GIS Exercise 09
Mar. 23, 2018   Due Mar. 30
ArcGIS and Geologic Maps
(updated version 2 instructions)

We'll explore using a base map and different coordinate systems in ArcGIS, then will start to create the elements of a Geologic Map database.

Part 1. Loading a basemap and GPS data.

1) Download onto your local storage the `exercise_09_data` zip file from the class website and unzip it.

2) Establishing a default coordinate system and projection: The latest versions of ArcGIS can do some on-the-fly reprojection between different coordinate systems. It normally uses for the display (the `Data Frame`) the coordinate system of the first layer added. In theory this can be changed later, but I've encountered a number of errors trying to do this. So to force it to use a "good" coordinate system, do the following. Start `ArcGIS ArcMap`. In the `Getting Started` window which opens in the left panel click on `New Maps/My Templates` and in the right panel click on `Blank Map`. The system will probably default to putting new information in a default database, listed at the bottom of the window. Later we'll see how to change that, but use the default for now. In the `Table of Contents` panel right click on `Layers` then select `Properties`. A window labeled `Data Frame Properties` should open. Select the `Coordinate Systems` tab. Open up the list of `Projected Coordinate Systems` by clicking on the `+` symbol in front of it, and in turn navigate through the list selecting `UTM / NAD 1983 / NAD 1983 UTM Zone 13N` which is the standard for recent USGS maps in eastern Wyoming then click on `OK`.

3) Add as a base map the `laramie_quad_usgs_1963.tiff` file. To do this in the `Table of Contents` panel right click on `Layers`, select `Add Data`, navigate to the `exercise_09` folder. If you don't already have a "folder connection" established to that directory or one above it, you will need to do that first using the `Connect to Folder` icon, which appears a folder symbol with a "+" sign. Select the laramie map file by single

clicking on it, then select OK. Do NOT double click on it or it will "open it up" into separate Red, Green, and Blue layers and will expect you to select just one of those. Next ArcGIS will ask you about creating Pyramids (precalculated images of sections of the map which it uses for quick display. Click Yes. At this point the system may ask you about the coordinate system for the map. It should recognize that it is based on NAD27 while you have chosen a NAD83 "Data Frame" for display and may need to know how to convert between them. If so it will bring up a warning dialog window. Click on the Transformations button then click on the down arrow on the drop-box to select conversions, and select NAD_1927_To_NAD_1983_NADCON. Finally click OK then Close the warning dialog. (If the map isn't visible right click on it in Table Of Contents panel and select Zoom to Layer.) With the map loaded, right click on it in the Table Of Contents panel, select Properties, select the Source tab, and scroll down through the list of properties till you see Spatial Reference. Examine that information. It should show you that the system recognized the map was using the NAD27 datum. Finally, click Cancel to close the Properties window.

4) Loading a GPX track file. To be sure the system properly projects between different coordinates, we'll now (temporarily)load the gps track file, which records information in latitude and longitude, in the WGS84 system. Open the ArcToolbox (with the red toolbox icon). Run Conversion Tools / From GPS / GPX To Features, clicking on the + to open each part of the tree, and double clicking on the final command. In the window which opens select gps_track.gpx as the input GPX file and select the default output it provides which will be a layer stored within the geodatabase (GDB) file. The data will be imported as a set of track points rather than a line. The points should begin close to the front door of the Geology building, go across Prexy's Pasture, follow along 15th street, then back. If there is any problem with the NAD27/ WGS84 conversion, they will be offset by roughly half the wide of the Geology Building. Open the attribute table by right clicking on the layer. Note that it actually contains not only positions, but the times at which they were recorded.

5) The above data was saved within the ArcGIS geodatabase. To export it into a shapefile which could be read by other software, right click on gps_track in the **Table of Contents**, select **Data** then **Export data** then change the name to **gps_track_shapefile**. Be sure to navigate to the exercise 09 folder. Also set the save as type type to Shapefile.

6) You could convert this set of points into a line, but that is slightly complicated so for this exercise we'll just delete the points and read in a shapefile where that is already done. To delete the points right click on the track layer(s) in the **Table of Contents** and select **Remove**.

Part 2. Created the Geological Map DataBase

We'll now begin to build a map based on previous shapefiles we've created. We'll pretend the GPS Waypoints around campus represent measurement points, the GPS track represents a volcanic dike, and the boundaries of the Laramie land addition polygons represent contacts between different geologic units.

The steps below use the ESRI created `Geologic Mapping Tools`. ESRI doesn't seem to be putting any recent effort into updating the tools, and as you will see below, there are major gaps.

The USGS itself has released a related toolbox which performs some but not all of the following functions. It has provided more recent releases and and in the long run the USGS toolbox is probably the one to use. For example that has, like ESRI, a tool which creates a new database, with the general NCGMP09 structure, but with some differences from ESRI's. It tends to create a slightly simpler format, and uses slightly different techniques for assigning symbols to different types of features.

We'll use the ESRI toolbox in this exercise as a starting point, but next Friday I'll demonstrate the differences in the newest USGS release, and show some ways to use both tools together.

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1) Adding the ESRI Geologic Mapping Tools to the toolbox. Open the `ArcToolbox`, and if the `Geologic Mapping Tools` are not already present, right click in that window, select `Add Toolbox`, navigate to `exercise_09`, double click on the `ESRI_Geology.gdb`, and select `GMT_Tools` then click `OK`.

2) Adding our shapefile data to the map. To avoid some problems with the gps track we directly imported we'll use one from a previous exercise. Right click on `Layers` in the `Table of Contents` panel, navigate to `exercise_09` and select `gps_track.shp` then click `Add`.

The system will probably again ask you about converting coordinate systems. These shapefiles are based on WGS84 but the displayed data frame is using NAD83. While the two were essentially identical in 1983 when they were defined, NAD83 is fixed to the North American plate while WGS84 is a world average, so they are slowly drifting apart. In the **Geographic Coordinate Systems Warning** window which probably opened, click on the **Transformations** button and a new dialog window should open. In the upper section under **Convert From:** select **GCS_WGS_84** and leave the lower **Convert to:** at what should be the default **CGS_North_American_1983**. In the **Using:** box where **None** probably appears, click the down arrow to open a drop-list and select **WGS84 (ITRF00)_To_NAD_1983** then click the OK button. These other transformations all use slightly different formulae. Back in the previous warning window, click **Close**.

Repeat the above for **gps_waypoints**, and the **rrh_laramie_land_addition_boundaries**, which is a shapefile made of of lines (rather than polygons) showing the boundaries of the various land additions. In a real geologic map we would start with these "contacts", and later use them to define the various geologic unit locations. Since these use the same WGS_84 coordinates as the previous shapefile we added, it we should not need to specify another Transformation.

3) Adding space for FGDC Reference Numbers. The next step in creating the ESRI version of the USGS standard database is to add a column specifying the FGDCRefNo for each feature. For example a volcanic fissure is FGDCRefNo =18.41. The table of features and numbers is given in the FGDC documents accessible from Class Website under **Reference material and Links / Geologic Map Standards / FGDC Cartography Standards.** A direct link to the tables showing various feature numbers is **<http://ngmdb.usgs.gov/fgdc_gds/geolsymstd/download.php>**. Beyond simply keeping track of what types of features we're adding, the GMT template can use these numbers we enter in a later step to control how these various features are displayed on the final map.

Lets pretend the gps track is a volcanic fissure. We'll use the **Geologic Mapping Tools** to add the desired column, then will manually enter the information for the feature. In the **ArcToolBox** open **GMT Tools** and double click on **Add FGDCRefNo Field**. In the window which opens click on the down arrow in the **Input Feature Class Box** select **gps_track**, and click **OK**. You should see a box which reports the column was added correctly. Click OK.

While we are here, repeat the process for the **gps_waypoints** and **rrh_land_addition_boundaries** layers.

We will need to edit the attribute tables to enter the FGDCRefNo values. To enable editing click on the **Editor∇** button in the ArcGIS Editor Toolbar, and select **Start Editing**. (If you do not see that button available you will first need to click on the **Editor Toolbar** button which is a pencil next to a set of vertices. In some cases when you enable editing, **ArcMap** may then display a dialog box where you must explicitly select which layer you want to edit, and it may also display a subsequent warning dialog box about incompatible coordinate systems. Because we will only be editing attributes you can just click **OK** to ignore that warning.) Once you have successfully enabled editing, open the attribute table of the **gps_track** layer. Into the **FGDCRefNo** column enter **18.41**, the proper number for a volcanic fissure. Once finished with that, open the **gps_waypoints** attribute table and fill the **FGDCRefNo** column with **31.21**, which is the code for sample locality. Finally, open the **rrh_land_addition_boundaries** attribute table and enter **1.1.1** for all of the features except the one which corresponds to the part of Laramie west of the railroad tracks. For it, enter **1.1.5**. (To tell which feature is which select it by clicking on the first, empty column in the attribute table.) The **1.1.1** is code for a contact whose identity and existence is certain, and the location is accurate. The **1.1.5** is the code for a contact whose location was inferred. The first will be drawn as a solid line while the second will be shown as a dotted line, once we apply the rules from the Geologic Mapping Template.

Examine the location of the features to be sure they do properly line up, for example with the front door of the Geology Building, 15th Street, and the underlying roads and extensions shown on the 1963 map. In general always test your GPS import techniques, as coordinate system and transformation errors can easily occur.

For the next step we'll need to use the **ArcCatalog** program rather than **ArcGIS**. So we can return to this map later, from the main menu use **File / Save as** make sure you are in the **exercise_09** folder, and enter the name **exercise_09_part1.mxd**. The file created, like a QGIS project file, does not contain the data itself, but rather a description of which data sets are to be loaded and how they are to be displayed. Now exit the **ArcGIS** program.

4) Creating a new Geologic Database (GDB) for our project. For this step to work the **ESRI_Geology.gdb** needs to be present in our Exercise 09 folder, or strange and poorly documented errors occur. It basically acts as a template for the new database we will create. It should already be there as I copied this folder from within the ESRI supplied geologic mapping template directory when I created the **exercise_09** data directory. If this were a project of your own, you'd need to make sure you placed a copy of **ESRI_Geology.gdb in your main data directory**. Once we create are own **gdb** and load some other features from the **ESRI_Geology.gdb** we won't need the latter **gdb** folder any longer. It could be deleted, leaving only the **exercise_09.gdb** folder we will shortly be creating.

Start **ArcCatalog**. (It can be found under **Start / ArcGIS / ArcCatalog**.) It will open a window which looks much like Windows (file) explorer, but has special capabilities for dealing with GIS data. From within **ArcCatalog** open the **ArcToolbox** (add it as we did in **Arcmap** if it isn't already there) and click the + before **Geologic Mapping Tool**, to expand the entries. You should see a (poorly named) **Apply Coordinate System to ESRI_Geology.gdb** which we will use to create the database.

If you are lucky it will NOT have an error symbol superposed on it. However if this is the first time you are trying to use it in a newer version of ArcGIS, it may. To fix the error symbol right click on this line in the tool list, choose **Edit**, and a **Model Builder** window will open showing graphically what this tool does. From that window's menu simply select **Model / Save** then **Model / Close** and the window should close and the error symbol will be gone.

Double click the **Apply Coordinate System to ESRI_Geology.gdb line** and a new window titled with the name of the tool should open. Under **Project Geodatabase Location** you need to tell it what directory the database will be located within. Click the folder icon and navigate to the folder **above** the **exercise_09** directory, then click on the **exercise_09** directory (which should appear in the **Name** box) then click **Add**. The system may pause for several seconds (at this and each subsequent step) before it is ready for the next step. Unfortunately it doesn't give any "busy" indication. You just have to wait for the tool to finish filling in the field you are working on.

Bug workaround: In the original V1 instructions we entered the **Project Geodatabase Name** *next then did the following steps. To avoid the bug (or at least unusual behavior in ArcGIS 10.5) we'll enter the name last.*

We need to specify two (sometimes optional) items: the coordinate system to be used for our map, and two transformations we'll want the system to use in converting from other coordinate systems to that particular one. Next to the **Project Coordinate System** click the "pick" icon and in the window which opens again select
Projected Coordinate Systems / UTM / NAD 1983 / NAD 1983 UTM Zone 13N
then click **OK**. On the **Geographic Transformations** line click the down arrow, scroll way down to **NAD_1927_To_NAD_1983_NADCON**, and click it. It should be added to the list of transformations in the original window, but that may take several seconds. Repeat this for **WGS_1984_(ITRF00)_To_NAD_1983_HARN** .

Finally, we'll go back up to **Project Geodatabase Name** and enter **exercise_09.gdb** . We will accept the default name **GeologicMap** for the **Feature Dataset Name**. Later, if you look within the **exercise_09.gdb** directory, you will see a subdirectory with that name, where your features are stored. Finally, in the main tool window, click **OK**. A window will open showing progress and output from the Python programs which make up the tool, as it uses **ESRI_Geology.gdb** as a template to create our new **exercise_09.gdb**. The process can take over 10 minutes if one is working across the network, and even longer if many students are doing this simultaneously. As it progresses you should see the tool creating a set of standard (but empty) features:

Contacts
Faults
Folds
VolcanicLineFeatures
MapUnitPolys

and a host of less frequently used feature classes such as:

Bedding, Cleavage, Foliation, GeophysicalBoundaries, GeophysicalContours, GlacialAndSurficialPoints, GSControlPoints, JointsAndLineaments, LandslideMWLineFeatures, LandslideMWPointFeatures, OverlayPolys, SmallMinorFolds, SmallMinorJoints, VolcanicLineFeatures, VolcanicPointFeatures

plus information you might want associated with above features such as

ObservatonsOrnamentations_Contacts
ObservationsOrnamentation_Faults
ObservationOrnamentation_Joints

When the tool is finally finished click the **Close** button. We now have a geodatabase in the nominal ESRI/USGS form ready to receive our data.

While still in **ArcCatalog** use it to explore the **exercise_09.gdb** geodatabase. For example if you open **GeologicMap** by double clicking on it you will see the above list of features. You could in turn click on them to see other properties, although so far we haven't added much of interest. Under **exercise_09.gdb** you will also see standard tables recommended by the NCGMP09 Proposed Geologic Map GIS Standard. For example the **DataSources** table lets you reference the source of various observations. The **DescriptionOfMapUnits** should contain more detailed descriptions of your geologic units. It can also contain information such as the colors used for the units. It is the equivalent of the key that would be printed on a paper map.

5) Importing our shapefiles into the geodatabase. We next will create a new map, based on the just created geodatabase, and import our data into that database. Start **ArcMap** and create a new map. Use the default **Blank Map Template**, but for **Defaultgeodatabase**, specified at the bottom of that new map dialog, select the just created **exercise_09.gdb** rather than the default gdb we used in Part 1. Next, right click on **Layers** and using **Add Data**, add the **Contacts** feature from within the database we just created. We can skip the step of defining the **Coordinate System** for the **Data Frame** which we performed in Part 1, because we've already set up this **ContactsAndFaults** layer to use **NAD 1983 UTM Zone 13N**, and ArcGIS will adopt for the **Data Layer** the coordinate system of the first layer added. Also displayed in the **Table of Contents** will be all the symbols used for the different types of contacts. You can use the leading + or - symbols to expand or collapse the list.

Next use **Add data** to add back in the Laramie tiff map and our three shape files. You may need to reenter the **Transformations** as we did above. We are finally ready to import those features into the geodatabase. Since we just added the shapefiles we know that no particular features are selected. If there were any chance there was, we would need to deselect them before the next step as if the next GMT tool sees some selected features, it will only import those into the geodatabase, rather than importing all features from the shapefile. To be sure nothing is selected, in the **Table of Contents** panel right click on **gps_waypoints**, left click on **Selection**, and if the **Clear Selections Features** command is NOT grayed out, click on it. If it is grayed out, then no features are individually selected, and the whole shapefile will be imported in the following steps. (There are also alternate ways mentioned later to choose just specific features from the shapefile for import.)

Open the **ArcToolbox** and within **Geologic Mapping Tools** double click on **(3) Append ProjectESRI_Geology.gdb**. (That really should be called **Append to new GDB**.) In the **Original Feature Class** box click on the down arrow and select **gps_track**. In the next box, if you wanted to just select some features out of that shapefile you could use an SQL statement to do that, but here we'll use the default which is to import all features. Next we select what type of feature this is in the standard USGS/ESRI scheme. We are pretending that this **gps_track** represents a dike so under

Project Feature Class click on the adjacent folder icon, navigate to the exercise_09 folder, the exercise_09.gdb geodatabase, the GeologicMap part of that data base, and finally double click on VolcanicLineFeatures. For this particular entry ignore the Field Map (optional) section which should now be populated. We'll return to it later. Just click OK. A progress window should appear and eventually report success in importing the data. Once it does, close that window. Repeat the above process to add the gps_waypoints, but place them in the GlacialAndSurficialPoints class.

Start to do the same for the rrh_land_addition_boundaries, placing them in the Contacts class, but before you click on the final OK, we will examine and modify the Field Map (optional) settings. First, click on the + before the FGDCRefNo line. The entry there tells the system to import the FGDCRefNo from that particular column in our gps_track shape file. We'll tell the system to import one other column from our shapefile. Right click on the Notes (Text) line and select Add Input Field. A new window appears showing the names and types of fields in our shapefile. Select year_added. Note this is a long (i.e. 64 bit integer) but the system will convert from the integer type in the input to the text type in the final database. Finally click OK, and when the status window reports success, Close it.

Back in the main window or ArcGIS, you can now add the VolcanicLineFeatures and GlacialAndSurficialPoints features stored in the database, and remove the no longer needed equivalent features from the shapefiles. We have one more step before our imported features are actually displayed with those symbols.

6) Specifying the symbols used to draw the different features.
Besides standard symbols which can manually be applied to different features, ArcGIS has "Representations" which are collected symbols combined with rules which determine what symbol will be used. Therefore we need to apply "Rules" to every feature. In theory the advantage to keeping a separate "Rule" column in the attributes table is that it is easy to change or override the normal symbol for a given `FGDCRefNo` . Most of the rules have the same "name" as the `FGDCRefNo` itself, and a "good" version of the template would just let you apply that rule to every feature based on the `RefNo`, then go back and change any exceptions. Unfortunately the procedure in the current version of the GMT from ESRI is far more obscure. We will need to go through a table (for example `Contacts`), using SQL to select every different type of contact, and apply the rule for all then entries of that type. Luckily, for our example, we only have two types: `1.1.1` (exposed contacts) and `1.1.5` (inferred contacts).

Within the `ArcToolbox / Geologic Mapping Tools` double click on `(4) Calculate Feature Representations`. In the window which appears on the `Input Feature Class` line use the down-arrow to select `Contacts`. On the `Select Features` line click the SQL icon. We will build an SQL query statement to select just the features whose `FGDCRefNo` is `"1.1.1"`, then will apply the rule `"1.1.1"` to those features. (Yes this is incredibly inefficient, but if there is a better way, other than rewriting the ESRI programs in the toolbox, I haven't found it.) To build the SQL statement, in the upper panel showing the names of all the columns in the attribute table, double click on `"FGDCRefNo"`. Next click on the = button, and then click on `Get Unique Values`. This latter command fills the panel above it with the unique values found in the `FGDCRefNo` column. Finally, double click on the `"1.1.1"`. This should have built the statement `"FGDCRefNo" = '1.1.1'` . (If later on you want to experiment with building SQL statements you can just open a layer's attribute table, and experiment with the `Select_by_SQL` icon there.) Finally click the `OK` button and this SQL statement (or really a statement fragment) will appear in the 2nd line of our tools window. Next, in the third line `Select Representation Class`, use the down arrow to select the only representation class available for `Contacts`, namely the `Contacts_Rep`. Finally, on the fourth line `Select Representation Rule` use the down arrow to select the `1.1.1` rule, then click OK. Close the status window after it (with some luck) reports success.

(Another bug or new "feature" workaround: With ArcMap 10.5 each time this tool is run, while it does really edit the Contact layer visible in ArcMap, it also creates a new "temporary" layer visible only to the GMT tools, called Contact_LayerN where N starts out as blank, but increments from that to 1, 2, etc. each time the tool is run. In the following step where you run the tool again, be sure to select as input the main Contact layer, not one of these additional Contact_LayerN temporary layers. If you select one of these temporary layers by mistake the changes are never written back to the main Contact layer. These temporary layers will disappear from GMT tools once you exit then restart ArcMap.)

Repeat the above for our one other type of contact, replacing 1.1.1 with 1.1.5 in the above instructions.

We could repeat the above very cumbersome procedure for the VolcanicLineFeatures and GlacialAndSurficialPoints but because we only have a few of those we'll change the Representation Rules directly. First select VolcanicLineFeatures in the Table of Contents Panel, then click on the EditorV button in the ArcGIS Editor Toolbar, and select Start Editing. If you do not see that button available you will first need to click on the Editor Toolbar button which is a pencil next to a set of vertices

Once you have enabled editing, open the Attribute Table. The FGDC Reference Number should be 18.41, the code for a volcanic fissure. Next, the RuleID, used to control the display of the feature, needs to have the same value. Click on that cell in the table. A dropdown box should give you a list of all possible rules for VolcanicLineFeatures, or at least those included so far in the ESRI GMT. Some less common ones in the FGDC standard have not been programmed in yet. Use the dropbox to select rule 18.41. Close the table and back at the EditorV button choose Stop Editing, then when asked save the changes.

Repeat the above steps for the GlacialAndSurficialPoints. But when you try to make the RuleID equal to the FGDC Reference Number, you'll discover there is no rule 31.21 (sample location) in the list of rules. They just haven't included a lot of useful features in the GMT so far. Probably the right choice is to select the last rule which is `Free Representation` and specify the symbol later. However to keep things simple here we will choose Rule `13.25`, which is the symbol for a glacial kettle. I chose that simply because it was an isolated, "point like" symbol rather than one where we'd need to specify additional properties such as orientation or size.

While here look at the other columns in the table. You could if you wanted enter other information or, if it had been present in your original shapefile, you could have told the import code how to import a column from your original attribute table into this "USGS Standard" table. Finally, to be sure the map has been redrawn with the new symbols, from the main menu select `View / Refresh`.

7) **Saving images of the resultant maps.** First, right click on `Contacts` in the `Table of Contents` panel and choose `Zoom to Layer`. In that `Table of Contents` panel turn off the display of the underlying map so you can see what features are present in the `GeologicMap`. You should see most of the contacts drawn with solid lines, but the western one drawn with the dotted lines appropriate for an inferred contact. You should see the volcanic fissure drawn with the standard red line, and the "Glacial Kettles" drawn with blue stars. Save an image version of this with `File / Export Map` and navigate to the `exercise_09` folder and choose name `exercise_09_features_lastname_firstname.png` and select the `png` output format. Next turn the basemap display back on and export it again but this time as `exercise_09_base_lastname_firstname.png`. Mail the two files to me.

Finally use `File / Save as` to save the map as `exercise_09.mxd`, in case you want to return to this point. Note the data itself is also saved within `exercise_09.gdb`. The `mxd` file just controls what should be displayed.

Additional steps not covered here:

8) Additional GMT tools not covered here. The GMT has two additional tools we have not covered here. Some symbols, for example those for dip, lineation, or fluvial flow, need to be oriented properly on the map and may also have labels which need to be oriented properly. Tools 5 and 6 in the GMT let you create symbols rotated as desired, usually based on columns within your attribute table which specify properties such as strike and dip.

9) Additional USGS NCGMP09 and standard map components. The map we have created so far shows contacts, but doesn't have the **`MapUnitPolys`** feature added yet. Those would be the polygons, bounded by the contacts and faults, which actually define the exposed units. Those in principle should be created FROM the contacts and faults list, as those contacts and faults do form the boundaries of all the possible units. The ESRI GMT unfortunately does not contain tools to generate those from the contacts and faults. As mentioned in the introduction, the USGS has released its own Toolbox for ArcGIS. It can in fact create the **`MapUnitPolys`** from the **`Contacts`** features, but it requires additional information in the database. I'll demonstrate that next Friday.

The USGS Toolbox has other tools, for example it can take a gdb and convert it into shapefiles which more open software can read. It can also check the "topology" of your resulting files, for example making sure that no **`MapUnitPolys`** overlap, but that every point is covered by some **`MapUnitPoly`**.

Finally, the NCGMP09 standard defines other tables which can and in some cases should be present, the most useful of which is the **`DescriptonOfMapUnits`** table, and the USGS Toolbox has some tools for helping to generate it. The ESRI GMT template does generate this table, although it will initially be empty. This table is the equivalent of the Key for your map. Open it and look at the columns. There would eventually be a line for every **`MapUnitPolys`** polygon, along with columns which gave the name of the unit occupying that polygon (both in full and abbreviated form) and other information such as the colors used to fill that polygon.