OK to finish joining to the table of one of the shapefiles.
   - Repeat this for all remaining shapefiles.
10. Open the attribute table of the layer *fence_points* by right clicking it and selecting **Open Attribute Table**. You should see all the columns from the shapefiles created for each of the surfaces.
    - Turn off all fields that do not contain picks by right clicking the title of the field.
    - Click **Turn Field Off**.
    - Only leave the columns “Fid,” “Shape” and columns with picks for different surfaces.

- Then, right click the *fence_points* layer.
- Select **Data | Export Data**.
- Name the output shapefile `fence_points_all_picks.shp`.
- Click OK.
- The shapefile *fence_points_all_picks.shp* will be created and automatically loaded on the map. Open the attribute table and make sure it has all the columns with picks for all the surfaces including the ground surface.

11. Open ArcScene (3D.sxd) if it is not open.

- Turn off the layer groups Wells, Surfaces and Cross Section to save memory for a fast display.
- Add *fence_points_all_picks.shp*.
- Right click the layer *fence_points_all_picks* and select **Copy**.
- Right click the data frame 3D and select Paste Layer(s).
- A second copy of the layer *fence_points_all_picks* is added to the data frame 3D.
- Repeat this for n-1 times where n is the total number of surfaces including the ground surface.

12. The following creates a 3D display of the fence for the interval from an elevation of -4000 m to the top of Precambrian.

- Right click one of the copies of the layer *fence_points_all_picks* and click **Properties**.
- Click the **Base Heights** tab.
- Select the **Use a Constant Value or Expression to Set Heights for Layer** option and type `-4000` in the box.
- Click the **Extrusion** tab and select the **Extrusion Value or Expression** option.
- Click the Expression Builder tool beside the Extrusion value or expression box to open the Expression Builder window.
- Form an expression like `[Precamb]+4000`.
- Click OK to return to the Layer Properties window.
- Select **Adding it to Each Feature's Base Height** in the Apply Extrusion By box.
- Click OK.

13. Now create a 3D display of the fence for the interval from the top of Precambrian to the top of Banff formation.

- Right click a second copy of the layer *fence_points_all_picks* and select **Properties**.
- Click the **Base Heights** tab and select the **Use a Constant Value or Expression to Set Heights for Layer** option.
- Click the Expression Builder tool beside the text box and form an expression, like `[Precamb]`, by clicking the Precamb field in the Fields box.
- Click OK to exit the Expression Builder window and return to the Layer Properties window.
- Click the **Extrusion** tab and select the **Extrusion Value or Expression** option.

- Click the Expression Builder tool and form an expression, like **`[Banff]-[Precamb]`**.
- Click OK to return to the Layer Properties window.
- Select **Adding it to Each Feature's Base Height** in the Apply Extrusion By box.
- Click OK to finish.
- Repeat for remaining copies of the layer *fence_points_all_picks* and ensure you assign the correct surface for the base of the interval to be displayed and the correct expression for the top of the interval to extrude to, as demonstrated above.

14. Change the layer colour for the interval below the top of Precambrian to red, the interval between the Precambrian top and the Banff Formation top to blue, the interval between the Banff formation top and the Debolt formation top to cyan, the interval between the Debolt Formation top and the Belloy Formation top to yellowish green, the interval between the Belloy Formation top and the BFSZ surface to dark green and the interval between the BFSZ surface to the ground to grey.

    - Click the symbol of the layer in the Table of Contents window.
    - Click the dropdown arrow for the Colour option to and select the colour you want.
    - Click OK.
    - Repeat for all layers.

15. Group all of the layers for the fence and manage as one item.

    - Select all layers for the Fence.
    - Right click one of them and select **Group**.
    - A new group created with the default name New Group Layer.
    - Right click the name New Group Layer and select Properties.
    - Click the **General** tab and type **`Fence`** in the Layer Name box.
    - Click OK.
    - The layer group name will now be Fence.
    - Click the collapsing box to the left of the layer group Fence to collapse it.

16. Save the ArcScene project.

Congratulations! You have successfully created a Fence Diagram in 3D.

3.6 How to Create a Block Diagram

The process for creating a block diagram is similar to creating a cross-section and fence diagram, except it starts with the outline of a rectangle defining the extent of the block in 2D, and includes adding and rendering a satellite image of the study area on top of the block diagram.

1. Open 2D.mxd in ArcMap.

   - If the Draw toolbar is not displayed, click **View | Toolbars | Draw** to open it.
   - Click the dropdown arrow for drawing tools on the Draw toolbar and select **New Rectangle**.
   - Draw a rectangle for the block extent on the ArcMap map area.
   - Double click at the endpoint to finish drawing the line.

2. Next create the shapefile *block_outline.shp* and load it onto the map.

   - Make sure the rectangle is selected.
   - Click the XTools Pro dropdown arrow, point to **Feature Conversions | Convert Graphics to Shapes**.
   - Select the file path in the Output Storage box and name the output shapefile **`block_outline.shp`**.
   - Click OK.
   - Delete the rectangle created using the New Rectangle tool.

3. Make sure the *block_outline* layer is selected.

   - Click the XTools Pro dropdown arrow, point to **Feature Conversions | Convert Features to Points**.
   - Select the file path in the Output Storage box and name the output shapefile **`block_points.shp`**.
   - Select the **Equidistant Points (Fixed Interval)** option in the **Points** section.
   - Type **`100`** in the Interval box.
   - Click OK.
   - The shapefile *block_points.shp* will be created and automatically loaded onto the map

4. Make sure 3D Analyst is open.

   - Select **Tools | Extensions**.
   - Check the 3D Analyst box.
   - Click the Close button to exit the Extensions window.
   - Click **View | Toolbars** and click **3D Analyst**.
   - 3D Analyst should be available for use.

5. Create the shapefile *block_points_precamb.shp* and add it to the map.
    - Click the 3D Analyst dropdown arrow, point to **Convert | Features to 3D**.
    - Click the dropdown arrow for the Input features box and select *block_points* from the dropdown list.
    - Click the dropdown arrow for the Raster or TIN Surface box and select *precamb_surface_u11.tif* from the dropdown list.
    - In the Output features box, name the output file `block_points_precamb.shp`.
    - Click OK to finish.
6. Click the XTools Pro dropdown arrow.
    - Point to **Table Operations | Add X, Y, Z Coordinates**.
    - Select *block_points_precamb* from the list in the Layers box.
    - Check the Add Z Coordinate box and the Only for 3D Shapes box and uncheck other boxes in the section to the right of the Layers box.
    - Type `Precamb` in the field name box.
    - Click OK.
7. In ArcMap, open the attribute table of the *block_points_precamb* layer by right clicking it and selecting **Open Attribute Table**.
    - You will see a column with the picks, extracted from the top of Precambrian (*precamb_surface_u11.tif*), for each point along the fence lines.
8. Repeat Steps 5 to 7 for each surface by using *banff_surface_u11.tif, debolt_surface_u11.tif, belloy_surface_u11.tif, BFSZ_surface_u11.tif* and *ground_surface_u11.tif*.
    - Ensure you select the correct layer and type in the correct field name for the picks for each surface.
    - Five shapefiles result from this process. They are, in ascending order of stratigraphic horizon, *block_points_banff.shp, block_points_debolt.shp, block_points_belloy.shp, block_points_BFSZ.shp* and *block_points_ground.shp*.
9. Join the table of *block_points.shp* with each of the shapefiles created in the last four steps.
    - Right click the *block_points* layer and select **Joins and Relates | Join**.
    - In the Join window, select the correct field for the join to base on and select one shapefile with picks of a specific surface.
    - Click OK.
    - Repeat for all remaining shapefiles.

10. Next you will create and load the shapefile *block_points_all_picks.shp*.
    - Open the attribute table of the layer *block_points* by right clicking it and selecting **Open Attribute Table**.
    - You should be able to see all of the columns from the shapefiles created for each of the surfaces.
    - Turn off all fields that do not contain picks by right clicking the title of the field and selecting **Turn Field Off**.
    - Only leave the columns "Fid," "Shape" and columns with picks for different surfaces.
    - Right click the *block_points* layer and select **Data | Export Data**.
    - Name the output shapefile *block_points_all_picks.shp*.
    - Click OK to finish.
    - Open the attribute table and make sure it has all of the columns with picks for all surfaces, including the ground surface.
11. Open ArcScene (3D.sxd) if it is not open.
    - Turn off the layer groups Wells, Surfaces, Cross Section and Fence to save memory for a fast display.
    - Add *block_points_all_picks.shp.*
    - Right click the layer *block_points_all_picks* and select **Copy**.
    - Right click the data frame 3D and click **Paste Layer(s).**
    - A second copy of the layer *block_points_all_picks* is added to the data frame 3D.
    - Repeat this for n-1 times where n is the total number of surfaces including the ground surface.
12. This process creates a 3D display of the block diagram for the interval from an elevation of -4000 m to the top of Precambrian.
    - Right click one of the copies of the layer *block_points_all_picks,* select **Properties** and click the **Base Heights** tab.
    - Select the **Use a Constant Value or Expression to Set Heights for Layer** option and type `-4000` in the box.
    - Click the **Extrusion** tab and select **Extrusion Value or Expression.**
    - Click the Expression Builder tool beside the Extrusion value or expression box to open the Expression Builder window.
    - Form an expression like `[Precamb]+4000.`
    - Click the OK button to return to the Layer Properties window.
    - Select **Adding it to Each Feature's Base Height** in the Apply Extrusion By box.
    - Click OK.

13. This process creates a 3D display of the block diagram for the interval from the top of Precambrian to the top of Banff formation.
    - Right click a second copy of the layer *block_points_all_picks*, select **Properties** and click the **Base Heights** tab.
    - Select the **Use a Constant Value or Expression to Set Heights for Layer** option.
    - Click the Expression Builder tool beside the text box to open the Expression Builder window.
    - Form an expression like `[Precamb]` by clicking the Precamb field in the Fields box.
    - Click OK to exit the Expression Builder and return to the Layer Properties.
    - Click the **Extrusion** tab.
    - Select **Extrusion Value or Expression** option and click the Expression Builder tool.
    - Form an expression like `[Banff]-[Precamb]`.
    - Click OK to return to the Layer Properties.
    - Select **Adding it to Each Feature's Base Height** in the Apply Extrusion By box.
    - Click OK.
    - Repeat for the remaining copies of the layer *block_points_all_picks* and make sure to assign the correct surface for the base of the interval to be displayed and the correct expression for the top of the interval to extrude to, as demonstrated above.
14. Change the layer colour for the interval below the top of Precambrian to red, the interval between the Precambrian top and the Banff Formation top to blue, the interval between the Banff formation top and the Debolt formation top to cyan, the interval between the Debolt Formation top and the Belloy Formation top to yellowish green, the interval between the Belloy Formation top and the BFSZ surface to dark green and the interval between the BFSZ surface to the ground to grey.
    - Click the symbol of the layer in the Table of Contents window to open the Symbol Selector window.
    - Click the dropdown arrow for the colour option to open the Colour Palette window.
    - Select the colour you want.
    - Click the OK button to finish; repeat for all layers.
15. Add a satellite or airborne image of the study area; e.g., *landsat_image_u11.tif*.
    - Right click the image layer *landsat_image_u11* and select **Layer Properties.**
    - Click the **Base Heights** tab.
    - In the **Height** section, select **Obtain Heights for Layer from Surface** and select *ground_surface_u11.tif* from the drop down list.
    - Click OK.

16. It is a good practice to group layers and manage as one item.
    - Select all layers for the Block Diagram.
    - Right click one of them and select **Group**.
    - A new group of layers is created with the default name New Group Layer.
    - Right click the name New Group Layer and click **Properties**.
    - Click the **General** tab and type `Block Diagram` in the Layer name box.
    - Click OK.
    - The layer group name will be changed to Block Diagram. Click the collapsing box to the left of the layer group Block Diagram to collapse it.
17. Save the ArcScene project.

Congratulations! You have successfully created a Block Diagram in 3D.

3.7 How to Create a Geological Solid 3D Presentation

To create a 3D display of a geological solid, it is necessary to construct its top and bottom surfaces and the side boundary surface. The top and bottom surfaces of the solid are created by clipping the top and bottom geological surfaces using the extent of the solid; the side boundary surface is created in the same way as a cross-section, fence diagram or block diagram. This process requires ArcGIS Spatial Analyst, 3D Analyst and XTools Pro extensions.

1. Open 2D.mxd in ArcMap.
    - Add *belloy_surface_u11.tif* and *debolt_surface_u11.tif.*
    - Add the shapefile (*geo_solid_pl.shp*) for the outline of the geological solid to be visualized in 3D, if it is available, then go to Step 4. If the shapefile for the outline needs to be created, go to Step 2.
2. If the Draw toolbar is not displayed, click **View | Toolbars | Draw** to open it.
    - Click the dropdown arrow for drawing tools on the Draw toolbar and select **New Polygon.**
    - Draw a polygon for the outline of the geological solid on the ArcMap map area.
3. Make sure the polygon is selected.
    - Click the XTools Pro dropdown arrow .
    - Select **Feature Conversions | Convert Graphics to Shapes.**
    - Select the file path in the Output Storage box and name the output shapefile **`geo_solid_pl.shp.`**
    - Click OK.
    - The shapefile *geo_solid_pl.shp* will be created and automatically loaded onto the map.

4. Make sure the layer geo_solid_pl is selected.
    - Click the XTools Pro dropdown arrow.
    - Point to **Feature Conversions | Convert Features to Points.**
    - Select the file path in the Output Storage box and name the output shapefile `geo_solid_points.shp`.
    - Select **Equidistant Points (Fixed Interval)** in the **Points** section.
    - Type `100` in the Interval box.
    - Click OK.
    - *Geo_solid_points.shp* will be created and automatically loaded onto the map.
5. Make sure 3D Analyst is open.
    - Click **Tools | Extensions**.
    - Check the 3D Analyst box.
    - Click the Close button to exit the Extensions window.
    - Click **View | Toolbars | 3D Analyst** to turn it on.
6. Create the shapefile *geo_solid_points_belloy.shp* and add it on the map.
    - Click the 3D Analyst dropdown arrow.
    - Point to **Convert | Features to 3D.**
    - Click the dropdown arrow for the Input Features box and select *geo_solid_points* from the dropdown list.
    - Click the dropdown arrow for the Raster or TIN Surface box and select *belloy_surface_u11.tif* from the dropdown list.
    - In the Output Features box, name the output file *geo_solid_points_belloy.shp*.
    - Click OK.
7. Click the XTools Pro dropdown arrow.
    - Point to **Table Operations | Add X, Y, Z Coordinates**.
    - Select *geo_solid_points_belloy* from the list in the Layers box.
    - Check the Add Z Coordinate box and the Only for 3D Shapes box and uncheck the other boxes in the section to the right of the Layers box.
    - Type `Belloy` in the Field Name box.
    - Click OK.
8. In ArcMap, open the attribute table of the layer *geo_solid_points_belloy* by right clicking it and selecting **Open Attribute Table.** You will see a column with the picks, extracted from the top of Belloy Formation (*belloy_surface_u11.tif*), for each point along the block outline.

9. Click the 3D Analyst dropdown arrow.
    - Point to **Convert | Features to 3D**.
    - Click the dropdown arrow for the Input Features box and select *geo_solid_points* from the dropdown list.
    - Click the dropdown arrow for the Raster or TIN Surface box and select *debolt_surface_u11.tif* from the dropdown list.
    - In the Output Features box, name the output file **`geo_solid_points_debolt.shp`**.
    - Click OK.
    - The shapefile *geo_solid_points_debolt.shp* will be created and automatically added on the map.
10. Click the XTools Pro dropdown arrow.
    - Point to **Table Operations | Add X, Y ,Z Coordinates**.
    - Select *geo_solid_points_debolt* from the list in the Layers box.
    - Check the Add Z Coordinate box and the Only for 3D Shapes box and uncheck other boxes in the section to the right of the **Layers** box.
    - Type **`Debolt`** in the Field Name box.
    - Click OK.
11. In ArcMap, open the attribute table of the layer *geo_solid_points_debolt* by right clicking it and selecting **Open Attribute Table**. You will see a column with the picks, extracted from the top of Debolt Formation (*debolt_surface_u11.tif*), for each point along the block outline.
12. Join the table of *geo_solid_points.shp* with that of *geo_solid_points_belloy.shp.*
    - Right click the layer *geo_solid_points* and select **Joins and Relates | Join**.
    - In the **Join Data** window, select the right field for the join to base on and select *geo_solid_points_belloy* as the table to join.
    - Click OK.
    - Repeat to join the table of *geo_solid_points.shp* with *geo_solid_points_debolt.shp*.
13. Create geo_solid_points_TopandBottom.shp and load onto the map.
    - In ArcMap, open the attribute table of the layer *geo_solid_points* and you will see all columns from the two shapefiles (*geo_solid_points_belloy.shp* and *geo_solid_points_debolt.shp*).
    - Turn off all fields that do not contain picks by right clicking the title of the field and selecting **Turn Field Off**.
    - Only leave the columns of “Fid,” “Shape” and columns with picks for the two surfaces (*belloy_surface_u11.tif* and *debolt_surface_u11.tif*).
    - Right click the layer *geo_solid_points* and select **Data | Export Data**.
    - Name the output shapefile **`geo_solid_points_TopandBottom.shp`**.
    - Click OK.

- Open the attribute table and make sure it has the two columns (Belloy and Debolt) with picks for the top and bottom surfaces of the geological solid.

14. Make sure Spatial Analyst is open.

    - Click **Tools | Extensions**.
    - Check the Spatial Analyst box.
    - Click the Close button to exit the Extensions window.
    - Click **View |Toolbars | Spatial Analyst** to turn it on.

15. Click the Spatial Analyst dropdown arrow.

    - Select **Options** and click the **General** tab.
    - Click the dropdown arrow for the Analysis Mask box and select *geo_solid_pl* from the dropdown list.
    - Click the **Extent** tab.
    - Click the dropdown arrow for the Analysis Extent box and select Same as Layer *geo_solid_pl* from the dropdown list.
    - Click OK.

16. Click the Spatial Analyst dropdown arrow.

    - Click the **Raster Calculator**.
    - Double click *belloy_surface_u11* from the list in the Layers box.
    - *[belloy_surface_u11]* will appear in the Expression box.
    - Click the Evaluate button to finish.
    - A layer named *Calculation* will be created and automatically loaded on ArcMap, with the clipped top surface of Belloy Formation based on the specified extent in Step 12.

17. Right click the layer *Calculation* and point to **Data | Export Data**.

    - Select the proper directory in the Location box and the TIFF format from the Format dropdown list.
    - Name the output file **`geo_solid_top.tif`** in the Name box.
    - Click the Save button.
    - The file *geo_solid_top.tif* will be created and automatically added to ArcMap.

18. Create another calculation layer.

    - Click the Spatial Analyst dropdown arrow and select **Raster Calculator**.
    - Double click *debolt_surface_u11* from the list in the Layers box.
    - *[debolt_surface_u11]* will appear in the Expression box.
    - Click the Evaluate button.

- A layer named *Calculation2* will be created and automatically loaded on ArcMap, with the clipped top surface of the Belloy Formation.

19. Right click the layer *Calculation2* and point to **Data | Export Data**.

    - Select the proper directory in the Location box and the TIFF format from the Format dropdown list.
    - Name the output file **`geo_solid_bottom.tif`** in the Name box.
    - Click the Save button.
    - The file *geo_solid_bottom.tif* will be created and automatically added to ArcMap.

20. Open 3D.sxd in ArcScene and add *geo_solid_points_TopandBottom.shp*, *geo_solid_top.tif* and *geo_solid_bottom.tif*.

21. Right click the layer *geo_solid_points_TopandBottom* and click Properties.

    - Click the **Base Heights** tab.
    - Select the **Use a Constant Value or Expression to Set Heights for Layer** option and click the Expression Builder tool beside the text box.
    - Form an expression like **`[Debolt]`** by clicking the field Debolt in the Fields box.
    - Click OK to exit the Expression Builder and return to Layer Properties.
    - Click the **Extrusion** tab.
    - Select the **Extrusion Value or Expression** option and click the Expression Builder tool beside the Extrusion value or expression box.
    - Form an expression like **`[Belloy]-[Debolt]`**.
    - Click OK to return to Layer Properties.
    - Select **Adding it to Each Feature's Base Height** in the Apply Extrusion By box.
    - Click OK.
    - Change the colour of the layer *geo_solid_points_TopandBottom* to yellowish green.

22. Right click the *layer geo_solid_top.tif* and click **Layer Properties**.

    - Click the **Base Heights** tab.
    - In the Height section, select the **Obtain Heights for Layer from Surface** option and select *belloy_surface_u11.tif* from the drop down list.
    - Click the **Symbology** tab and select the Red to Blue colour ramp from the drop drown list for the Colour Ramp box.
    - Check the Invert box.
    - Click OK.
    - Repeat this process for the layer *geo_solid_bottom.tif* by selecting *debolt_surface_u11.tif* as the height for the layer.

23. Group the layers for the geological unit.

- Select all layers for the Geological Solid.
- Right click one of them and click **Group**.
- A new group of layers is created with the default name New Group Layer.
- Right click the name New Group Layer and click **Properties.**
- Click the **General** tab.
- Type **`Geological Solid`** in the Layer Name box.
- Click OK.
- The layer group name will be changed to Geological Solid. Click the collapsing box to the left of the layer group Geological Solid to collapse it.

24. Save the ArcScene project.

Congratulations! You have successfully created a Geological Solid in 3D.

3.8 How to Create a 3D Display of a Fault

Faults are conventionally presented as linear features on a 2D map. They can be derived from well log data, including formation picks (Mei, 2006). In 3D modelling/visualization, a fault is treated as a 3D surface that cuts through stratigraphic layers. The intersection of a fault with a surface is a line, and a fault surface is a surface between the line of intersection of the fault with the top surface and the line of intersection of the fault with the bottom surface. Faults are first interpreted as linear features from different formation top surfaces, and the lines that are believed to represent the same 3D fault are used to create the 3D display of this fault. If the fault is not vertical, the intersection lines from different surfaces will have different locations on a 2D map by shifting to the dip direction with descending stratigraphic horizons (for details see Mei, 2006). This process requires ArcGIS Spatial Analyst, 3D Analyst and XTools extensions. For simplicity, this process is demonstrated with an example of a 3D display of a single fault.

1. Open 2D.mxd in ArcMap and add the shapefile with lines of faults representing the intersections of the faults with the top geological surface. Here we use the faults interpreted from the surface of Basal Fish Scale Zone (*interpreted_faults_BFSZ.shp*).

2. Select a single fault from *interpreted_faults_BFSZ.shp* to be displayed in 3D; e.g., the Gordondale fault.

   - Right click the layer *interpreted_faults_BFSZ* and point to **Data | Export data**.
   - Type **`Gordondale_fault_top.shp`** in the Output shapefile or feature class box.
   - Click OK.
   - The *Gordondale_fault_top.shp* will be created and automatically loaded on the map. It contains only the fault selected (the Gordondale fault).

3. Next create the Gordondale_fault_top_3D.shp and add it to the map.

    - Click the 3D Analyst dropdown arrow and point to **Convert | Features to 3D.**
    - Click the dropdown arrow for the Input features box and select *Gordondale_fault_top* from the dropdown list.
    - Click the dropdown arrow for the Raster or TIN Surface box and select *BFSZ_surface_u11.tif* from the dropdown list.
    - In the Output features box, name the output file **`Gordondale_fault_top_3D.shp`**.
    - Click OK.

4. Add the shapefile with lines of faults representing the intersections of the faults with the bottom geological surface. Here we use the faults interpreted from the top of the Precambrian (*interpreted_faults_Precam.shp*).

5. Select the line that represents the same fault (e.g., the Gordondale fault) from *interpreted_faults_Precam.shp.*

    - Right click the layer *interpreted_faults_Precam* and select **Data | Export Data**.
    - Type **`Gordondale_fault_bottom.shp`** in the Output shapefile or feature class box.
    - Click OK.
    - *Gordondale_fault_bottom.shp* will be created and automatically loaded on the map. It contains only the fault selected (the Gordondale fault).

6. Click the 3D Analyst dropdown arrow and select **Convert | Features to 3D**.

    - Click the dropdown arrow for the Input features box and select *Gordondale_fault_bottom* from the dropdown list.
    - Click the dropdown arrow for the Raster or TIN Surface box and select *precamb_surface_u11.tif* from the dropdown list.
    - In the Output features box, name the output file **`Gordondale_fault_bottom_3D.shp`**.
    - Click OK.
    - *Gordondale_fault_bottom_3D.shp* will be created and automatically added to the map.

7. Open ArcCatalog and select the proper working directory in the Catalogue Tree window.

    - Select **File | New | Shapefile**.
    - Type **`Gordondale_fault_edges_3D`** in the Name box.
    - Select Polyline from the Feature Type dropdown list.
    - Click **Edit** to open the Spatial Reference Properties window.
    - Click **Import** and select a shapefile with the correct map projection; e.g., *Gordondale_fault_top.shp* or *Gordondale_fault_bottom.shp*.
    - Click the Add button to close the Browse for data window.
    - Click OK to return to the Create New Shapefile window.
    - The selected coordinate system will appear in the Description box.

- Check the box **Coordinates will Contain Z Values. Used to Store 3D Data**.
- Click OK.
- An empty 3D shapefile named *Gordondale_fault_edges_3D.shp* will be created.
- Close ArcCatalog and return to ArcMap.

8. Add *Gordondale_fault_edges_3D.shp* to ArcMap.
   - Click **View | Toolbars | Editor** to turn on the Editor toolbar, if it is not displayed.
   - Click the Editor dropdown arrow.
   - Click Start Editing to open the Start Editing window.
   - Select the directory of *Gordondale_fault_edges_3D.shp* in the upper box and select *Gordondale_fault_edges_3D.shp* in the **These Layers and Tables Will be Available for Editing** box.
   - Click OK.
   - Make sure *Gordondale_fault_edges_3D* appears in the Target box on the Editor toolbar. If not, select it from the Target dropdown list.
9. Select both the line in *Gordondale_fault_top_3D.shp* and the line in *Gordondale_fault_botom_3D.shp.*
   - Click **Copy** and **Paste**.
   - The two selected lines will be copied into *Gordondale_fault_edges_3D.shp*.
   - Open the attribute table of *Gordondale_fault_edges_3D.shp* to confirm this.
10. Click the Editor dropdown arrow and click Snapping.
    - Check the box under the End column beside *Gordondale_fault_edges_3D*.
    - Close the window.
    - Click the **Sketch Tool** from the editing tool dropdown list.
    - Draw a line to connect the two lines in *Gordondale_fault_edges_3D.shp* at one end, and another line to connect the two lines at the other end.
11. Click the Task dropdown arrow on the Editor toolbar and select **Modify Feature** from the dropdown list.
    - Select one of the two lines that connect the top and bottom edges of the Gordondale fault at the end.
    - Click the **Sketch Properties** button on the Editor toolbar.
    - Fill in the Z values for the two end vertices of the line, using the corresponding Z values of the two end vertices of the top and bottom edges of the Gordondale fault it is connecting.
    - Click Finish Sketch.

12. Repeat Step 8 for the second line connecting the other ends of the top and bottom edges of the Gordondale fault.
    - Click the Editor dropdown arrow, select **Stop Editing**.
    - Click Yes when prompted whether you want to save the edits.
13. Create *Gordondale_fault_edges_3D_poly.shp* and add it to the map.
    - Click Show/Hide ArcToolbox Window on the standard toolbar.
    - Double click **Data Management Tools** to expand it.
    - Double click the Features toolset to expand it.
    - Double click **Feature To Polygon** and select *Gordondale_fault_edges_3D* from the dropdown list for the Input Features box.
    - Name the output file **`gordondale_fault_edges_3D_poly.shp`** in the Output Features Class box.
    - Click OK.
14. Now display the Gordondale fault in 3D.
    - Add *Gordondale_fault_edges_3D_poly.shp* to ArcScene.
    - Right click the layer *Gordondale_fault_edges_3D_poly* and click **Properties.**
    - Click the **Base Heights** tab.
    - Select the option **Layer Features Have Z Values. Use Them for Heights**.
    - Click the **Symbology** tab.
    - Click the symbol to open the Symbol Selector window.
    - Select purple for the fill colour.
    - Click OK three times to finish.
15. Repeat the above-mentioned steps for each additional fault to be displayed in 3D. The same fault can also be displayed for different stratigraphic intervals. Alternatively, the 3D polygons for different faults can be generated at the same time. However, this could add complexity to the process. If the faults are vertical, the same steps used for creating cross-sections and fence diagrams can be followed to create the 3D display of faults.
16. Group the fault layers to manage them as one item.
    - Select all of the fault layers, right click one of them and select **Group**.
    - A new group of layers is created with the default name New Group Layer.
    - Right click the name New Group Layer and click **Properties.**
    - Click the **General** tab.
    - Type **`Faults`** in the Layer name box.
    - Click OK.

- The layer group name will be changed to Faults. Click the collapsing box to the left of the layer group Faults to collapse it.

17. Save the ArcScene project.

Congratulations! You have successfully created a 3D display of faults.

3.9 Putting It All Together

So far, you have created a frame for 3D display, 3D display of wellbores, geological surfaces, a cross-section, a fence diagram, a block diagram, a geological solid and faults. You have almost all of the building blocks ready for creating a 3D visualization and model. In ArcScene, you can turn all of them on and examine the 3D model by turning off one or two components at a time. You can also examine the 3D model in animation mode, which allows you to see all aspects of the 3D model. However, you will notice some of the components block the view of other components; this is especially true when you print the 3D model, and it frequently causes problems. It is difficult to find the best combination of components to display subsurface geology in 3D. Below are instructions to generate a few examples of 3D visualization.

Example 1: A Block Diagram

1. Add *river_u11.shp*, *road_u11.shp* and *urban_u11.shp* in ArcScene.
2. Right click the *river_u11.shp* layer and click **Properties.**
3. Click the **Base Heights** tab.
4. In the Height section, select **Obtain Heights for Layer from Surface** and select *ground_surface_u11.tif* from the drop down list.
5. Click OK.
6. Change the colour of the river layer to green.
7. Right click the *road_u11.shp* layer and click **Properties**.
8. Click the **Base Heights** tab.
9. In the Height section, select the **Obtain Heights for Layer from Surface** and select *ground_surface_u11.tif* from the drop down list.
10. Click OK.
11. Change the colour of the road layer to cyan.
12. Right click the *urban_u11.shp* layer and click **Properties**.
13. Click the **Base Heights** tab.
14. In the Height section, select the **Obtain Heights for Layer from Surface** and select *ground_surface_u11.tif* from the drop down list.
15. Click the **Extrusion** tab and type `100` in the Extrusion Value or Expression box.
16. Click OK.

17. Change the colour for the urban layer to dark grey.

18. Turn on the layer groups for the block diagram.

19. Adjust the perspective and start the animation. You will be looking at a typical block diagram. Figure 2 shows a snapshot of the 3D block diagram.

Example 2: 3D Visualization of Wells, Faults, a Fence Diagram and a Geological Solid

1. Make sure *river_u11.shp*, *road_u11.shp* and *urban_u11.shp* are turned on and properly rendered in ArcScene.

2. Turn on the layer groups for wells, fence diagram, faults and unit solid and turn off the layer groups for the block diagram and the cross-section. Set the colour for the layer group Faults to purple. For the layer group of geological surfaces, only turn on the surface for the top of the Precambrian.

3. Adjust the perspective and start the animation. You should be able to see wells, fences, faults, a geological solid and the Precambrian top in relation to rivers, roads and urban areas. Figure 6 shows a snapshot of the 3D model.

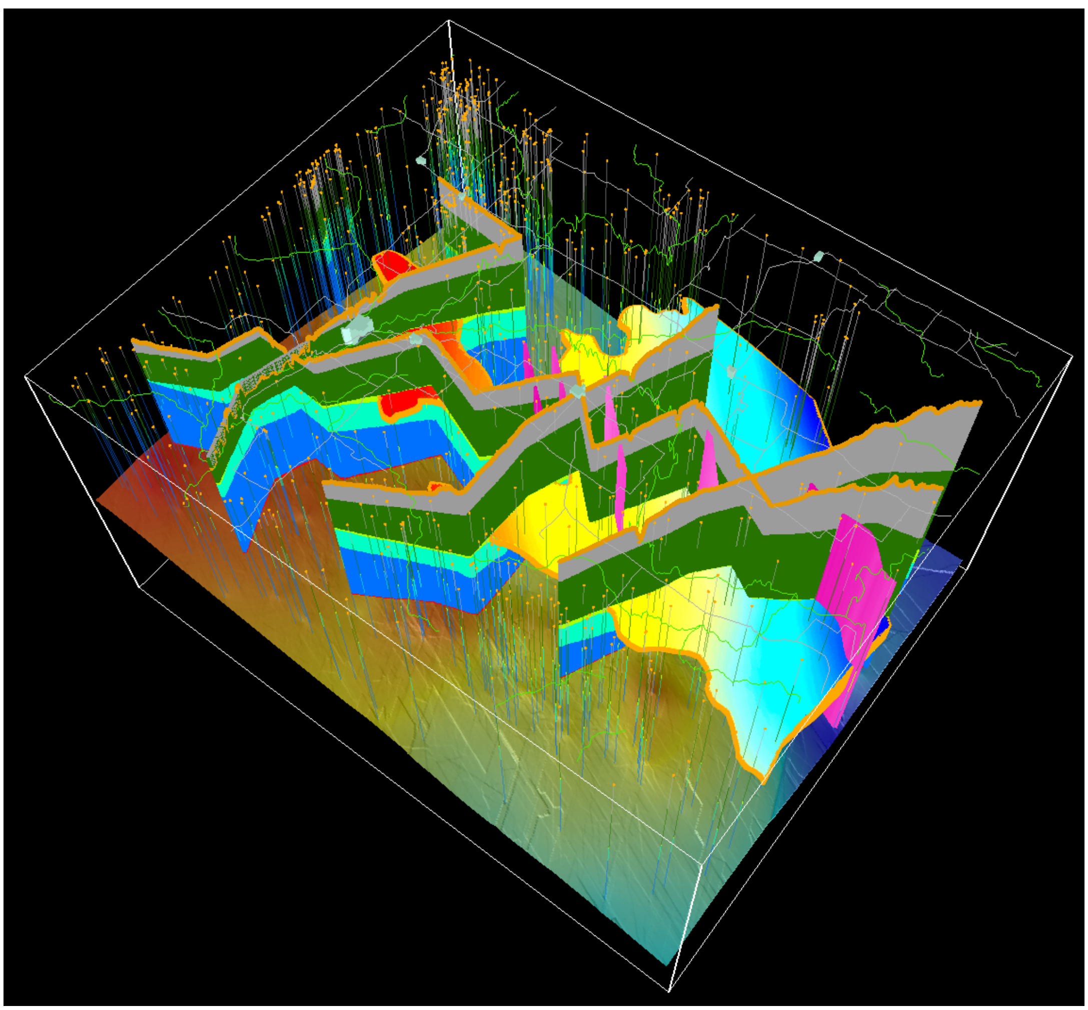

Figure 6. A snapshot of the 3D model showing wells, fence diagrams, faults and a geological solid.

Example 3: 3D Visualization of Wells, Faults, a Cross-Section and a Geological Solid

1. Make sure *river_u11.shp*, *road_u11.shp* and *urban_u11.shp* are turned on and properly rendered in ArcScene.

2. Turn on the layer groups for wells, cross-sections, faults and the geological solid and turn off the layer groups for the fence diagram and the block diagram. Set the colour for the layer group Faults to purple. For the layer group of geological surfaces, only turn on the surface for the top of the Precambrian.

3. Adjust the perspective and start the animation. You should be able to see wells, a cross-section, faults, a geological solid and the Precambrian top in relation to rivers, roads and urban areas. Figure 7 shows a snapshot of the 3D model.

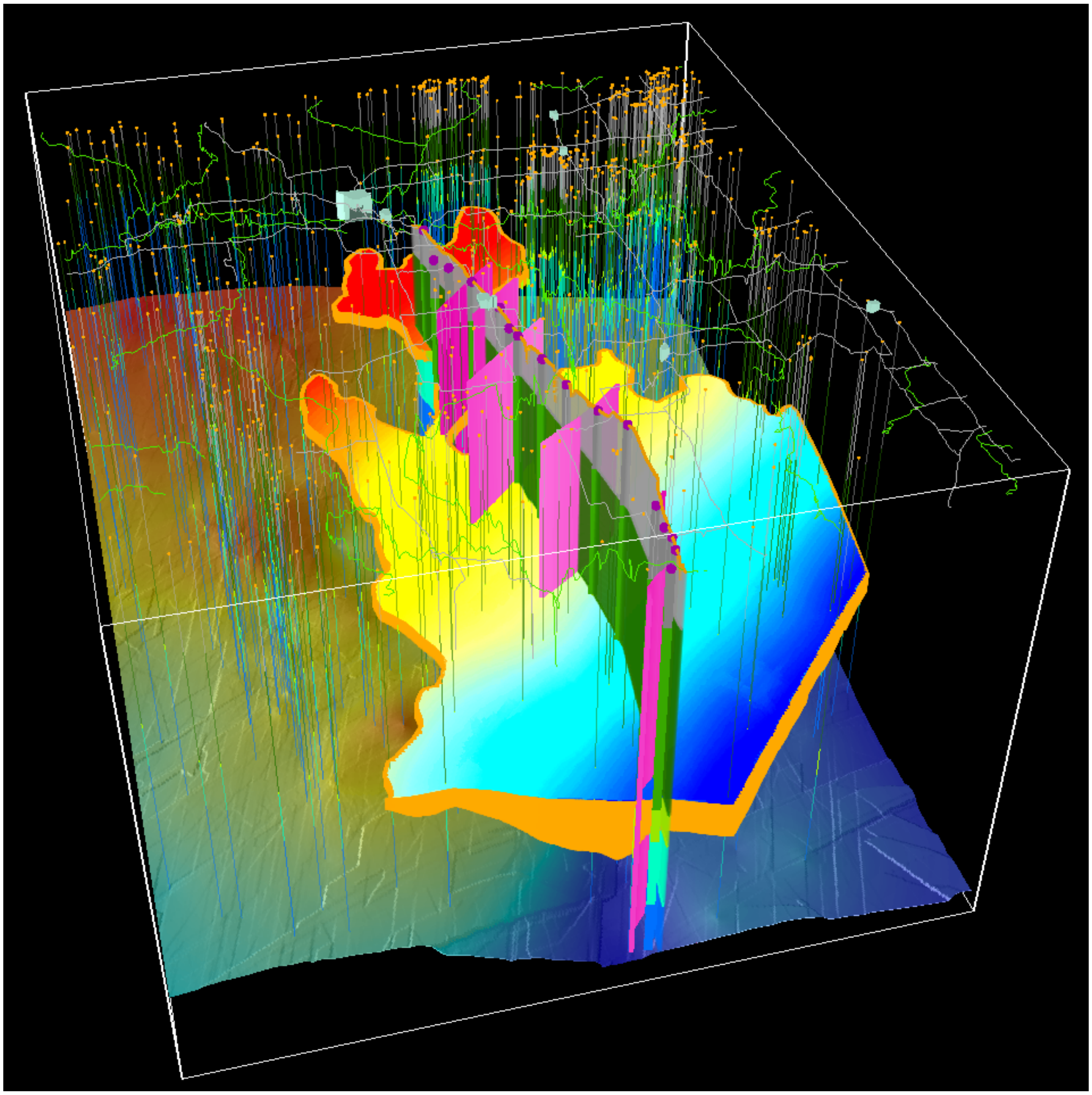

Figure 7. A snapshot of the 3D model showing wells, faults, a cross-section and a geological solid.

Example 4: 3D Visualization of Wells, Surfaces, Faults and a Geological Solid

1. Turn off *river_u11.shp*, *road_u11.shp* and *urban_u11.shp* in ArcScene.
2. Turn on the layer groups for wells, faults, surfaces and the geological solid and turn off the layer groups for the fence diagram, the cross-section and the block diagram.
3. Set the transparency to 80% for the layer group Faults.
4. Adjust the perspective and start the animation. You should be able to see wells, surfaces, faults, a geological solid and the Precambrian top. Figure 8 shows a snapshot of the 3D model.

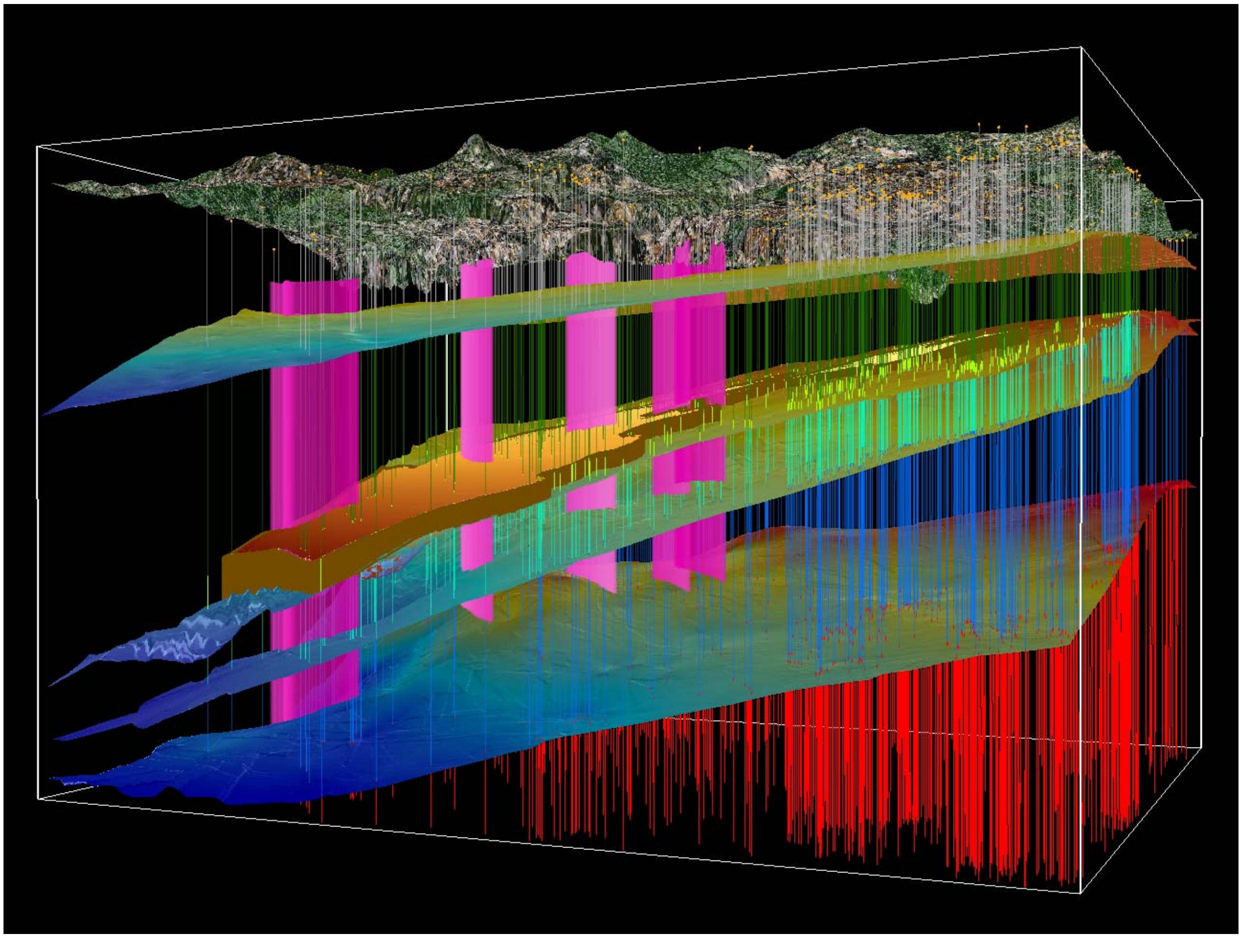

Figure 8. A snapshot of the 3D model showing of wells, surfaces, faults and a geological solid.

You are encouraged to experiment with your own combination of the 3D building blocks and render each layer according to your taste. The best way to present a 3D geological model is to visualize it in a video. Please refer to your ArcScene manual for instructions on exporting to a video format.

A video clip named *PRA_anatomy.avi*, demonstrating the anatomy of subsurface geology for the Peace River Arch region, is included with this manual as an example. This video was created by exporting the animation in ArcScene with a screen capture freeware called ScreenHunter.

4 Concluding Remarks

Building blocks for 3D visualization/modelling, including 3D wellbores, geological surfaces, cross-sections, fence diagrams, block diagrams, faults and geological solids, can all be derived from well log data including well locations (x and y coordinates) and picks for geological formation tops (z value). ArcGIS makes this achievable and proves to be one of the useful tools for 3D visualization and modelling of subsurface geology, based on well log data.

The instructions provided in this manual are based upon ArcGIS 9.2 and XTools Pro 4.2 and represent only one of the solutions to 3D visualization/modelling. There is no guarantee these instructions will work for other versions of ArcGIS and XTools Pro. It is possible to explore and develop individual workflows with some modifications to this manual, based on different versions of software and different solutions to the same task. Regardless, this step-by-step manual serves as a valuable reference for 3D visualization/modelling of subsurface geology using well log data and ArcGIS.

This manual is designed to provide first-time users with opportunities to practice basic editing skills to create cross-sections, fence diagrams and box diagrams. After becoming proficient with the process, you are encouraged to explore the possibility to streamline the process by accomplishing similar tasks simultaneously. For example, creation of a cross-section, a fence diagram and a block diagram can be combined by creating a single shapefile containing the lines for the cross-section, the fence and the block outline, respectively. Then, all of the lines can be converted into points simultaneously and the extraction of picks for the points from the surfaces can be accomplished with one process. Finally, the points with extracted picks for the surfaces can be separated into those specifically for the cross-section, fence diagram and block diagram. This can be accomplished by selecting the appropriate group of points with the correct lines, using the tool **Select By Location**.

The term "3D visualization/modelling" has been used throughout this report for convenience. Strictly speaking, using GIS terminology, the visualization/modelling demonstrated in this manual actually represent 2.5D visualization, not a true 3D presentation. Significant differences exist between 2D, 2.5D and 3D data/presentation, and these are not explicitly clear in the contemporary GIS literature concerning the vocabulary used to describe data dimensionality. 2D data come in the form of ***x, y, a*** with ***x*** and ***y*** being the coordinates and ***a*** an attribute. 2D systems represent the world as a collection of data layers, and all conventional GIS, including ArcGIS, use this data model as its base. 2.5D data are stored as (x, y, z) and signify that although the layer has an ***x*** and ***y*** spatial coordinate, its height ***z*** is actually treated as an attribute. For example, a digital elevation model is a series of ***x*** and ***y*** points where the elevation ***z*** was sampled. This matrix of elevations are considered 2.5D data; however, they are usually plotted as a DEM surface to be visualized in a 3D perspective drawing. This surface need not be elevation; formation picks, porosity, permeability, lithological facies or some other parametric variables, sampled at a number of 2D points, could be represented as surfaces. 3D data are signified by ***x, y, z, a*** with ***x, y*** and ***z*** being the coordinates and ***a*** an attribute. 3D data are represented as volumes and the three dimensional heterogeneity within a geological unit can be presented only in a true 3D presentation using 3D data.

In a 2.5D representation, it is impossible to represent different attributes at two different elevations at the same 2D point (which is a true 3D presentation) and maintain a 2D data model. As a result, the three dimensional heterogeneity within a geological unit cannot be modelled and displayed in ArcGIS; this limits the full use of well log data that contain geophysical attributes measured at ***x, y*** and ***z*** coordinates.

This manual could evolve with the advancement of software and improvement of solutions to some of the tasks. Any comments for improvements and feedback are greatly appreciated and should be forwarded to shilong.mei@ercb.ca.

5 References

Mei, S. (2006): Structure mapping for the Clear Hills–Smoky River region using well-log data and geostatistical analysis; Alberta Energy and Utilities Board, EUB/AGS Earth Sciences Report 2006-04, 89 p.

Mei, S. (2007): Updates on faults and structural framework of the Peace River Arch region, northwest Alberta, obtained using a new approach; 2007 CSPG CSEG convention, Calgary, Extended Abstract, 5 p.