G4200-2018 GIS
Exercise 12, based on the following USGS short course.

Modified to be slightly simpler, use the latest 2018 "GeMS" tools, and contain more explanation.

Changes or additions by RRH indicated in Red Text or with ~~strike-throughs.~~

See the note on pg. 27 about what to turn in.

There is also a section on Georeferencing and digitizing with QGIS at the end, but I've provided the data generated from QGIS so you don't actually need to do that work as part of this exercise.

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A short course on

Making digital geologic maps with the NCGMP09 database schema

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Introduction

There are several ways to use the NCGMP09 schema while creating a geologic map. Each path implies its own workflow, set of tools, and problems. Among these paths are:

1. Heads-up digitizing an existing analog map (map image) into the NCGMP09 schema
2. Creating a new map by heads-up interpretation and digitization of source data (field maps, aerial photographs, topographic images, other remote sensing images) within your GIS using the NCGMP09 schema
3. Translating an existing GIS database into the NCGMP09 schema

These exercises demonstrate the first two paths.

Prerequisites

This course assumes you have the use of ArcGIS (version 10.1 or higher) and a reasonable familiarity with both ArcGIS and geologic mapping.

Typography

Computer file and folder (directory) names are shown in bold proportional serif font: **C:\ArcGIS**. Objects (feature datasets, feature classes, rasters) within a geodatabase are shown in the same font.

Window, menu, sub-menu, and textbox names are in bold san-serif font; an inequality sign (>) is used to separate menu > submenu, e.g., **File > Save**, or <right-click> **> Copy**.

Text you type, either in a textbox or at the command prompt, is denoted by bold mono-spaced serif font, e.g., to save a file under a new name in MSWord, click **File > Save As** and in the **File Name:** textbox enter **`MyNewFilename.doc`**

ESB1006 Setup

We will need to install a couple ArcGIS "Style" files plus the new 2018 GeMS Toolbox (in place of the older NCGMP09v1.1 version listed below). If it were possible we should also install a couple special fonts which contain geological symbols, for example for Triassic or Cambrian. However permissions on the ESB1006 computers are set so that we don't have permission to do that. We'll just tolerate a few symbols being rendered incorrectly.

In place of the following Setup instructions, for the ESB1006 computers do the following:

Download and unzip the exercise_12 data file. Within it you will find a Resources directory containing various files listed below. You will also find inside the unzipped directory another zip file, **`GeMS_Tools-02Apr2018,`** which I just downloaded from the USGS GeMS site. Unzip that file as well which will create a **`GeMS_Tools-02Apr2018`** directory. We will only use some of the files contained within it. There is also an **`rrh_resources`** directory containing contact information files I generated (using QGIS) which we will import instead of digitizing everything from scratch.

Before starting ArcMap we also need to edit one of the scripts included in the above USGS toolset to fix a bug I've discovered. Because in the future you may sometime have to make other fixes like this, I'm describing how to make the fix rather than simply providing my personal updated version of the USGS toolbox.

Use **`Windows (File) Explorer`** which you can open with the **`Windows Key + E`** or by clicking on **`This PC`** to open the above **`GeMS...`** directory you just extracted. Inside it (or sometimes inside another subdirectory of the same **`GeMS...`** name) you should find a **`Scripts`** directory containing the actual Python code. Right click on **`GeMS_MakePoly3_Arc10.py`** and choose **`Edit with IDLE.`** (The normal **`notepad`** and **`wordpad`** editors unfortunately are having problems with the format of the latest USGS scripts even though they worked with the older USGS scripts.)

Search for a line containing the text "**`Deleting centerPoints2 MapUnit`**" (without the quotes). The next line, which should be Line #178, is what we need to change. That line creates an sql query but there is a mistake. It reads

```
sqlQuery = arcpy.AddFieldDelimiters(fds,'MapUnit') + "= '' "        .
```

To fix this add a space then a \ (backslash) after the final double quote, to continue the statement on the next line, then insert a new line under it so the two lines now read as shown below. You may want to use copy and past to duplicate the original line, then modify it. Be careful to add spaces as indicated, especially around the **`OR`** and before the **`IS NULL`** .

```
sqlQuery = arcpy.AddFieldDelimiters(fds,'MapUnit') + "= '' " \
+ " OR " + arcpy.AddFieldDelimiters(fds,'MapUnit') + " IS NULL"
```

Note that in the above the **`"`** is a single character double quotation mark used to indicate the beginning and end of the Python text strings. However the two symbols **`''`** slightly after the equal sign are two back-to-back single quotes, in effect defining a zero length string. Once you have made the change, save the file and exit the IDLE editor.

While you don't really need to know what the above bug fix does to use it, in case you are interested, the intention of the original USGS code was to select those polygons for which no **MapUnit** label had yet been assigned. It tried to do that by checking for an empty string in the **MapUnit** column of the attribute table. However the sql query is failing (at least some of the time) and the fix is to not only check for an empty string, but also to see if **MapUnit** is equal to the **NULL** value, which ArcPy is somehow treating as different than an empty string. In a simpler world the new SQL query would read

```
MapUnit = '' OR MapUnit IS NULL
```

and we could create that with a Python statement reading

```
sqlQuery = "MapUnit = '' OR MapUnit IS NULL"
```

but the ArcPy functions are needed to sometimes add **[]** or double quote marks around **MapUnit**, because in ArcPy the exact syntax depends upon what type of database is storing the layer.

With the above editing finally done, start ArcMap and when it offers to create a Blank Map, click **Cancel.**

Open the **Style Manager**, from the main **Customize** menu. Click the **Styles** button and in the **Style References** window which appears click **Add Style to List ...** and navigate the **resources** directory then add the **USGS Symbols.style .** You should now see this style in the **Style References** list, with a checkmark in front of it. You can enable or disable individual styles by setting or clearing the checkmarks. Repeat the above steps to install the **FGDC_GSC_20100414.style** . Back in the **Style References** window, click OK to close the window. You should now be back in the Style Manager Window. Click the + sign before the FGDC style to explore some of the just loaded styles. For example under **Line Symbols** there are the various standard FGDC lines used to mark various contacts, etc. Under **Marker Symbols** there are other symbols we will use for Dips, etc. Unfortunately, since we can't install the proper USGS geology fonts, some of these will use rather random symbols from the Wingdings set. We will fix the one symbol we actually care about for this excercise.

In the **Style Manager** window double click on the **FGDC_GSC_20100414.style** line, navigate to **Marker Symbols** in the left panel, and in the right panel scroll to and double click on **06.02** which should be the dip ("T shaped") symbol. Instead of that, some strange circle-with-ears, from the Wingdings set, will be visible. In the Fonts field scroll down till you find **ESRI Geology USGS 95-525**, which IS a font that was installed as part of ArcGIS. In the **Unicode** box type **111**, the code number for the dip symbol. You should now see the "T shaped" symbol. Finally, change to color to Red so the symbols will be more obvious in later steps then click **OK**.

We will change two other symbols -- those used to decorate the anticline line. Within the above **FGDC** style navigate to **Line Symbols** and double click on **5.01.03**, the symbol for an exposed anticline whose location is slightly uncertain. In a small **Layers** panel on the right within the **Symbol Property Editor** window you should see two lines, the upper one decorated by what should have been the outward arrows marking an anticline but probably will instead show a small box -- again another bad choice taken from the Wingdings font set. Click on the **`Symbol`** button which should be visible, then in the new window which appears, double click on the **`Edit Symbol`**. Once again select the **`ESRI Geology USGS 95-525`** font and this time in the **`Unicode`** box, enter 70, which should give the correct set of outward directed arrows. Click **`OK`** to close two successive windows which should take you back to the list of **`Line Symbols`**. Repeat the above steps to change the symbol for line type 5.01.07, a concealed anticline, to again be the outward directed arrows (# 70) instead of the Wingding box. Note that the anticline line itself will be drawn as long dashes for the exposed anticline 5.01.03, but with short dashed for the concealed one 5.01.07. (An exposed anticline with location well constrained is drawn as symbol 5.01.01, with a solid line.) Finally close the **`Style Manager`**.

Next open the **`ArcMap Toolbox`** and right click to add the **`GeMS_ToolsArc105.tbx`** file (in place of the older one described below) from within the GeMS directory which you just unzipped. For the ESB1006 machines which have ArcGIS 10.5 installed, be sure to add the **`105`** version, not the **`10`** version. Finally, add the RRHToolbox.tbx file which is located in the **`rrh_resources`** directory.

Skip the rest of the original USGS Setup instructions described below.

~~Setup~~

~~It is convenient to have additional resources in your ArcGIS installation. Install the following sets of files, all available in the **Resources** folder of the course disk:~~

~~**USGS Symbols.style**~~	~~I recommend this file be placed in **ArcGIS\DesktopNN.n\Styles**~~
~~**GSC_FGDC-style**~~	~~See contents of this folder. Install **FGDC_GSC_20100414.style** into **ArcGIS\DesktopNN.n\Styles**. Install 5 TrueType fonts (*.ttf) by right-clicking on each and selecting **Install**.~~
~~**NCGMP09v1.1-Tools3_arc10.1**~~	~~Copy the entire directory to, perhaps, **\ArcGIS\DesktopNN.n\NCGMP09v1.1-Tools3_arc10.1**, but can be anywhere.~~

Exercise 1. Digitize 1:100K-scale geologic map of the Purcell Mtn, WA 7.5' quadrangle

We start with Washington Division of Geology and Earth Resources Open-file Report 87-16 by Hank Schasse. You will need the following source materials, all available in the Resources folder of this exercise:

ContactsAndFaults~~100~~24K.lyr	*ArcMap lyr file set up for digitizing 1:~~100~~24K scale linework*
DMU_export.dbf	*Prepared DMU table in dbase format, for import into your DescriptionOfMapUnits table*
~~**PurcellMtn.png**~~	~~*screen capture of part of WaDGER OFR87-16*~~

The above map is very hard to read in places. I've created a slightly modified duplicate, with certain critical features highlighted in red. Use this **`PurcellMtnRRH.png`** file in place of the above.

PurcellMtnRRH.png	Modified screen capture of part of WaDGER OFR87-16
wa_ger_ofr87_16_ plt1.pdf	*map sheet of WaDGER OFR87-16 in pdf format*
wa_ger_ofr87_16_text.pdf	*text of WaDGER OFR87-16 in pdf format*

You will create the following:

PurcellMtn.gdb *an NCGMP09-format geodatabase*

PurcellMtn-TopologyReport.html *output of TopologyCheck tool*

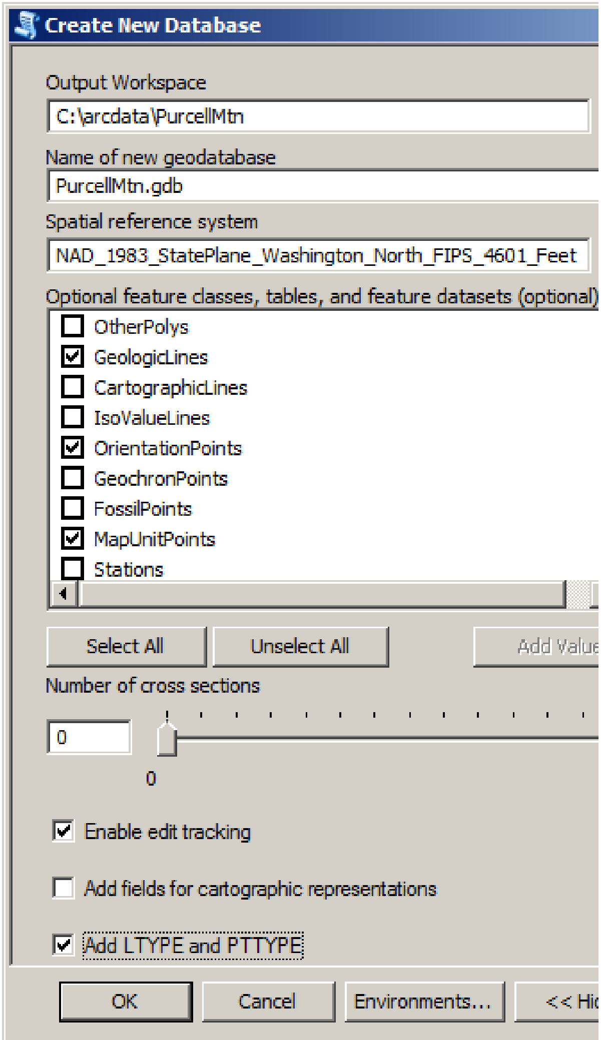
PurcellMtn-Validation.html *output of ValidateDatabase tool*

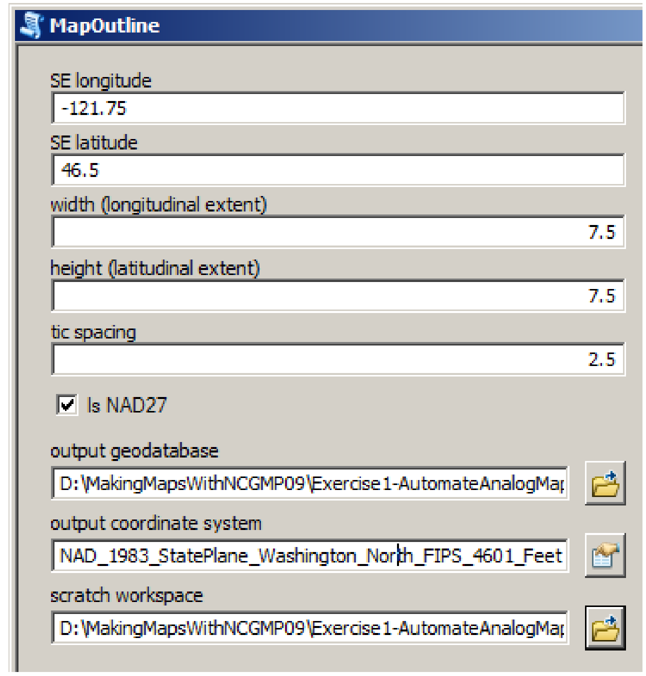
A page-size paper map made from **PurcellMtn.gdb**, scale 1:100K, using FGDC symbols, with mapunit colors given in **PurcellMtnDMU.dbf**

We've already done the following step 0 as part of the above setup.

~~0. Start ArcMap and install the NCGMP09 toolbox~~

~~Start ArcMap. When offered an existing project, **CANCEL** to start with an empty map composition. Open the **ArcToolbox** window. Right-click on an empty part of the **ArcToolbox** window and select **Add Toolbox…** In the **Add Toolbox** window that opens, navigate to your **NCGMP09v1.1-Tools3_arc10.1** directory and select **NCGMP09v1.1_Toolbox3_Arc10.1.tbx**. <Right-click> again on an empty part of the **ArcToolbox** window and **Save Settings > To Default**.~~





1. Make an empty GeMS ~~NCGMP09~~ geodatabase specific to this project and add map tics and map boundary

Start ArcMap if it is not already open. Open the **ArcToolbox** window.

A. Run the **GeMS Tools for Arc10.5 2018-03-04** **~~NCGMP09 Tools for Arc10~~** **> Create New Database** script to make an empty geodatabase (In the following I won't bother editing the text to show the new name of the toolbox. Just assume that substitution.)

   a. Make a new folder for your output workspace. I recommend a location such as **c:\arcdata\PurcellMtn or c:\users\<username>\Documents\PurcellMtn**. (For our class, select an **exercise_12** folder on your H: drive.)

   b. Name the new geodatabase `PurcellMtn.gdb`.

   c. Set the projection to **Projected Coordinate Systems > StatePlane > NAD83 (USFeet) > Washington North FIPS 4601**. We choose this projection to match the lidar data we will use later. *This is not the projection of the source map. Why is it OK to do this?*

d. Make optional feature classes GeologicLines , and OrientationPoints~~, and MapUnitPoints~~.
Note that in GeMS under Optional feature classes they no longer list MapUnitPoints. I'll describe an alternate way to handle this later.
e. You can enable edit tracking—or not. Don't add fields for cartographic representations. Check "Add LTYPE and PTTYPE". **OK**. (You may need to scroll down in the window with the outer scroll bar to see these options.)

B. Run the **NCGMP09 Tools for Arc10 > MapOutline** script.
a. SE corner of Purcell Mtn 7.5' quad is at 46°30' N, 121°45' W. *Note that west longitudes are negative. SE longitude can be entered as* ***-121.75*** *or* ***-121 45*** *(degrees minutes or decimal degrees). SE latitude can be entered as* ***46 30*** *or* ***46.5****.* (Note the width and height should already be set to the default 7.5' .)
b. Leave **IsNAD27** checked. (*Why?*)
The reason we should leave **IsNAD27** checked (although the provided png image doesn't really provide enough information to know) is that this png image is scanned from a paper map where the latitude and longitude lines and other coordinates were marked using the NAD 1927 coordinate system. If we had the full map we would see that NADxx information in the "map collar" text. When georeferencing we need to give coordinates that match whatever system was used in originally marking the features on the map. While in a step below we set the OUTPUT coordinates to use a NAD83 state plane, ArcMap needs to know the correct INPUT coordinates reference used on the map, and that is NAD27. ArcMap will convert the screen coordinates to the output datum and projection as we draw and digitize features. The location of the same nominal (Longitude,Latitude) point is actually about 300 ft different in NAD83 vs. NAD27 so if we entered the wrong NAD when Georeferencing based on the marked (Longitude, Latitude), then all are coordinates would be off by that 300 ft.

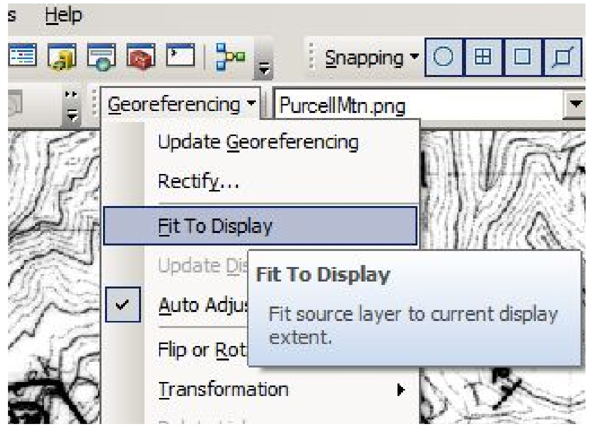
I actually digitized the features and generated the shapefile in QGIS. If interested, see the notes at the end about how to georeference and digitize in QGIS.

c. Tic spacing can be set to 7.5 minutes or left at 2.5 minutes.
d. Use your newly-created **PurcellMtn.gdb** as the output geodatabase.
e. Set output coordinate system to **Projected Coordinate Systems > StatePlane > NAD83 (USFeet) > Washington North FIPS 4601**.
You may also need to set the scratch workspace to some directory for which you actually have write permission. For example create an exercise_12_scratch directory on H: and set it to that.
f. **OK**.
g. Look at the catalog for your new geodatabase. You should see feature classes MapOutline and tics at the top level.
h. Add the tics (and outline) feature class(s) to your map composition. (One way to do this is to use the **Catalog** panel, probably on the right, and navigate to your new database and click the + sign to open it. Then drag the **MapOutline** and the **tic** entries into the **Table of Contents** panel on the left.

C. *Save the map composition to your PurcellMtn workspace as PurcellMtn.mxd.*

2. Georegister scanned map image

If you have not completed step 1, make a new working folder, copy the contents of folder **Exercise1-AutomateAnalogMap\2-GeoregisterScan** *into this folder, and double-click on* **2PurcellMtn.mxd** *to start ArcMap.*



A. Copy file **PurcellMtnRRH.png** from the **Resources** directory to your working folder.

B. Add **PurcellMtn.png** to the map composition. You should get a warning message about missing spatial reference information. **OK**. Save! (Do allow it to build pyramids when it asks.)

C. Go to **Customize > Toolbars** and □ **Georeferencing**. **Snapping** should also be checked.

D. Ensure that PurcellMtn.png shows in file window on the **Georeferencing** tool bar. Tap the **Georeferencing**□ dropdown and select **Fit to Display**. Check **Auto Adjust** also.

E. Add links for the 4 corner tics. *The tics are hard to see. The lower tics are marked by the intersection of half-length vertical bars with the map margin and are inside the map boundary. The SE corner (just above 45' on lower right of map image) will be easiest to find and add first. The upper tics are full crosses +*

   i. **Snapping**□ **Use Snapping** should be checked.

   ii. Click on the **Add Control Point** button on the **Georeferencing** toolbar

   iii. Zoom into a tic in the map image.

   iv. Click on the tic location in the map image.

   v. Zoom out if need be. Click on the corresponding tic point symbol.

   vi. Repeat for remaining tics.

F. Check residuals on the link table (**View Link Table** button on the **Georeferencing** toolbar). Because we are fitting 4 points—only 1 point of redundancy—the residuals should be excellent (less than 10 ft, or 0.03 mm at 1:100,000 map scale).

G. If you are satisfied with your results, go back to **Georeferencing**□ dropdown and click **Update Georeferencing**. This will write a world file (**PurcellMtn.pgwx**) that describes the transformation from image coordinates to map coordinates and allows ArcMap to place the image in the correct place any time the image is loaded into a data frame with the correct coordinate system.

H. Disable the Add Control Point tool by clicking on another icon, perhaps the **Select Elements Tool**. Turn the Georeferencing toolbar off: **Customize > Toolbars > Georeferencing**.

I. ***Save (floppy-disk symbol) your map composition.***

3. Setup for digitizing

If you have not completed step 2, make a new working folder, copy the contents of folder **Exercise1-AutomateAnalogMap\3-SetupForDigitizing** *into this folder, and double-click on* **3PurcellMtn.mxd** *to start ArcMap.*

A. Do you have the necessary toolbars? I usually work with **Advanced Editing**, **Editor**, **Snapping**, **Standard, Tools**, and **Topology** enabled

B. Load the MapOutline you made into the ContactsAndFaults feature class.
   i. Open the **Catalog** window, navigate to **PurcellMtn.gdb/GeologicMap** ***in your current workspace***, right click on **ContactsAndFaults**, and **Load**□**Load Data…** The **Simple Data Loader** will open.
   ii. Click on the folder symbol (or click on Next in some ArcMap versions then click on the folder symbol) to open the **Open GeoDatabase** window and navigate to **PurcellMtn.gdb** ***in your current workspace*** and select **MapOutline**. Click **Open**, **Add**, **Next>**, **Next>**, **Next>**, **Next>**, and **Finish** to load the data in **MapOutline** into the **ContactsAndFaults** feature class.

C. Add ContactsAndFaults to the map composition.
One of the challenges in working with the NCGMP09 schema is that most lines have multiple attributes. **ContactsAndFaults~~100K~~24K.lyr** *sets up a four-fold view of ContactsAndFaults, such that attributes LTYPE (optional, not required by the NCGMP09 schema), ExistenceConfidence, IdentityConfidence, and LocationConfidenceMeters are all symbolized, so that you can see what the values of these attributes are.* **ContactsAndFaults~~100K~~24K.lyr** *also provides a set of templates that—when a template is selected and a line is created—set appropriate values for these attributes and the attribute Type.*
   i. Click the **Add Data** button, navigate to the **Resources** folder in the course CD, and **select ContactsAndFaults~~100K~~24K.lyr**. **Add**.
   ii. In the **Table of Contents**, expand ContactsAndFaults~~100K~~24K if necessary. Right-click on LTYPE, move down to **Data**, and select **Repair Data Source…** Set the data source to **PurcellMtn.gdb/GeologicMap/ContactsAndFaults** ***in your current workspace***. This should also fix data sources for sublayers ExistenceConfidence, IdentityConfidence, and LocationConfidenceMeters. *You should now see a red line that is the boundary of the Purcell Mountain 7.5-quadrangle.* (It's blue in my display.)

   At this point rather than adding data manually, we will actually load some data I've already digitized. Open the `RRHToolbox` and double click `AppendFeatures`, which I have copied from the old ESRI toolbox. For `Original Feature Class` select `rrh_resources/contacts_FIPS4601.shp` . (Do **not** use the `contacts_no_gaps_fips4601.shp` file. I'll explain that file later.) Skip the select `Features` option. For `Project Features Class` select the `ContactsAndFaults` element within our main `Geological Map`. After you run this you should be able to see most of the contacts added to the map although you may need to momentarily turn off the display of the png file to make them visible. (The previous steps using the ContactsAndFaults24K.lyr file set up default styles which are a little hard to see.) Besides contacts, we also have one fault which separates different units and it needs to also be added to to properly define all the exposures. Repeat the above steps except use `Fault_FIPS4601.shp` rather than `Constats_FIPS4601.shp` .

   There are just a few minor edits you will need to do below to complete these. In a few spots I've left deliberate errors (mentioned below) which you will need to fix. The `contacts_no_gaps_fips4601.shp` file mentioned above already has those mistakes fixed, but don't use it unless something goes wrong with fixing the digitizing mistakes yourself, as described below.)

D. Tap the **Snapping**□dropdown and ensure **Use Snapping** is checked. **Intersection Snapping**, ~~**Midpoint Snapping**, and **Tangent Snapping**~~ should all be enabled. (For some other work you may want `Midpoint Snapping` and `Tangent Snapping` enabled, but we won't need them here.)

E. ~~Optional: enable **Snap To Sketch**.~~

If you build polygons in bulk, using the NCGMP09 toolbox Make Polygons script, it is convenient to be able to digitize small polygons as a single arc—that is, to snap the endpoint of an arc to its own start point. This is "Snap to Sketch".

If you build polygons piecemeal, using the Construct Polygons tool on the Advanced Editing toolbar, it may be undesirable to have single-arc polygons, as every time you later build an adjoining polygon, using the shared bounding arc, you will create a copy of the initial polygon which must be deleted.

You must have an active edit session to enable **Snap To Sketch**. In **Table Of Contents**, right-click on LTYPE (under ContactsAndFaults100K), scroll down to **Edit Features**, and click on **Start Editing**. ~~Then tap the **Snapping** dropdown and click **Snap To Sketch**.~~

The one feature you will need to correct is the closed contour labeled TiD near the center of the map -- just to the west of the Anticline axis. If you zoom in on it, on its eastern end you will see that the contact line does not quite close as it should. (An unclosed contour will cause problems later, as the interior TiD exposure is not fully separated from the surrounding Tva2 exposure. To fix this, start editing the `LTYPE` layer, click on the Edit Vertices tool, about 7 toolbar icons to the right of the Editor button. As a message box will tell you, click on a single feature (in this case the almost-closed contour) to start editing it. Double click on it to show the individual vertices making up the contact. Then click and drag one vertex at the end of the almost-loop towards the other open end vertex. You should see the mouse snap to that other vertex when it gets close enough. (We do need the start and end to be exactly coincident, which is what the snapping produces.) Release the mouse to finish that vertex move. If you need to add a couple more vertices to clean up the shape of the line, you can right click on a segment and select that option, then move the newly created vertex to a good location. When finished, turn off editing and when it asks, OK saving the result.

Where one contact intersects another I have placed vertices at the intersection, and have tried to use similar snapping techniques to make sure all three contact lines intersect exactly at that "triple-junction" vertex. There are some other tricks when digitizing contacts which will be imported into GeMS, and I discuss those briefly in the QGIS section at the end.

We'll proceed assuming there are no "topology" errors in the contacts, and they all combined to divide the area up into well defined polygons. However in a later step we will check that, and may need to return and make some final edits if there are any problems.

In this somewhat simplified exercise (although it is already more complicated that I'd like) we'll actually end up with a map which still has some "unimportant" topology errors because of limitations in the GeMS ability to import contacts. We'll ignore those for now although in a professional map you would probably need to make further edits to address them.

At this stage we are almost ready to try running Make Polygons to turn our contacts into polygons.

However before doing that we'll create a MapUnitPoints layer which can be used to label the polygons. The old NCGMP09 toolset use to create a layer of this name, which is useful for labeling the different polygons. They have removed it in GeMS but I find it useful enough that

I've creates a MapUnitPoints Shapefile manually. However for the GeMS tool to use it, we must first convert it into a Layer in the map Geodatabase. Trying to use it directly as a shapefile causes errors in the USGS code. I have provided the file as **`rrh_resources/mapunitpoints_fips4601.shp`**. To convert it into a geodatabase layer right click on this file in the **`Catalog`** panel and select **`Export`** then **`To Geodatabase (single)`**. In the dialog which appears this shape file should already be selected as **`Input Features`**. In the next line click on the folder icon and set the **`Output Location`** to **`GeologicMap`**. In the next line, **`Output Feature Class`**, type in the name **`MapUnitPoints`**. Leave the **`Expression`** line blank. In the **`Field Map`** which should contain a list of all the names of the input columns, we need to make one adjustment because of differences between shapefiles and geodatabase layers. Column names in shapefiles are limited to 10 characters and so have been truncated from the names that GeMS wants. For the following entry right click, select **`Rename`**, and change the shortened name to the proper full name:

```
Short Name   Full Name
IdentityCo   IdentityConfidence
```

Click **`OK`** and after it finishes you should see the **`MapUnitPoints`** in the **`Table of Contents (ToC)`** and visible on the map. Double click on it in the **`ToC`** to bring up the **`Layer Properties`** window. Select the **`Labels`** tab and check the box **`Label features in this layer`**. If the **`Label Field`** is not already set to **`MapUnit`** (the first column), set it to that. Change to color to something obvious like Red and perhaps increase the size of the font (12 points is usually good). You should now see both the points and the **`MapUnit`** labels on the map. After later steps the polygons created will have their own labels and we'll turn off display of these points, but for now this provides a check that the units are properly identified.

The next step will be to run the **`Make Polygons`** tool within the **`GeMS toolbox`** but first, in case something goes wrong (for example you find contacts that don't meet correctly), to start this next step over, do NOT delete the **`MapUnitPoly`** layer as that would force you to go all the way back to running **`Create Database`**. Instead, if you need to do the following step over, open the **`MapUnitPoly`** attribute table, enable editing, delete all the features, then end editing, saving the result. Next, in the **`Catalog`** panel, delete any new layers created during a failed attempt. Those could include various **`error_xxx`** layers (discussed below), or various **`center_xxx`** layers which are temporarily created by the tool and cleaned up when it successfully exits.

To run **`Make Polygons`** first, double check that the **`MapUnitPolys`** layer does **not** appear in the **`Table of Contents`**, as that can cause errors in the tool. Also, make sure you've edited the script as described above in setup, to fix the bug which causes it to fail to properly add labels. Double click on **`Make Polygons`** in the GeMS Toolbox to run the tool. In the dialog window which appears, for the **`Input Feature dataset`** select **`PurcellMtn.gdb\Geological Map`**. For **`Label points feature class (optional)`** select the **`MapUnitPoints`** layer in the map geodatabase. For this initial run don't bother checking **`Save old MapUnitPolys`** although you might want to use that on subsequent runs, in case something goes wrong. After running for a couple minutes the log should show:

1 multi-labeled polys
11 multiple, conflicting, label points
10 unlabeled polys

We'll see these represent potential errors, although not serious ones. **`Close`** the **`Make Polygons`** dialog window.

In the **`Catalog`** panel under **`GeologicMap`** you should now see the following new layers which let you diagnose any problems which occurred during **`Make Polygons`**:

`edit_ChangedPolys`
`errors_multilabelPolys`
`errors_multilabels`
`errors_unlabeledPolys`

Drag **`errors_multilabelPolys`** from the **`Catalog`** to the **`Table of Contents (ToC)`** to see which in fact have multiple labels. Opening the attribute table actually shows no entries. The "1" quoted above is apparently some inconsistency in how GeMS counts these "polygons". We'll see below the "polygon" it was probably referring to is some combination of the different exposures outside the map outline which are NOT completely separated by any contacts. If you did have either two label points within the same polygon, or perhaps more likely, a gap in the contacts which left two intended polygons connected, that that polygon would be highlighted and show up in the feature attribute table. Once done with this step, right click on errors_multilabelPolys in the ToC and remove it.

Drag **`errors_unlabeledPolys`** from the **`Catalog`** to the **`Table of Contents`**. You should see 3 polygons on the left, 6 on the right, and one tiny one at the very bottom, all just outside the outline. (You may need to temporarily turn off the display of the underlying png image.) Those 9 polygons were in fact all labeled, with **`MapUnitPoints`** within that exposure but inside the outline. However the map outline has cut the polygons apart and "orphaned" the portions that lie outside the outline. We'll see how to avoid this problem later, but it does in fact highlight the need for placing **`MapUnitPoints`** in the right location:

1) **`MapUnitPoints`** to be effective must not only be in the right unit, but must be inside the map outline.

2) If you have a unit exposure which is connected outside the outline but which will be separated into individual exposures by the outline, then you need to add separate **`MapUnitPoints`** in each of those separated exposures. For example in our map the **`Toh`** exposure occupies most of the northern boundary, and extends around and pokes into the eastern boundary in a small "peninsula". Besides the original **`MapUnitPoint`** labeling the northern region, I had to had a second **`MapUnitPoint`** to label that small "peninsula" sticking into the outline from the east. Otherwise that "peninsula", cut off from the main northern **`Toh`** region by the map outline, would have been unlabeled.

When done with this step right click on **`errors_unlabeledPolys`** in the **`ToC`** and remove it.

Next drag **`errors_multilabelPolys`** from the **`Catalog`** to the **`ToC`**. This shows all the polygons which have more than one label point inside. In fact, despite the warning message given by the **`Make Polygon`** tool, there are not any such polygons in our map. You can confirm this by opening the attribute table and checking that it is empty. Remove this layer from the ToC once done.

Finally, drag **errors_multilabels** from the **Catalog** to the **Table of Contents**. This shows all the label points where more than one seems to reside in a polygon. (Be sure to turn off the display of **tics** and perhaps **MapUnitPoints** as those can be confused with our points.) In this particular case a number of points are shown but they points all correspond to labels I defined for unit exposures outside the map outline. Because we haven't created a "outer outline" to define the outer edge of the *original* map, these exposures connect together through the region outside that original map. This area doesn't show up in the above **errors_multilabelPolys** since it really isn't considered a true polygon although perhaps that is what the **Make Polygons** tool is reporting when it says there is one "Multilabel-poly". The points here are not really errors, but they have confused the GeMS tool. Sometimes you will see additional label points which you did not create manually. If you run **Make Polygons** more than once, or you manually edit the **MapUnitPolys** attribute table to enter **MapUnit** values the script creates its own temporary label points. If those labels give **MapUnit** values which conflict with the ones in your **MapUnitPoints** then both points are shown as multilabels.

In the steps above I had you remove the layers from the **ToC** when done. The actual data still exists as shown in the **Catalog** panel. If you really don't need these **error** layers anymore, then you can right click on them in the **Catalog** panel and actually **Delete** them.

> Note that in real work **Make Polygons** will most likely report many more errors than shown above. Misplaced labels or slight gaps in contacts and faults which improperly leave different units connected usually show up at this stage as unlabeled or multiply labeled polygons. For this example it took several iterations to produce contacts and faults which did produce correct polygons (at least within the map outline). Use the presence of those errors as a clue to finding which contacts, faults, and labels have problems.
>
> When errors occur, first edit the features in the **ContactsAndFaults24K** layer, or delete those features, edit your original contacts and faults shapefiles, then reimport them. (When deleting features in **ContactsAndFaults24K** remember not to delete the very first feature which is the the **Map Outline**.) Next, load the **MapUnitPolys** into the **ToC**, open the attribute table, delete all the polygons, and then remove **MapUnitPolys** from the **ToC**. Finally, run **Make Polygons** again. This will probably take several iterations to get right. In a later step we'll examine other tools which will check the topology of the contacts and faults.

At this point drag **MapUnitPolys** from the **Catalog** panel to the **ToC** so you can see those polygons. We'll fix the display properly in a later step, but for now just so you can see some progress, double click on it in the **ToC** to bring up the **Properties** window. In the **Symbology** tab select **Categories** rather than the default **Single Symbol**. It should default to using the **MapUnit** field as the **Value**. Click on **Add All Values** to make it assign random colors to each different **MapUnit**. In the **Display** tab set the transparency to 50%. You should now have a display that looks more-or-less like a geological map.

F. Add some data to the **DescriptionOfMapUnits** table in **PurcellMtn.gdb**. *For description of the DMU table, see the NCGMP09 documentation on the course CD. I have prepared a list of map-*

unit codes, map-unit labels, names, ages, hierarchy codes, and symbols (colors) as spreadsheet file **PurcellMtnDMU.dbf**, *largely so we can readily color map-unit polygons*.

i. Open the ArcMap **Catalog** window. Navigate to **PurcellMtn.gdb/DescriptionOfMapUnits** ***in your current workspace*** ***(that is, within PurcellMtn.gdb in the Catalog panel. This is one of the tables formed by Create New Database)***. Right-click on DescriptionOfMapUnits and scroll down to **Load > Load Data…** In the **Simple Data Loader** window, click on the folder icon to bring up the **Open GeoDatabase** window. Navigate to the **Resources** folder on the course CD and select ~~**PurcellMtnDMU_.dbf**~~ **DMU_export.dbf**. **Open**. **Add**.

ii. **Next> and Next>** to bring up a field mapping table (headings "Target Field" and "Matching Source Field") in the **Simple Data Loader** window. Fields MapUnit, Label, Name, and Age should already be matched. Scroll down to HierarchyKey, click on <None> in the second column, and scroll down to select HierarchyK.
(These steps will import data, such as names and colors of units, from the **DMU_export.dbf** spreadsheet/database into the standard GeMS **DescriptionOfMapUnits** table, so we can avoid typing that in manually. The import automatically matched the names of identical columns in the table and the dbf file, but because the column name **HierarchyKey** in the table didn't exactly match **HierarchK** in the dbf file, we had to manually tell it to copy contents from the latter column into the former. You can open the dbf file with Excel if you want to examine its contents.)

iii. **Next>**, **Next>**, and **Finish**.
At this point also drag the **DescriptionOfMapUnits** table from the **Catalog** panel into the **ToC**.

G. ~~Add **MapUnitPolys** to the map composition. Click the **Add Data** button, navigate to **PurcellMtn.gdb/GeologicMap** in your current workspace, and select **MapUnitPolys**. **Add**.~~
(We've already done this.)

H. Join feature class **MapUnitPolys** to table **DescriptionOfMapUnits**. In the **Table of Contents** window, right-click on MapUnitPolys, scroll down to **Joins and Relates**, and **Join…** In the **Join Data** window that opens, "Join attributes from a table" (top list-box) should already be selected.

i. **1. Choose the field**… Select "MapUnit".
ii. **2. Choose the table…** Select **DescriptionOfMapUnits** from **PurcellMtn.gdb** ***in the current workspace***.
iii. **3. Choose the field …** Select "MapUnit".
iv. **Join Options**: Select **Keep all records**
v. **OK**. You will get an error message about the joined table having no rows. 'Tis OK.

I. Set labeling and make MapUnitPolys semi-transparent.

i. Double-click on MapUnitPolys to open the **Layer Properties** window. Tap the **Labels** tab. Check **Label features in this layer**. **Method:** should be "Label all the features the same way" (this is the default value). At **Label Field:**, hit the drop-down arrow and scroll down to and select the second occurrence of "Label". Change **Text Symbol** color to red.
ii. Still in the **Layer Properties** window, tap the **Display** tab. Set **Transparent:** to 50%.
(We already did this above.)
iii. **OK**.

J. ***Save (floppy-disk symbol) your map composition.***

4. Digitize arcs and make polygons

We've already done the equivalent of most of the steps here to enter contacts and faults. (However you may find the instructions useful for later work editing those features in ArcGIS.) For now skip down to step D: "Set Polygon symbolization".

If you have not completed step 3, make a new working folder, copy the contents of folder **Exercise1-AutomateAnalogMap\4-Digitize** *into this folder, and double-click on* **4PurcellMtn.mxd** *to start ArcMap. You may have to change the source of PurcellMtn.png. (In* **Table of Contents***, right-click on PurcellMtn.png, tap Source tab, click Set Data Source..., navigate to your workspace for step 3, or to* **Exercise1-AutomateAnalogMap\3-SetupForDigitizing***, and select* **PurcellMtn.png***.)*

A. Digitize ContactsAndFaults.

   i. Right-click on ContactsAndFaults100k/LTYPE and navigate to **EditFeatures > Start Editing**. If feature templates do not appear, go to the ArcMap toolbar, tap the **Editor□** dropdown, and navigate to **EditingWindows > CreateFeatures**.

   ii. Pick an LTYPE template and click away. Double-click or F2 to terminate a feature. Repeat.

   iii. **Save Edits** (available **at Editor□** dropdown) ***frequently!***

Snapping: *You* ***really*** *want to ensure that lines join precisely, without undershoots or overshoots. It is possible to fix such problems later, using various editing tools, but much more efficient to avoid them from the get-go. Do this by (1) setting the Snapping environment properly (see ArcGIS Help if you are unfamiliar with this), (2) digitizing at the appropriate scale (so snapping works as you wish it to), and (3) taking a modicum of care while digitizing.*

Working scale: *If Windows is configured to properly recognize your monitor and monitor resolution, the scale statement on the ArcMap toolbar will be approximately correct. In general, I find it best to work at a somewhat larger scale than the intended final display scale AND to adjust the working scale so that edges are well defined (fuzzy features get sharper as they are shrunk).*

Choice of template: *Use the working scale as a guide to setting LocationConfidenceMeters, i.e., if a working scale of 1:10,000 gives moderately well-defined edges, select LocationConfidenceMeters to be 10. If you are digitizing at 1:100,000 scale, select LocationConfidenceMeters of 100; a value of 30, or 10, is certainly not appropriate. It's OK to use approximate or rounded numbers for LocationConfidenceMeters. This attribute is a real (floating point) number* ***not*** *because we know it precisely but because we use it to denote a real-world quantity. Integers are for counting, reals are for measuring.*

Strategy: *Work from youngest to oldest. This eases snapping to correct line positions and gives the cleanest, most continuous lines and best symbolization. First create the map boundary. Then digitize Recent contacts (water boundaries, margins of modified land and artificial fill). Then digitize older Holocene arcs (young landslides, young alluvium, etc.). Continue into the past.*

Line direction: *Some arcs, particularly low-angle faults, have ornaments that lie to one side of the arc. Typically such ornaments are on the right side of the arc, thus we digitize low-angle faults with the hanging wall to the right. An arc can be flipped after the fact: while editing, and with the Edit Tool active, double-click on the arc, right-click on the arc, and select Flip.*

Managing multiple attributes: *A properly-built, relatively small set of templates greatly eases the task of managing the multiple line attributes of the NCGMP09 schema. However, it is unlikely that any usable set of templates will allow you to specify all attributes of all arcs. For example, the templates in ContactsAndFaults100K.lyr do not create faults that are queried because their identity (e.g., contact versus fault, or strike-slip fault versus normal fault) is uncertain. Nor do the templates set DataSourceID values (was this arc digitized from an analog map, interpreted from* *aerial photographs, or walked in the field while creating a GPS tracklog?). Think about your map, build appropriate templates, hand-calculate some values, and use the edit-tracking attributes to identify arcs that were created or modified during the same edit session and thus (probably have a common data source.*

B. Make Polygons. Two methods for creating polygons from linework are the NCGMP09 **Make Polygons** script and the Advanced Editing **Construct Polygons** tool.

   i. **NCGMP09 toolbox > Make Polygons** is an enhanced wrapper for the Feature to Polygon (Data Management) script provided with ArcGIS. **Make Polygons** creates polygons from all arcs in **ContactsAndFaults** and labels these polys with both a) existing poly attributes and b) attributes of any **MapUnitPoints** label points. Make Polygons also creates ancillary feature classes that identify unlabeled polygons, polygons with multiple label points, label points that are multiples within a single poly, and the polygons that border each arc segment. Its scope is the entire feature dataset.
   You can use **Make Polygons** to make unlabeled polygons that you later select and attribute with MapUnit, or you can add points to feature class **MapUnitPoints** that you attribute with MapUnit, and these values will be transferred to the created polygons.

   ii. Use the **Construct Polygons** tool to create polygons from selected arcs. Advantages of using this tool are (a) its limited scope and (b) its immediacy, including feedback on digitizing quality. The primary disadvantages are that (c) it is easy to create duplicate polygons that must be deleted, (d) not all conceivable polygons will be created, and (e) polygons must be labeled after they are created; any label points are ignored.

   iii. I typically create label points (**Make Polygons** method) or select newly created polygons (**Construct Polygons** method) and attribute these with MapUnit only, leaving all other attributes null—except that if the polygon label has a query (e.g., “Tva2?”), I set MapUnit = “Tva2” and IdentityConfidence = “questionable". I later open the attribute table of MapUnitPolys, select all polys with IdentityConfidence <> “questionable”, and calc IdentityConfidence of those polys to be “certain”. I set Label and Symbol values later.

C. **Editor□ Save Edits**. **Editor□ Stop Editing**.
Pick up the instructions here, to set the way the MapUnitPolys will be displayed.)

D. Set polygon symbolization. In the **Table of Contents** window, double-click on MapUnitPolys to open the **Layer Properties** window. Select the **Symbology** tab.

   i. Under **Show:** (left side of window), select **Categories > Match to symbols in a style**

   ii. Set **Value Field** to the second occurrence of Symbol in drop-down list.

   iii. **Match to symbols in Style**—tap **Browse…** and navigate to and select **USGS Symbols.style**. *Remember where you put it?*

   iv. Click on **Match Symbols**. Then click on **OK**.
   These steps set up the display to use specific colors (and sometimes fill patterns) for specific units. This will replace the random colors we assigned initially. For example, not that the Quaternary sediment is colored the expected yellow.

Symbolization can be set before all polygons are labeled. And set again.

At this point open the MapUnitPoly attribute table and examine it. While many columns are still null, in the later columns considerable information has been added such as a Name and a (Geologic) Age for each MapUnit. The HierarchKey provides information about how the different units would be organized in a paper "Description of Map Units" panel. The second Label column usually duplicates the text in MapUnit but could be used to provide fancier formatting, for example using geology specific fonts for Precambrian or Triassic. The Symbol column gives information about the colors used to display each unit. The AreaFillPattern could give information about a pattern (rather than a simple color) to use in filling the polygon.

The following step will create a **`GeologicMap_topology`** layer which will let us check the topology of the generated map. When you drag that layer into the ToC (and perhaps turn off other confusing layers) a variety of locations will be highlighted in red to indicate errors. For example "dangling contacts" that just end without connecting to some other contact are marked by a red box.) However all the errors are in fact on or outside the map outline. Within the outline everything looks OK. We'll see later how to avoid these problems. Again, in real world use, the tool will probably reveal problems with your contacts or labels which you need to fix.

E. Make and inspect topology. To create an unambiguous map, and to allow certain sorts of queries, it is important that contact and fault arcs not overlap, contact and fault arcs not intersect themselves, polygons not overlap, that there be no gaps between polygons, that there be no dangling unconcealed contacts (dangling concealed contacts and dangling faults are typically OK), and that all polygon boundaries are coincident with an unconcealed contact or fault.
   i. Check that you do not have an open edit session.
   ii. Open **ArcToolbox**. In the **ArcToolbox** window, open **NCGMP09 Tools for Arc10**. Double-click on **Make Topology**. For **Input feature dataset**, navigate to and select feature dataset **PurcellMtn.gdb/GeologicMap** ***in your current workspace***. **OK**.
   iii. Open the Catalog window and navigate to PurcellMtn.gdb/GeologicMap in your current workspace. Add **GeologicMap_topology** to your map composition. You will be asked whether you also want to add participating feature classes. Answer **No** (they should already be present).
   iv. Start editing (right-click on MapUnitPolys and **Edit Features > Start Editing**). Look at the map for errors, and (or) open the **Error Inspector** window and check for errors. Note that ArcMap will tag dangling fault arcs as errors, but we accept them. You may mark them as exceptions. Fix any errors that you find. Re-validate the topology. Repeat until there are no errors. *Your map should have one dangling fault arc.*

F. **Editor□ Save Edits**. **Editor□ Stop Editing**. **Save** your map composition.

5. Digitize orientation points and geologic lines

If you have not completed step 4, make a new working folder, copy the contents of folder **Exercise1-AutomateAnalogMap\5-DigitzeOrientationPointsAndGeologicLines** *into this folder, and double-click on* **5PurcellMtn.mxd** *to start ArcMap. (You may have to change the source of PurcellMtn.png. In* **Table of Contents**, *right-click on PurcellMtn.png, tap Source tab, click Set Data Source…, navigate to your workspace for step 3, or to* **Exercise1-AutomateAnalogMap\3-SetupForDigitizing**, *and select* **PurcellMtn.png.**)

We digitized lines using feature templates to set the multiple attributes that characterize NCGMP09-style data. Our source map has only one flavor of orientation point ("bedding") and two flavors of geologic line ("anticline axis" and "anticline axis, concealed"). We will manage without prepared feature templates—instead, we will digitize generic point and line features and manually set the relevant attributes. If you are digitizing a variety of OrientationPoints Types (e.g., bedding, upright bedding, foliation, joint, stretching lineation) or GeologicLine Types, you will probably find it useful to create a palette of feature templates similar to that in ContactsAndFaults~~100~~24K.lyr.
The point of this section is to learn how to draw features like the "dip indicator T" symbols, and orient them correction. Just try to add a couple, matching them to the existing ones on the map. In modern

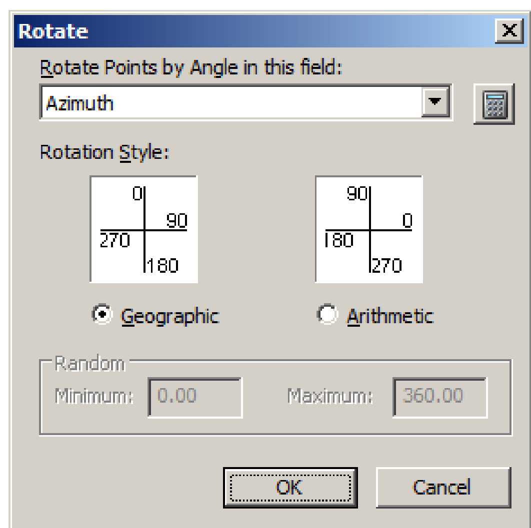
work we'd probably import this information as a spreadsheet giving dip indicator locations, along with the recorded azimuth and inclination.

A. Square your map with the world. We do this to have on-screen rotation = geographic rotation. At the ArcMap main menu, **View > Data Frame Properties...** In the **Data Frame Properties** window, tap the **General** tab and adjust **Rotation:** until the map is square with the world. *I find that a value of* `0.75` *works for this region and map projection*.
B. While you are at the **General** tab of the **Data Frame Properties** window, set **Reference Scale:** to 1:100,000.
C. Add **OrientationPoints** and **GeologicLines** to your map composition.
   i. Open the **Catalog** window.
   ii. Navigate to **PurcellMtn.gdb/GeologicMap** in your current workspace. Expand the **GeologicMap** feature dataset.
   iii. Drag **OrientationPoints** and drop it into the Table of Contents window. Repeat with **GeologicLines**.
D. Create temporary symbology for OrientationPoints
   i. In **the Table of Contents**, expand OrientationPoints. Double-click on the symbol (probably a dark-colored dot) to bring up the **Symbol Selector** window. Next to **Search:**, tap the radio button for "**All Styles**". Type "`bedding`" into the search window and hit <Enter>. Select symbol 06.02 from FGDC_GSC_20100414.

      The follow instructions will set up ArcGIS so it rotates the displayed dip symbol to match the Azimuth value in the attribute table, and labels it with text giving the Inclination value from the attribute table. The instructions then show you how to use a tool to manually rotate the symbol to match the one on the map, and that simultaneously changes the Azimuth value stored in the attribute field.

      Click on **the Color:** □ dropdown and change the color of the symbol to something highly visible like bright red. **OK** to exit.
   ii. In the Table of Contents, double-click on "OrientationPoints" to summon the **Layer Properties** window. Click on the **Labels** tab. Check "**Label features in this layer**". Set **Label Field:** to Inclination. Set **Text Symbol** color to match your bedding symbol. Click **Placement Properties...**, click the **Placement** tab, and select **Place label on top of the point**. **OK**.
   iii. Select the **Symbology** tab in **the Layer Properties** window. Click on the **Advanced**□ dropdown and select **Rotation...** Click the dropdown for **Rotate Points by Angle in this field:** and select "Azimuth". Ensure that **Rotation Style:** is Geographic. **OK**. **OK**. Save your .mxd again.

      While the above rotates the dip symbol, it doesn't rotate the inclination label. To do that click on the `Label` panel then click on `Placement Properties`. Select `Place label at an angle specified by a field`, click on `Rotation Field`, select `Azimuth`, be sure `Geographic` is checked, then finally check `Place label perpendicular to the angle.`



E. Digitize orientation points.

   i. You may need to right-click on OrientationPoints in the **Table of Contents** window and re-start editing (**Edit Features□ Start Editing**). If the Create Features window is not available, click **Editor**□ and navigate to **Editing Windows > Create Features**. Go to the **Create Features** window and select the OrientationPoints template.
      Just add a few points to see how this is done -- for example the three near the top of the map, all within Toh, which have dips of 45, 36, and 27. Make sure the ones you add are actually within the Map Outline. At the end of the following process the inclination numbers should be displayed next to the dip symbols, but because of font issues they may be superposed on them.

   ii. I find it quickest to first place all bedding points and then set their attributes:

      a. Zoom into the map. Select the OrientationPoints template from **the Create Features** window. Click on the center of a bedding attitude that is shown on the map. This will place an OrientationPoints marker with Azimuth = 0, Inclination=0, and labeled with Inclination. Go to the next attitude and repeat until you've added points for all bedding attitudes. **Editor**□ **Save Edits**!

      b. Select the **Edit Tool** on the **Editor** toolbar. Select a bedding symbol. Select the **Rotate** tool on the **Editor** toolbar. Grab an end of the bedding symbol and rotate it until it is aligned with the bedding attitude shown on the map. Go to the **Attributes** window and key in the inclination value shown on the map. Repeat until all bedding values are set. **Editor**□ **Save Edits**!

      c. In the **Table of Contents**, right-click on OrientationPoints and **Open Attribute Table**. In the **OrientationPoints** window that opens, right-click on the Type column then navigate to and click **Field Calculator...** Set Type = "bedding". Then **OK** to set all Type values to "bedding". (To be more explicit about the preceding step, we will use the field calculator to more-or-less easily set all entries in given columns of the attribute table to certain specified values. First make sure no rows (features) are actually selected, or only that row will be changed. You can use to icon at the upper left of the table to clear any selection. Within the Attribute Table right click on the Type column and select Field Calculator. It should show a blank panel under the text Type =. Enter "bedding" (with double quotes) into that panel and click OK. That will set all entries in that column to the string "bedding". Use the same technique to set all entities in the following columns to the values given. As part of the GeMS standard, for any information like Orientation (dip) data, we have to specify how accurate it is, and where the data came from. In this case another table will give us information about the DAS1 "reference". Repeat for PlotAtScale = 120000, LocationConfidenceMeters = 100, IdentityConfidence = "certain", OrientationConfidenceDegrees = 5, LocationSourceID = "DAS1", and ~~DataSource~~ OrientationSourceID = "DAS1". (The latter is another name change between NCGMMP09 and GeMS. They have also added a separate OrientationSourceID in case the information on orientation comes from a different source than location.) **Editor**□ **Save Edits**! Close the attribute table.

F. Digitize geologic lines.

   i. Go to the **Create Features** window and select the GeologicLines template. On the map, digitize the exposed (continuous) anticline axis as one arc, then the concealed (dotted) anticline axis as a second arc. Note when adding these, you SHOULD use snapping so the end of the exposed arc and the beginning of the concealed arc lie exactly on the boundary of the contact which conceals them. Also, there is a third portion which is exposed, but it lies outside the Map Outline, so you don't need to add it.

ii. In **the Table of Contents** window, right-click on OrientationPoints and **Open Attribute Table**. Highlight (click on left margin) one row. Is this dotted line on the map? If so, type `Y` into IsConcealed. Or `N` if not. Enter the appropriate value for the other row. For both rows, calculate (i.e. set as above using the field calculator) Type `= "anticline"`, ExistenceConfidence = `"certain"`. IdentityConfidence = `"certain"`, LocationConfidenceMeters = `200`, and DataSourceID = `"DAS1"`. **Editor** **Save Edits**! **Editor** **Stop Editing**. Close the OrientationPoints attribute table.

The GeologicLines feature class is a hold-all for linear features that are present in the real world—that is, they may be concealed and they may have uncertainty in their position, identity, and existence—but they and their kin do not participate in the map topology. If there are a large number and variety of such lines it may be appropriate to create one or more additional feature classes for some of these features. See the NCGMP09 documentation.

Because we imported the ContactAndFault data without setting all the critical attribute information, we should do that now before asking the system to set up symbols for the features. Using the above examples, open the Attribute Table and by using the Field Calculator, set all entries in the **`Type`** column to **`"contact"`**. Then change the first one to **`"outline"`** and the last to **`"fault"`**. (You could double check these are the right to entries to change by selecting them and looking at what feature is highlighted in the map.) Next, set all entries of **`LocationConfidence`** to **`50`**, and all entries of **`ExistenceConfidence`** and **`IdentityConfidence`** to **`"certain"`**. Also set **`IsConcealed`** to **`"N"`** and **`DataSourceID`** to **`"DAS1"`**. We COULD have created a ContactsAndFaults shape file which contained these attributes (or at least the 10 character shortened versions of these names) then simply imported this information along with the contacts themselves.

6. Add Metadata

If you have not completed step 5, make a new working folder, copy the contents of folder **Exercise1-AutomateAnalogMap\6-AddMetadata** *into this folder, and double-click on* **6PurcellMtn.mxd** *to start ArcMap.*

The NCGMP09 schema requires a significant internal feature-level metadata. You created some of this (e.g., values of LocationConfidenceMeters) as you digitized features. Now add the remainder.

A. Back up the geodatabase. You are going to make significant, wholesale modifications to the geodatabase. Best to keep a copy, in case you screw things up.

i. Open the **ArcToolbox** window. Expand **NCGMP09 Tools for Arc10** and double-click **Compact and Backup**. For **Input Geodatabase**, tap the folder symbol and navigate to **PurcellMtn.gdb** ***in your current workspace***. **OK**.

ii. Look at your current workspace, either with a directory window or via the **Catalog** window. Note that the backup copy of the geodatabase.

(As of 2018_04_20 I get an error when I try to create the backup. Just ignore that for now although not having a reliable backup certainly isn't ideal. Apparently this is a know problem in ArcMap when you try to do backups over a network. It seems to work reliably when the database is on a local disk.)

B. MapUnitPolys, IdentifyConfidence=certain. You have probably already noted which polygons have uncertain identities. You now need to specify IdentifyConfidence for the remainder. In the **Table of**

Contents window of ArcMap, right-click on MapUnitPolys and navigate **to Open Attribute Table**.

- i. Select some rows.
  - a. At the upper left corner of the **Table** window, click the **Table Options**□ dropdown and **Select by Attributes…** In the **Select by Attributes** window, build an SQL expression:
    1. **Method:** should be Create a new selection (the default).
    2. Double-click on MapUnitPolys.IdentityConfidence. *The field name is compound because MapUnitPolys is joined to DescriptionOfMapUnits*.
    3. Click on **<>**.
    4. Click on **Get Unique Values**.
    5. Double-click on 'questionable'.
  - b. **Apply**.
  - c. All rows in the MapUnitPolys feature attribute table should be highlighted except those with IdentityConfidence = "questionable".
    The reason this column is already populated is that we imported these values from the IdentityCo column of MapUnitPoints. Given that, we probably don't really need to change these values, but proceed with the following steps so you understand how you would do this if we hadn't already set this attribute.
- ii. Calculate values.
  - a. Right-click on the IdentityConfidence column heading and navigate to **Field Calculator…**
  - b. In the text window **MapUnitPolys.IdentityCOnfidence =**, enter `"certain"`.
  - c. **OK**.
  - d. Clear the selection: **Table Options**□ **Clear Selection**.
  - e. **Editor**□ **Save Edits**!
    You may have noticed that some rows in the table don't have an entry under MapUnit. Those are the unlabeled polygons which lie outside the Map Outline. We've just said that their identity is certain, which is probably a contradiction in terms. But the real solution should be to remove those irrelevant polygons. We'll see how to do that automatically later. For now, just take this as a lesson on the inconsistencies you can build into your geologic map if you aren't careful.

C. Calc DataSourceIDs.

- i. In the MapUnitPolys attribute table, right-click on the heading of column DataSourceID (which is different than DataSource) and navigate to **Field Calculator…** In the text box **MapUnitPolys.DataSourceID =**, type `"DAS1"`. **OK**. Close the attribute table.
- ii. Open the attribute table for **ContactsAndFaults** (right-click on ContactsAndFaults100K/LTYPE). Calc DataSourceID = `"DAS1"`. Close the attribute table.
- iii. You have already set ~~Data~~*Location*SourceIDs for **OrientationPoints** and **GeologicLines**. But you could check. *Note that OrientationPoints has both OrientationSourceID and ~~DataSource~~LocationSourceID, as orientation and location may have separate sources. For this transcription, both should be "DAS1".*
- iv. **Editor**□ **Save Edits**!

D. Add information to metadata tables **DataSources** and **Glossary**.

- i. Open Catalog window. Navigate to **PurcellMtn.gdb** ***in your current workspace***. Add tables **DataSources** and **Glossary** to your map composition.
- ii. In the **Table Of Contents** window, right-click on DataSources and **Open**.
  So far, all the information in PurcellMtn.gdb has a single source: Washington DGER Open-file Report 87-16, by Hank Schasse, transcribed by you. You need to add an entry to

describe this source.

(Open the table for editing which creates a new row, under the existing reference to the FGDC.)

a. In table DataSources, in column DataSources_ID, enter **`DAS1`**.
   This DAS1 serves as a link, a shorthand reference, connecting the "citations" in the various data tables, and the "Bibliography" in this DataSources table.

b. In column Source, enter an appropriate modification of the following (copy and paste works): **`Geology of the Mount Rainier quadrangle, Washington, compiled by Henry W. Schasse, Washington Division of Geology and Earth Resources Open File Report 87-16, 1987, map scale 1:100,000. Digitized and interpreted by Ralph Haugerud in September-October 2014.`**

c. In the Notes field, you might enter an appropriate modification of the following: **`Values of LocationConfidenceMeters, ExistenceConfidence, IdentityConfidence, and OrientationConfidenceDegrees assigned by Haugerud on the basis of source map scale, source map symbolization, and his experience. These values may not coincide with the intent of the author of the source map.`**

d. Close Table **DataSources**. **Editor Save Edits**.

iii. In the **Table Of Contents** window, right-click on Glossary and **Open**.

Table **Glossary** contains definitions of the terms used in an NCGMP09 geodatabase. All terms used in a Type field or a Confidence field should be defined here. *We will later run a script to check that the list of terms defined in* **Glossary** *is complete. For now, we add a few that we can remember.*

a. *Start editing*. In table Glossary, *in a new row,* in the Term column, enter **`contact`** <return>. Continue to enter, in successive new rows of the Term column, **`fault`**, **`bedding`**, **`anticline`**~~, **`certain`**, and **`questionable`**~~. *(These last two have already been entered automatically.)*

b. We leave Glossary_ID empty for now.
   (For this excercise, don't actually spend time entering the following definitions).

c. You have several choices for definitions. You may write your own. You may paraphrase definitions from your favorite dictionary or geology text. Or you may paraphrase definitions from the American Geological Institute's Glossary of Geology (recommended).

   Note that **`certain`** and **`questionable`** are not defined in the AGI Glossary; the best definition for their meaning in this context that I am aware of is that on pages 16-17 of the FGDC Geologic Map Symbolization standard (FGDC-STD-013-2006).

d. In another document, draft your definitions. Copy and paste them into the appropriate Definition field in table **Glossary**.

e. For each unique source of definitions, create a new DataSourceID value and enter it in the DefinitionSourceID field. If all definitions have the same source, all DefinitionSourceIDs will be the same (e.g., **`DAS2`**).

f. Close Table **Glossary**. **Editor Save Edits.**

iv. For each new value of DefinitionSourceID that you created in **Glossary**, create a corresponding entry in table **DataSources**. *See step ii, above.*
(For this exercise, skip this step as well.)

v. Add information to **DescriptionOfMapUnits**. In the **Table of Contents** window, right-click on DescriptionOfMapUnits and **Open**. You are going to provide additional attributes for each map unit identified in the DMU, but not for those rows that correspond to DMU headings.

vi. Select rows that correspond to map units.

   a. In the **Table** window, tap the **Table Options**□ dropdown at the upper left corner of the window.
   b. **Select By Attributes…**
   c. In the **Select By Attributes** window, **Method:** should be Create a new selection (the default). In the list of fields below, double-click on "MapUnit". Tap **<>**. Tap **Get Unique Values**. In the list of unique values, double-click ''. *(That is, the empty string, so no MapUnit is specified. You are selecting all the rows that DO have some name.)*
   d. **Apply**. All rows of DescriptionOfMapUnits that have non-null values of MapUnit should now be highlighted.

vii. FullName. Some map-units, on some maps, have names like "sandstone member" that are not informative until you know that this is the "sandstone member of the XYZ Formation." Fullname is a field for storing the latter, compound name that might be used in a flyout that appears when a user's cursor hovers over a map-unit polygon in a web display of the map.

   a. For this map, FullName can be the same as Name. Right-click on the FullName heading and open the **Field Calculator…**
   b. In the **Field Calculator** window, in the **Fields:** box, double-click on Name.
   c. **OK**. Values of FullName for all rows should now be the same as values of Name.

viii. Description. In a better world our source-map text would not be a scanned image and we could copy map-unit descriptions from the source map and paste them into the DMU table. Unfortunately this is not possible

   a. Open file **Resources/OCR/MapUnitDescriptions.docx** in the course CD. Read the introduction on how this file was created.
      (Do the following for just one or two units, so you know what eventually is expected. I've copied the above docx file into the main **`resources`** *directory.)*
   b. Copy map-unit descriptions and paste into appropriate places in Table DescriptionOfMapUnits.

ix. DescriptionSourceID. Our descriptions all come from OFR 87-16.

   a. Right-click on the DescriptionSourceID heading and open the Field Calculator…
   b. In the Field Calculator window, in the DescriptionSourceID box, type "DAS1". OK.
   c. Close **Table DescriptionOfMapUnits**.
   d. **Editor**□ **Save Edits**.

x. GeneralLithology

   a. Open the NCGMP09 documentation (**Documentation/ usgs_of2010-1335_NCGMP09.pdf**) and the text for OFR 87-16 (**Resources/ wa_ger_ofr87_16_text.pdf**). Scroll to Appendix A. ~~Lithology and Confidence Terms for GeneralLithology in the NCGMP09~~ *Terms for GeoMaterial and GeoMaterialConfidence in the GeMS* documentation (p. ~~125~~*46* and following).

      (Do the following for just one or two units, so you know what eventually is expected. Note in GeMS they have renamed as "GeoMaterial" what they use to call GeneralLithology.)
   b. For each map unit in table **DescriptionOfMapUnits**, find the ~~GeneralLithology~~ *GeoMaterial* term that you think best fits. Copy and paste the ~~GeneralLithology~~ *GeoMaterial* term into the appropriate row of the ~~GeneralLithology~~ *GeoMaterial* column in **DescriptionOfMapUnits**. *(As you will see in Appendix A, these general terms are things like "Sedimentary material", or perhaps more specific ones like*

"Dune sand". When you click on an cell in GeoMaterial it will present a drop-down box of the allowed choices. Before clicking you may want to make the column wider so you can see the full text for the choices.) Also add the ~~GeneralLithology~~ *GeoMaterial*Confidence term (High, Medium, Low; page 134) that you find appropriate. *It is OK if no ~~GeneralLithology~~ GeoMaterial term fits well—find the best-fitting term, either a general term that is uninformative or a specific term that omits some lithologies within the map unit—and set the corresponding value of GeneralLithologyConfidence to High, Medium, or Low as appropriate.*

c. **Editor□ Save Edits**. **Editor□ Stop Editing**.
d. Close **Table DescriptionOfMapUnits**.

E. Set ID values. Except for DataSources _ID and related DataSourceID values, you have not set any _ID or ID values. These can be created with an NCGMP09 toolbox script that creates new values for any missing values and preserves existing relations.
(Before running this, remove the MapUnitPoints layer from the ToC, and delete it from the Geodatabase, as it causes problems in this next step.)
   i. Open the **ArcToolbox** window. Open **NCGMP09 Tools for Arc10** and double-click **on (re)Set ID values**. In the **Input NCGMP09-style geodatabase field**, click on the folder symbol and navigate to **PurcellMtn.gdb** ***in your current workspace***. Select it and **Add**.
   ii. **OK**. When script has completed, **Close**.

7. Check topology, symbolize, and validate your database.

If you have not completed step 6, make a new working folder, copy the contents of folder **Exercise1-AutomateAnalogMap\7-CheckSymbolizeValidate** *into this folder, and double-click on* **7PurcellMtn.mxd** *to start ArcMap.*

(Skip step A, checking topology, as we've already tried to do this. Do briefly skim the statement below about the direction of faults. Then skip to step B, setting symbols. If you do get an error there, just move on to the next step.

A. Check topology. Beyond requirements that lines not cross or dangle and that polygons neither overlap nor have gaps (step 4E above), there are other aspects of map topology that can be checked to guard against digitizing errors and implausible map relations.
   i. Run NCGMP09 **Topology check** script. Input geodatabase **is PurcellMtn.gdb**. Check the box to validate the topology of all feature datasets—you only have one, **GeologicMap**. Set map scale to 100000. You shouldn't need to change any other input values. **OK**. *Note that the Topology check script is a work in progress.*
   ii. Look at output file PurcellMtn_TopologyReport.html. You should see one **Line and point topology** error:

      errors_GeologicMapTopology_line
```
        1    Must Not Have Gaps    esriTRTAreaNoGaps
```
      You may also have an **End-points of fault arcs that may need flipping** error, which in this case (these fault lines are not directional) may be ignored.
      Note the tables showing how many arcs, and what cumulative length of arc, there are in the classes "Concealed contacts and faults", "Contacts (not concealed)", and "Faults (not concealed)". These can be useful in identifying digitizing errors. One might imagine that for a large, complex map these might even teach you something about the stratigraphy of the map (is it layer-cake or not? What are the significant unconformities?)

B. Set symbolization. *One of the strengths of GIS, and of the NCGMP09 schema, is that symbolization*

may be almost entirely divorced from semantic content—that is, unlike with a paper map, ***heavy black line*** *need not equal* ***fault****. We choose to set symbolization separately from the Type, ExistenceConfidence, and other attributes of a feature. One advantage of this is that we can easily re-symbolize as we change the scale at which map data are to be displayed. Zoom out, so that 1:24,000 scale becomes 1:100,000 scale, and many dashed contacts should be shown as continuous. You can pick line weights and colors that are appropriate for your display medium. And so on.*
If you choose to use FGDC symbology (FGDC Digital Cartographic Standard for Geologic Map Symbolization, FGDC-STD-013-2006, available on the web at ngmdb.usgs.gov), you may find the NCGMP09 **Set Symbol Values** script helpful.
To avoid an error when you run the following script, first open editing on the ContactsAndFaults layer. Stop editing and save the result once the script has finished.

i. Run the NCGMP09 **Set Symbol Values** script. Open the **ArcToolbox** window, expand **NCGMP09 Tools for Arc10**, and double-click on **Set Symbol Values**.
   a. Set **Feature dataset** to **PurcellMtn.gdb/GeologicMap** ***in your current workspace***.
   b. Set **Map scale denominator** to `100000`.
   c. Accept defaults for the remainder of the script parameters.
   d. **OK**.

ii. **Set Symbol Values** uses a dictionary file ***that you can edit*** to set *Symbol* values. This file, **Type-FgdcSymbol.txt**, lives in the **Scripts** folder of the NCGMP09 toolbox and lists *Type* values and a corresponding symbol identifier from the GSC implementation of the FGDC cartographic standard.
   a. For many line types (e.g., contact, fault) there are eight (2^3) line symbols defined in the FGDC cartographic standard for all combinations of is or is not concealed, location confidence (certain versus approximate,) and existence/identity confidence (queried or not). These line types are listed in the dictionary file under the heading **Eight-fold Lines**.
   b. Some structural orientation symbols have different forms depending on whether the orientation is known exactly or approximately—that is, whether *OrientationConfidenceDegrees* is less than some critical value. These, and other structural orientation symbols that do not have different forms, are listed under **Two-fold Orientation Points**.
   c. Other symbols are invariant once *Type* is given. *Type*-to-symbol mapping for such symbols is given under **My Symbols**.

   By default (but you can choose not to) **Set Symbol Values** also calculates some attribute values for polygons in **MapUnitPolys**. *Symbol* is set equal to *DescriptionOfMapUnits.Symbol*. *Label* is set to *DescriptionOfMapUnits.Label*, except for polygons for which *IdentityConfidence* <> **certain**, for which "?" is appended to the label.
   By default (but again you can choose not to), if this is the **GeologicMap** feature dataset and there is an **OrientationPoints** feature class, **Set Symbol Values** will create a new feature class **OrientationPointLabels**, add points to this class with attribute *Inclination*, position these points according to the dictates of the FGDC standard, and add a layer to your map composition that draws these labels with the font and size specified by the FGDC cartographic standard. You may find this a good start towards correctly positioned dip numbers.

C. Validate your database and fix errors that are identified.
   i. First, **Compact and Backup** your database with the script in the NCGMP09 toolbox.
   (This will probably fail again. If it does, just move on to the next step.)
   ii. Run the NCGMP09 **Validate Database** script.

*(As we haven't filled in all the required information tables, and haven't fixed the topology issues caused by features extending outside the outline, the following html files will probably report lots of problems. Just look through those reports briefly. The HTML files will be in your main **exercise_12** directory, and double-clicking on them in Windows Explorer should open them in a browser.)*

a. Open the output file PurcellMtn-Validation.html. What errors are identified? Likely problems include:
   1. Excess fields. You enabled error tracking on all feature classes and tables. While extensions to the schema are not errors, you are likely to choose not to retain this information in the final, public, version of the database. In the **ArcCatalog** window, navigate down to **PurcellMtn.gdb/GeologicMap** in your current workspace, expand, right-click on each feature class, navigate down to **Manage**, and **Disable Editor Tracking**. **OK**. In the **Table Of Contents** window, right-click on the corresponding layer, open the attribute table, navigate to the editor tracking fields, and delete them. Repeat for all feature classes in **GeologicMap**. Repeat for tables **DataSources**, **DescriptionOfMapUnits**, and **Glossary**. *Here is a script that needs to be written!*
   2. Unneeded feature classes. **MapOutline** and **tics** (at the root level of the geodatabase) are excess. Delete them. You have not used **GeologicMap/MapUnitPoints** and it is optional. Delete it.
   3. Missing **Glossary** entries. Validate Database almost certainly will have identified several terms that should be defined in the Glossary table.
      a. Open the **Glossary** table for editing and add the missing terms.
      b. You also need to add values of *Glossary_ID* for each new term, either manually or by running the NCGMP09 **(re)Set ID values** script when you are done editing **Glossary**.
      c. GeneralLithology and GeneralLithologyConfidence terms are defined in Appendix A of the NCGMP09 standard. ***These terms should not be redefined!*** As a convenience to the users of your database, copy and paste the relevant definitions into Glossary. Add the appropriate value of DefinitionSourceID.
      d. **Editor□ Save Edits. Editor□ Stop Editing**.
   4. **Validate Database** is not smart enough to identify missing definitions, missing map unit descriptions, or lousy descriptions of data sources. However, it does list the contents of tables **DataSources**, **DescriptionOfMapUnits**, and **Glossary**. Scan these. Fix that which needs fixing.

iii. Re-run the **Validate Database** script. Fix any remaining errors. Repeat until done.

8. Make a map image and print it.

A. Go **to View > Data Frame Properties...** on the ArcMap menu bar. Under the **General** tab, ensure that **Reference Scale:** = `1:100,000`.

B. Add unadorned **ContactsAndFaults** to your map composition. Either open the ArcCatalog window and drag, or click the Add Data icon and Add Data... Uncheck ~~ContactsAndFaults100~~24KK. *(Rather than unchecking ContactsAndFaults24K, uncheck LTYPE ExistenceConfidence, IdentityConfidence, and LocationConfidenceMeters. Note these "adorned" versions would have been of more use if we had* *actually digitized ContactsAndFaults within ArcMap, rather than importing them in shapefiles.)*

C. Go back to **Table Of Contents**. Symbolize layers OrientationPoints, GeologicLines, and ContactsAndFaults with the FGDC cartographic standard.
   i. In the Table Of Contents window, double-click on OrientationPoints. In the **Layer Properties** window, click on the **Symbology** tab. In the **Show:** box, select **Categories > Match to symbols in a style**. For **Value Field**, select `Symbol`. For **Match to symbols in Style**, click the **Browse...** button and scroll down and select **FGDC_GSC_20100414.style**. **Open**.
   ii. Back at the Layer Properties window, click **Match Symbols**. Uncheck **`<all other values>`**.
   iii. For OrientationPoints ***only***, click the **Advanced□** button and select **Rotation...** Set **Rotate Points by Angle in this field:** to **`Azimuth`**. Ensure that the **Geographic** radio button is selected. **OK**. *See the note above about setting the rotation of the inclination text.*
   iv. **OK**.
   v. Repeat for ContactsAndFaults and GeologicLines.
   To get this to work right for ContactAndFaults we first need to fill in some as yet missing information in the Attribute table.

D. For MapUnitPolys, symbolize via **Match to Symbols in Style**, **Value Field** `Symbol`, and at **Match to symbols in Style**, **Browse...** to and select `USGS Symbols.style`. *This style file may not be present in your ArcMap installation. It is available in the Resources folder of the course CD.*

E. Adjust the labeling of MapUnitPolys.
   You will probably want display of the Map Outline, the OrientationPoints, GeologicLines, MapUnitPolys, and ContactsAndFaults enabled, but everything else including the original png image disabled. It makes it too hard to see the overlying symbols.

F. Switch to Layout View and adjust. **Save**. **File > Export Map...** and **Save as type:** PDF (*.pdf). *Note that you may have to navigate to a different* **Save in:** *folder.*

G. Open the PDF with Adobe Reader and inspect. If everything is OK, print.

What to turn in:

Work through the above excercise at least to the point that you can generate a pdf map showing the underlying png image, superposed by Map Unit Polygons with appropriate colors and labels, a few Orientation (Dip) points, and the anticline line. Save a copy of that image and mail it to me.

Try to finish the steps of populating the full GeMS set of tables with the type of information described in the steps above -- but don't necessarily spend the time to enter every MapUnit description or SourceID value. Clearly it can get tedious entering all those details. For THIS class, the main point of that part of the excercise is to understand in general what type of information is expected in a final GeMS standard map.

Do try to enter enough information into the ContactsAndFaults, OrientationPoints, and GeologicalLines tables so that the display of those features is correct.

Notes on QGIS GeoReferencing.

(These are all notes added by RRH, but to make it easier to read, since they don't need to be called out as different from the original USGS text, I will just print them in black.)

While ArcGIS can accept the world coordinates of the Control Points in (latitude, longitude), for QGIS, if we are going to output the map in Washington State Plane N-4601 it's simplest if we actually enter the world coordinates (easting, northing) in that projection. Also, while ArcGIS can accept just the corner coordinates and then the tic spacing, for QGIS we'll need to coordinates of each corner point.

While there are local tools which could convert from the (longitude, latitude) listed on the map to the projection (easting, northing), its simplest to use the on-line converter provided by the National Geodetic Survey, at <https://www.ngs.noaa.gov/NCAT/>. To use it we will need to enter the (longitude, latitude, altitude) for each point. (The altitude has only a small effect on the conversion, but for completeness I've looked it up using the contours on the map.) For the four points, in **NAD1927** (see the note below), we have

	Lat.	Long.	Elev.		Lat.	Long.	Elev.
NW:	46.625	-121.875	1085m	NE:	46.625	-121.750	720m
SW:	46.500	-121.875	652m	SE:	46.500	-121.750	1426m

When I input these into the converter as described below, I get coordinates of:

	Easting	Northing		Easting	Northing
NW:	1,378,312.332	-135,084.517	NE:	1,409,727.459	-135,484.552
SW:	1,377,695.466	-180,681.653	SE:	1,409,184.609	-181,082.420

You clearly don't need these to thousandths of a foot, but the converter can give that.
The converter outputs numbers with commas to make them easier to read, but QGIS won't let you paste text including those commas, so here is a copy without those them which you can use for cutting and pasting.

	Easting	Northing		Easting	Northing
NW:	1378312.332	-135084.517	NE:	1409727.459	-135484.552
SW:	1377695.466	-180681.653	SE:	1409184.609	-181082.420

To generate the above coordinates in the converter, select **NAD1927** as the input datum and **NAD1983 (2011)** as the output datum. (Note that output 1983 datum is what is specified by the USGS example in order to match other potential data in the project.) Enter the latitude, longitude, and elevation, then if necessary click **Convert**. The converter will output numbers in a varieties of systems, such as UTM and SPC (State Plane Coordinates). For the latter it outputs meters, international feet, and US feet, and we want the latter. It also lets you chose the output State Plane projection. Purcell Mountain is actually in the southern part of Washington and so by default the converter will output coordinates in the WA S-4602 projection used for the southern part of the state. However to match other potential data in this USGS example we actually want coordinates in WA N-4601, normally used for the northern part of the state. To force output in that, clear the **Zone** field under **SPC** and start to type in **WA**. It should bring up to boxes showing the **WA N-4610** and **WA S-4602** options. Click on the former. Finally, copy the easting and northing as given in US feet.

Importance of the Input Map Datum: It is very important to specify the datum of the input map correctly. Since I didn't have the collar information from the full map I initially assumed the map was marked in NAD83 (although the **`ISNAD27`** option checked in the ArcGIS instructions should have been a clue that assumption was wrong.) When I originally did the conversion I specified that the tics were at the above (latitude, latitude) in NAD83, and that gave the following projected coordinates:

```
     Easting        Northing              Easting        Northing
NW:  1,378,615.018  -135,025.944     NE:  1,410,029.627  -135,425.674       WRONG VALUES!!!!
NW:  1,377,997.779  -180,623.855     SE:  1,409,486.453  -181,024.523       WRONG VALUES!!!!
```

If you compare them to the above ones you will see that the easting differs about 303 ft and the northing differs by about 58 feet. I originally digitized the contacts with the wrong settings, and discovered that when imported into ArcGIS they were all positioned wrong by the above offset. I could have gone back and redigitized them all, but in this case, since the offset was the same for all points, I used the **`QGIS vector Geoprocessing / Affine Transformation`** tool to shift all the vector points by the above offset and make them properly align with the map.

Now that we have the (correct) world coordinates of our four control points we can GeoReference the image in QGIS.

To GeoReference in QGIS first use the main menu **`Plugins / Manage`** and **`Install Plugins`** dialog to be sure the **`Georeferencer GDAL`** plugin is installed and active. (It is one of the default QGIS plugins so it should be installed, but might not initially be activated. If activated the box in front of it in the plugin list will be checked.) Next in the main menu go to **`Raster / Georeferencer`** to open a new window which will have two panels: the upper for the image and the lower for a list of the control points. Use **`File / Open Raster`** and select the **`PurcellMtnRRH.png`** file. Set as the **`CRS`** you will use **`NAD_1983_StatePlane_Washington_North_FIPS_4601_Feet`** (which is also known as **`EPSG:102748`**). We will enter the "world" coordinates for our known control points using the ones obtained above from the NCAT converter. As described above, in QGIS it is simplest if we actually use (easting, northing) in the Washington FIPS_4601 State Plane. If you have previously defined control points then they will appear in the bottom panel. (By default they are saved in a file with the same name as the raster, with **`.points`** appended to the name.) If you don't want to use some of them then right click on that row and **`Remove`** it, or at least "uncheck" it so it won't be used in the warping calculation.

Select the **`Add control points`** tool, zoom in to each of our four control points, click on the point, then enter the appropriate (easting, northing) as measured in the **`WA N-4601 (US feet)`** projection. You can use the mouse scroll wheel to zoom in and out. Also note if you are cutting and pasting from the above coordinate text, you need to paste text without any commas. QGIS will refuse to allow you to paste text with commas. Once you have entered all four points, from the menu select **`Settings / Transformation Settings`**. In the window which opens accept the default **`"Thin Plate Spline"`** for interpolating the transformation between screen and world coordinates. Under **`Output Raster`** click "`...`" and navigate to a reasonable writable directory for placing an output image. Accept the default name **`PurcellMtnRRH_modified.tif`**. The program will produce a tif image "warped" to the new projection and the "geotif" format file will contain embedded information about the real world coordinates. For tif there are several compression options. Select **`Deflate`** which can be read by most systems and does not introduce compression artifacts in the image. One of the default parameters will be to load the image into the QGIS canvas when done. We could also specify target resolution and other options, but the defaults are usually reasonable.

Once done specifying parameters select **`OK`**.

Note that we actually don't know what input projection was used in generating the original map. With just three or four control points we are assuming there is some linear relationship between screen coordinates and world coordinates. If the map covered a large enough region where the projection distortion pattern changed, we would need to define many more control points scattered across the map.

Next, from the menu select **`File/Start Georeferencing`** which produces the TIF image warped to the new projection and matched to the control points, and then loads it into the QGIS Canvas. You can now close the Georeferencing window. It will ask you if you want to save the control points. Say yes, and they will be written to the default **`.point`** file described above.

With the image loaded you could now create new shapefiles tracing features on the map. If this is the first image loaded that will set the "Project CRS" (used to control the display) to the same CRS as the image, namely **`NAD_1983_StatePlane_Washington_North_FIPS_4601_Feet`**. If we output that shapefiles using that same projection they will have the greatest accuracy, as internally they will have feature (x,y) given as easting and northing in that projection. With QGIS you can also specify output in other projections, but then QGIS will need to **`Transform`** coordinates into the new system, which can potentially introduce some (usually small) errors. For this project I have tried to keep all shapefiles in this FIPS 4601 system, as it is important to make sure our contacts line up exactly with each other.

QGIS Digitizing Tips

As mentioned in the main Exercise instructions, it is critical for GeMS that faults and contacts all meet cleanly so that they divide up the whole area of the map into well defined polygons corresponding to the different rock unit exposures. GeMS will also be unhappy if any contacts or faults (or segments along them) are duplicated. It also will complain if a contact or fault is broken up into segments without some good reason, like a change in its properties (certain to uncertain). Furthermore, contacts lines never cross each other -- although they could meet at "triple junctions" where three different rock exposures touch at one point.

It also turns out that there are peculiar interactions in the GeMS software between the contacts and the Map Outline, which is treated as a contact but is clearly an unusual one. The following tips help generate contact and fault shapefiles with which GeMS is more likely to be satisfied.

1) Be sure that any junction between contacts (or faults) occurs at a well defined vertex. Use snapping to ensure that the end-vertices of the three possibly joining lines all have exactly the same coordinates.

2) If you do have an apparently single contact which changes character, then digitize it as two features, again using snapping so the last vertex of one matches exactly the first vertex of the second. Make sure some attribute, like LocationConfidenceMeters, changes at the boundary.

3) If you have a contact which forms a closed loop, digitize it as a "line", not a polygon, and use snapping to make the last vertex coincide exactly with the first. But see the note below in case the loop crosses the map outline.

4) If you do have a contact loop but the loop crosses the Map Outline, make sure the first/last vertex lies outside the map outline. When constructing the map GeMS will clip the contact at the Outline and if the first/last vertex is within the outline that contact gets broken into a left half / right half pair which violates the rules that contacts should NOT (without a good reason) have multiple parts.

5) Contacts (and sometimes faults) should always end where they meet some other feature, or they are marked by GeMS as "Dangling Contact" errors. When digitizing within ArcGIS contacts end either at another contact or fault, or at the Map Outline. We will see in QGIS that we can leave contacts dangling after they move outside the Map Outline, but this will be flagged as an error we will have to override.

6) Each created polygon needs to be labeled with one and only one MapUnitPoint, or the unit names need to be added later by other means. If using MapUnitPoints, remember that the Map Outline can potentially break a single rock exposure into separate exposures which reach into the Outline from different sides of the map. You will need to add an extra MapUnitPoint for each of those ultimate polygons as the GeMS script isn't smart enough to follow the exposure outside the outline and then back inside again.

QGIS Outline Polygon

For some later steps it is convenient to have a shapefile which is a polygon representing the map outline, and we want the outline points to be exact. I have created a **CSV** text file **outine_points_fips4601.csv** which contains those coordinate using the **FIPS_4601 CRS.** To create a point shapefile in QGIS select the **Add Delimited Text** tool from the left edge menu, or from the **Layer / Add Layer / Add Text Delimited Layer** menu. Browse to select the above csv file. For **File format** select **CSV**. Look through the other parameter choices but the defaults are probably good. If they do look good click **OK**. It will ask you want CRS is used for these coordinates. Select **NAD_1983_StatePlane_Washington_North_FIPS_4601_Feet** (or equivalently, **EPS: 102748).** If that is the Project CRS, then it should be the default choice. If you have the georeferenced map loaded, then you should see points added which match the maps control points. Next we will turn this four point file into a polygon. Install the plugin **Points2One** if it isn't already available and start it from the menu **Vector / Points2One** . Select our outline_points_fips4601 as the input layer, check Create polygons, and create an output shapefile called **outline_polygon_fips4601.** Also check the **Add results to canvas box**. (Note for plugins like this the system often forgets what default directory results should be written to.) (An alternate to using this plugin is to use **Vector / Geoprocessing / Convex Hull** and while it works for this simple case, computing a "Convex Hull" is overkill for a simple polygon like this.) Once the polygon is create it you'll want to edit its style. The default is **Single symbol / Fill / Simple fill** but that makes the whole polygon opaque. Click on **Simple fill** and in the dialog box which appears, to the right of **Fill** click on the down arrow and select **Transparent Fill**. Click on the Outline color and select something which stands out. Finally, perhaps adjust the outline width.

Part of the reason to create the above outline is that, as we will see in ArcGIS, we can encounter problems if faults or other lines extend outside the outline of the map. We can use the above outline polygon to create a clipped version of those lines. From the main QGIS menu select **Vector / Geoprocessing tools / Clip** . Select the **contacts_fips4601** layer as input, the **outline_polygon_fips4601** layer as the clip layer, and tell it to output the result to the **shp** file **contacts_clipped_fips4601** then click **Run**. (Hint: Make sure no features are selected when you run this, or only the selected features will be included in the possible output.)