Field Geology I   **Digitizing a Geologic Map**   October 17, 2005
Lab Exercise 3

Introduction

From Lab 2 we learned to download, manage and create some standard GIS data. We will now apply that technique to making digital geologic maps. I will give you a scanned portion of a geologic map (a raster) and you will go through a sequence of steps to create an attributed GIS version of the scanned map. You will create point features like strike and dip data, linear features like faults and polygon features like geologic units. As this process is not a simple or a speedy task, we will dedicate two lab sessions (and some of structural geology's lab-time!) to completing the project. And just in case you were concerned, this is not a esoteric exercise. You will seldom examine a geologic map as closely than when you digitize it. You will learn about different kinds of faults and contacts as well as the varying levels of certainty with which the geologist identified them. You will also get practice identifying different structural symbols. This will be a great exercise for both learning GIS technique and geologic map interpretation. As well, when we are in the field, you will have to do this EVERY NIGHT and the last thing you'll want is to be missing out on the campfire because you are in the computer tent stumbling through these techniques. Honing your skills now will pay off in the desert!

Materials

GIS-ready computer   Internet connection   Scanned Geologic Map
Some basemap data to build your GIS on   Some musical entertainment?

The Workflow
1. View your .mxd file, examine the available layers.
2. Load and georeference the scanned geologic map.
3. Create and attribute blank shapefiles for storing your geologic data in.
4. Digitize and attribute the faults
5. Digitize and attribute the contacts
6. Turn your lines into polygons
7. Make sure that all your geologic units are represented by the polygons
8. Attribute your polygons
9. Manually measure the strike or trend of point data
10. Digitize and attribute the point data
11. Prepare symbology for each of your layers so that your map looks beautiful!
12. Prepare the map for printing using the Layout View.

1. Viewing the basemap data

Open ArcMap and browse to your directory on Langtang. you will find a folder there called Lab03. Open the ArcMap document 'Lab03_DevilsFence.mxd.' You will see that there are already files in the table of contents. These I downloaded and reprojected into UTM: NAD 27, zone 12. Turn on the different layers of your basemap and make yourself familiar with them. These datasets are not stored in your personal folder, but rather at a single site on Langtang. Modifications you make to the way these files are displayed are stored only in you .mxd file and have no impact on the static parent file.

- Two 1:24,000 Digital Raster Graphics (DRGs) USGS scanned topo sheets.
    - o I have made the white areas on the map transparent so you can see the DEM below.
- a roadmap of the region (this is not really that useful)
    - o this is the same 'BTS roads' data that we used in Lab 2
- a DEM of the region (Devils Fence, Montana. Near Butte and Boulder, MT)
    - o note that the transparency is set to 30% so you can see the underlying slopemap
- a Slopemap of the region
    - o note that the slopemap is under (lower in the legend) the semi-transparent DEM

2. Loading and georeferencing the geologic map

a) Go the add data button on the top toolbar and look in your Lab03 folder for the file called 'devils_geo_raw_scan.jpg.' This is the un-georeferenced geologic map. If you make the mistake of double-clicking the file, ArcMap will display the three color bands that the .jpg is composed of (red green blue). Go back up on directory and single-click on the main .jpg file and then click the 'open' button.

b) ArcMap will ask you if you want to build pyramids. Say YES. Building pyramids will create different resolution views of the .jpg file so that when you are zoomed out, you are looking as a low resolution version of the map. As you zoom in, finer and finer resolution data will be displayed. This feature makes the viewing and manipulation of raster data way more efficient.

c) After the pyramids are built, there will be a warning about your layer "lacking spatial reference information." That's just fine as this image is nothing more than a scan. It has no information about where ArcMap should display the geologic map. It will be your job to give the image it's appropriate position in the world. This is called 'Georeferencing.' For now, ArcMap has sent your scanned image down to UTM coordinates around (0,0). That's on the equator somewhere south of Baja California. Let's fix that.

d) We will use an imprecise but efficient method called 'rubber-sheeting' to do this. In essence we will select a number of points visible in the geologic map and match them to the same localities on the DRG maps. Start the process by right-clicking on a blank gray area near the toolbars at the top of the ArcMap window. Open the toolbar by selecting 'Georeferencing' from the list.

e) Now right click on one of the DRGs in the Table of Contents and select 'Zoom to Layer.' Now use the zooming tools to make both the DRGs visible and centered in your window. Now change the scale of your may to 1:50:000. Notice the flat area where there are not many contours slightly right of center. It is called Sagebrush Park and will be visible as the grey blob on the scanned geologic map. At this point, make sure that the geologic map is selected in the 'Layer' pull-down menu of the Georeferencing toolbar. Now make sure that the scanned map is turned on in the Table of Contents (TOC) and then, from the Georeferencing pull-down menu, select 'Fit to Display.' This will position the scanned geologic map to fit within the window you are viewing.

f) Take some time alternating back and forth between the two maps (turning the scanned map layer on and off) until you can recognize the same geographic features on the two maps. Note that the contour interval and the road network is different between the two maps. One thing that has not changed is the 'township and range' grid present on both maps. Once you find one intersection on this grid that you can recognize in both maps are you are ready to begin georeferencing. Begin by zooming into the point on the geologic map.

g) In the Georeferencing toolbar, click to icon that looks like a blue and a red plus connected by a line. This is the 'Add control points' tool. Click on the control point in the scanned image. Now zoom out and turn off the scan layer so that you can find the same point on the DRG. Zoom in on the point in the DRG. Click the 'add control point' tool again. Connected to the cursor, you should see a line linking off the screen to your first click. Move the cursor to the matched point on the DRG and click once. Once you turn on the geologic map in the TOC, you should see that it has been shifted so that the two clicks are now over one-another.

h) Repeat the procedure of clicking a point on the geologic map and then matching it on the DRG with a subsequent click until there are 5-6 Control Points well distributed over the geologic map. At this point the maps should be very well aligned. If they are not, click the 'view link table' icon just right of the 'add control point' icon. This will bring up a table showing your matched points and in the far right column the Residual Error at that point. If one of your points is not well matched, you will see large values here. Aim to have all residuals around 5, but not much more than 10. If there is a bad one, click on that row and hit delete. That pair of matched points will disappear and you can add another pair to replace it.

i) Once you are happy with your georeferencing, select 'update georeferencing' from the Georeferencing pull-down menu. This will write a 'world file' (.jgw) in the same directory as your .jpg. This file tells ArcMap the spatial position of your scanned file so it now has an appropriate position in space!

3. Creating blank, attributed shapefiles for geologic data.

a) Open ArcCatalog, and as you did in Lab02, create some new shapefiles. You learned this technique in the last lab so I won't describe the process again here. Save them into your personal directory in the Lab03 directory. Make sure that you assign the correct projection to each of the shapefiles (projected, UTM, NAD 27, Zone 12). Once you do the first one your can just use the 'import' button and select the previous field that you already defined the projection for.

Type	Name
Line	Devils_contacts
Line	Devils_faults
Polygon	Devils_geo_polys

b) Open ArcMap, open the attribute tables and add the following attributes to those shapefiles:

Shapefile	Attribute 1	Attribute 2
Devils_contacts	Certainty (text, 10 char)	
Devils_faults	Type_cert (text, 20 char)	
Devils_geo_polys	Unit_code (text, 20 char)	

4. Digitizing faults.

a) You will begin digitizing by tracing all the faults on the map. Different segments of the same fault are drawn with varying levels of certainty. We must create unique lines for each of these segments, but we must also make sure that the tips of adjacent segments share the same nodes or points so as not to leave gaps in the line. This is FUNDAMENTAL to our later success in creating polygons for geologic units. To assure that our line segment tips are perfectly matched, we will use the 'node snapping' function in the Editor toolbar.

b) Begin by zooming to some part of the map where there is a fault to trace. Then from the Editor toolbar, select 'Start Editing.' Next, select the appropriate directory where your fault shapefile is stored. Then, under the editor menu, select 'Snapping.' In the Snapping Environment window that opens, make sure to check each of the three the boxes for the shapefiles you created. Snapping will allow your editing cursor to pseudo-magnetically snap to a vertex, an edge or an end of some other editable feature. Once these are turned on, close the snapping window.

c) Make sure in the editor toolbar to set the target to your faults shapefile. Click the pencil tool and begin clicking out the line as we did in lab02. When the fault you are tracing changes certainty (changing from a solid to a dashed or dotted line), double-click and terminate that line segment.

d) Continue digitizing the same fault from where you stopped by allowing the cursor to snap to the end vertex on the last segment. Click once and continue tracing out the fault, terminating and initiating segments as the fault-certainty changes. If the fault splays (or divides off into multiple strands) you can end your segment and start a new suite of diverging faults from that last node.

e) You can attribute line segments as you go or wait until you have completed tracing ALL the faults. The easiest coding of the certainty is (1=certain, 2=partially exposed, 3=concealed, see legend)

e) If you decide to wait on attributing your faults, I recommend using the following method: Make the faults as visible as possible (bright, bold lines). Open the attribute table for the faults. Click the 'selected' button next to the word 'show'. Start editing, setting the target to faults. Click on each fault with the arrow editing tool. Your selected fault will appear in the Attribute Table window. Write in the correct certainty. Once you have one of each type, you can set the line-properties do display the attributed faults appropriately (Lab3, part 11b).
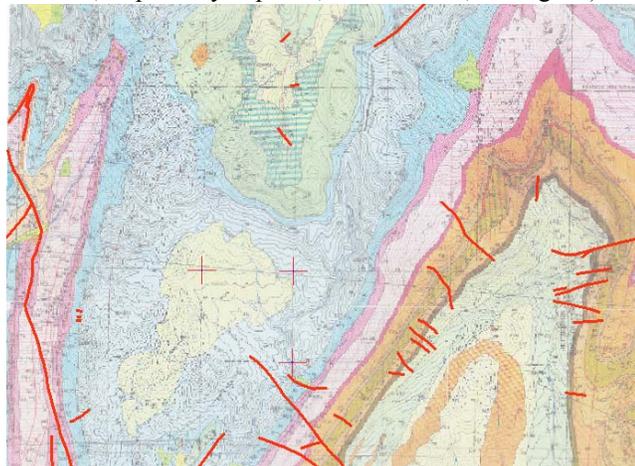
*here is a map with the faults complete and some georeferencing points visible just below and left of center.

5. Digitizing contacts.

a) You will now digitize all the contacts between all geologic units on the map. This is no more than glorified line-clicking but it is a fundamental skill in making digital geologic maps. Start your project by creating a bounding box that encircles the whole map. In the editor, change the target to 'devils_contacts,' then use the pencil tool to click your way around the edge of the map, but ending the line (with a double click) short of your initial point. Use the snapping tool (it was turned on when you were doing the faults), to confidently close your bounding box. We have to do it this way because you cannot snap-to a line that you are in the process of creating. The closure of your bounding box is essential.

b) Now lets begin with the contacts. This *is* tedious work and here are a few words of advice:
   a. Lithologic units must be bound on all sides by either faults, edges of the bounding box or contact line segments. Most units will have multiple line segments bounding them. To assure that your unit boundary is complete, ALWAYS start and end your line segments by snapping to an existing line segment. Never create a contact that is dangling in space.
   b. Do not worry about digitizing every line perfectly. This is a lab exercise, not a professional map. Just make sure that each line gets represented well.
   c. Like with faults, contacts have variable exposure or certainty (observed, partially exposed, obscured). You will create different line segments to demonstrate how this certainty changes, BUT, do *not* try to capture all the changes in certainty or you will never finish the lab. Look for general trends…e.g., "along this section, the contact is mostly 'observed'," while, "over here the contact is mostly 'obscured." Remember, you will have to specify the certainty for each contact that you draw. I would recommend dividing up the 'certainty' attribute into something simple. For example, solid lines are observed contacts (written as '1' in the database), dashed lines are inferred contacts ('2') and short-dashed or dotted contacts are poorly constrained ('3'). You can do this anyway you please, but make sure it is clear and efficient for you and the map viewer. The legend from the Devils Fence map is attached at the end of this document for reference.
   d. For sanity's sake, it may help to listen to music once you have the technique wired.

Here is an example of a map with contacts and faults complete
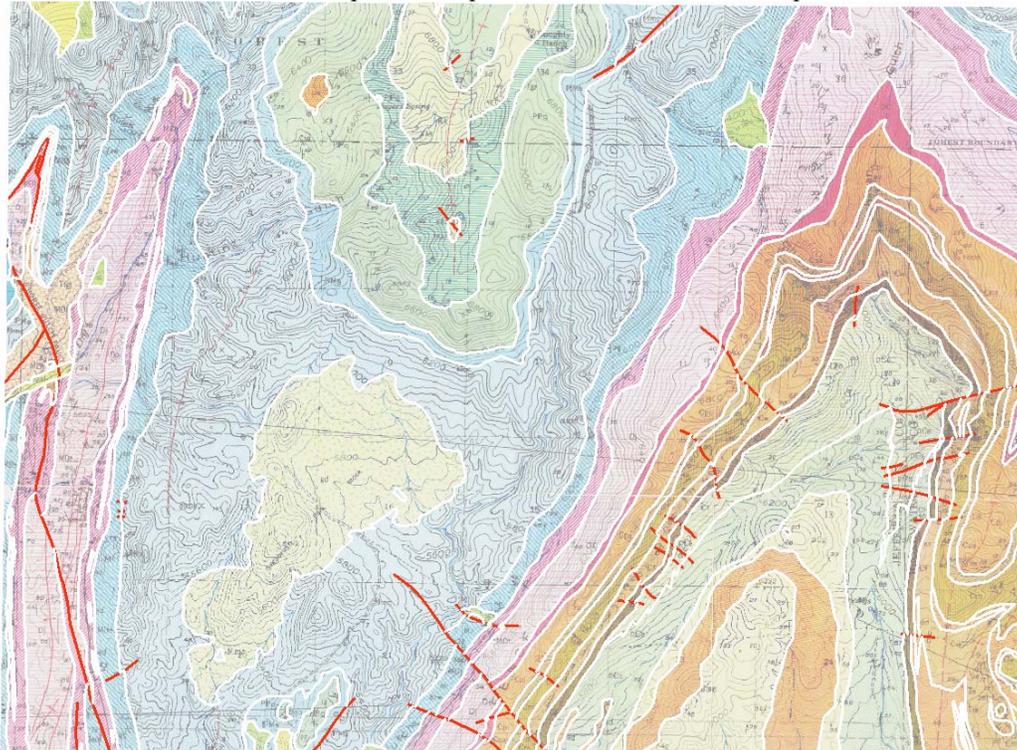
6-8. Transforming your line data into lithology polygons and adding the unit_code.

a) Now that you have line data that bounds polygons, you are ready to use the Topology toolbar. It is activated the same way the other toolbars are. Right click on the gray area at the top of the ArcMap window. Here is the sequence of steps:

    a. Turn off ALL layers except for the faults, the contacts and the polygons. This will help you see what you are doing.

    b. Start editing, then use the arrow tool in the editor toolbar to trace a box around and select all the displayed line data. This is the data you will use to make polygons.

    c. Make sure that in the editor toolbar, the target is the polygon shapefile.

    d. Click the second icon on the Topology toolbar, 'Construct Features.' This will bring up a window asking about tolerance…leave it alone and just say ok.

    e. The process will run and create a group of polygons.

    f. Click the editor arrow in a blank spot and deselect the lines. Now use the TOC to switch the lines on and off. Confirm that each polygon is appropriately unique and that each contact was used as an edge for a polygon. When I first did this, I found a few errors in my work. Find the errors now, *before* you add attributes to the polygons.

        i. If you find errors, (unbounded polygons), follow these steps:

            1. In the TOC, turn off all the layers except the polygons.

            2. With the editor running, use the editor arrow tool to draw a box around all of your freshly created polygons. Hit 'Delete.'

            3. Change the target in the editor to the contacts shapefile. Double click with the arrow tool the offending line segment. Grab the point that you need to snap to another line and make it so.

            4. Now that you have fixed all your dangling, unsnapped lines, save your edits and repeat the process outlined above starting at (a.)

    g. Now that you have good looking polygons, you will need to attribute each one. At the end of this document, there is a legend from the geologic map that shows the unit_codes (the short abbreviated name written on the colored box or on the unit in the geologic map). The name, age and character of the unit is also stated. For now, just write the short unit_code for each polygon. The easiest way to do this is just to open the attribute table and click on the far left end of the row and see which polygon is selected. If the polygon layer is made very transparent, then you will be able to see which unit is below. We will later add all the other lithologic information in an efficient manner.
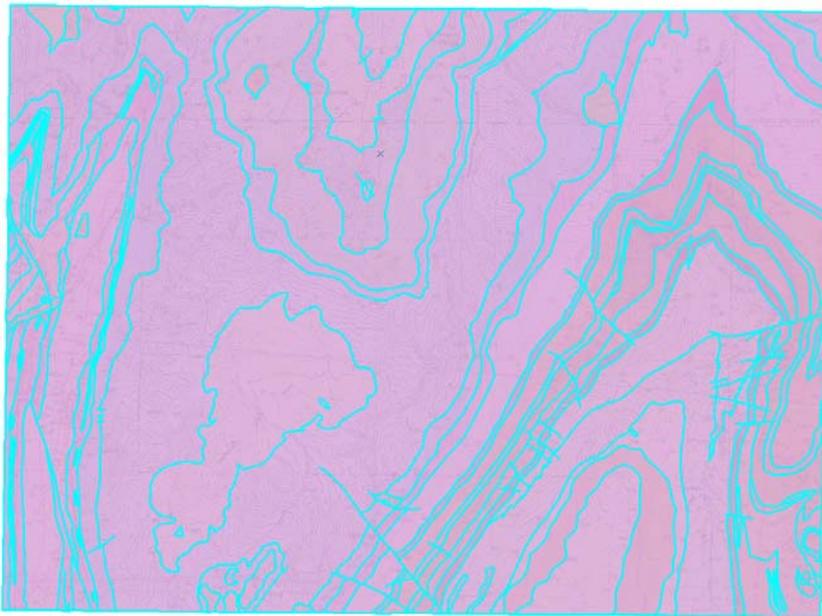
This is the map with all lines selected and unattributed polygons.

Courtesy of ESRI. Used with permission.

9-10. Manually measuring and the digitizing the point data

a) This will take some time but you will get really good at using your C-Thru ruler. The best way to do this task is to share the workload. I have divided up the map into areas so that we are each responsible for part of the work. On the table in the GIS lab you will find a copy of the map with lines dividing it up into regions. Find your region and do that work. There is a point data shapefile in the Lab03_data directory on Langtang. In turn, we will each open and add data to it. Only one person can add data at a time (like Piggy and the conch). We will have an early deadline for this task so that we can all begin working with the data ASAP. Here are the steps:

    a. Use your C-Thru ruler to measure the azimuth of each structural point feature you can find in your map region. Write this number on the paper map sheet and circle the point.

    b. Add the devils_points_group shapefile to your map and begin editing it. To add a point, make the scanned geologic map visible and click on the center of each symbol (the intersection of the strike and dip). Use the key in the back to determine what each symbol is. Use the following terminology in the type column of the attribute table: Strike/Dip (sd), Strike/Dip of a contact (sdc), Strike/Dip of a fault plane (sdf), Strike/Dip of an overturned contact (sdoc), Vertical bedding (vb). These different terms for the structural data will allow unique symbols for each.

    c. When you are finished, stop editing and pass the map to the next person. The idea of writing the data down is that if the file is corrupted or is lost somehow we have a paper version to work from and do not have to do all the measurements over again.

11. Prepare symbology for each of your point, line and polygon layers.

Now we get to make our maps look beautiful. We will display the faults, contacts, point structural data and polygons in such a manner that the data is not only clear for reading but looks good too.

a) **Fault** Line symbology

    a. We want the faults to be distinct from the contacts, we don't know the sense of movement on these features so we cannot use structural symbology for thrust or normal faults. Instead, we will display faults according to their certainty. To make them stand out from the unit contacts, we draw them in red and with a line twice as thick. To do this, we open the Properties/Symbology tab and select 'Categories: Unique values'.
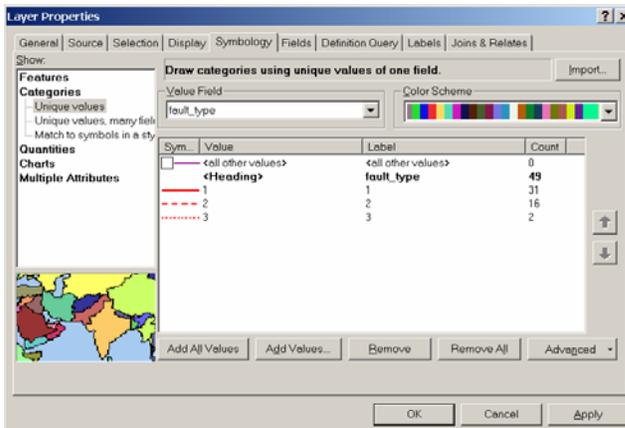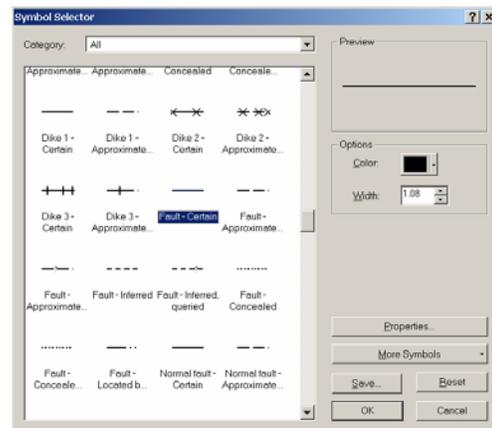
Courtesy of ESRI. Used with permission.   Courtesy of ESRI. Used with permission.

    b. Under the Value Field pull-down menu, select the attribute that describes the fault's certainty. Click the 'add all values' button. You should only have line segments for the attributes you created. There should be no counts for values of 'zero' or for '(all other values).'

       i. If there are then that means you have faults that are not attributed or that they are attributed incorrectly. If that is the case, go back to the main window, open the attribute table for the faults layer and right click on the heading that you used for the fault certainty. Arrange the attribute values by 'sort ascending' and scroll through to find the errors. Start editing and change the values. Save your edits.

c. Now that all your faults are attributed correctly, go ahead and set the way you want your lines to display. Open Properties/Symbology and click on the line beside the value field. This will bring up the 'Symbol Selector' window. Make sure that the Geology 24K symbols have been selected under 'more symbols' button. If you single-click on one of the lines on the left and start typing 'fault' it will automatically scroll down to the faults. I decided to use 'Fault - Certain' for '1,' 'Fault - Inferred' for '2' and 'Fault - Concealed' for '3.' I left the line width at 1.08 but changed the color from black to red.
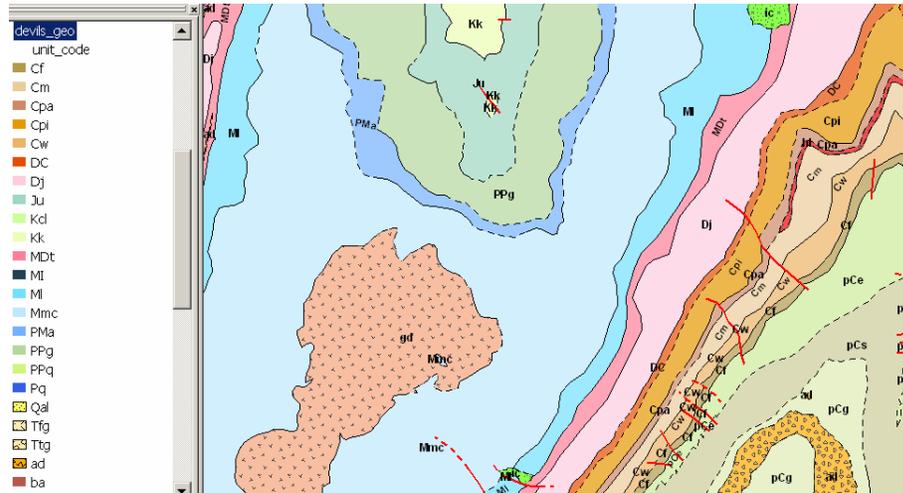
b) **Polygon** Lithologic Symbology

a. Use the properties/symbology tab again to assign unique colors to each unit_code. Remember to add all values or you will not see each of your units. Use the TOC to change the colors for each of the units on the map. Single click on the TOC box showing the polygon color to open the 'Symbol Selector' window. In this window, click 'More Symbols' and select 'Geology24K.' This will add more colors and patterns to your palette. Try to follow the color scheme used on the paper map. The use of the line-pattern within different units is valuable if the image is duplicated in black and white. We have a color printer and will not worry too much about texture. If you decide to use texture, scroll down through the predefined colors to find the black and white geologic patterns. For fills that are not lines (like 317 Igneous), you can change the color of the symbol *and* the background color. For the fills that are just lines (like 661 Flint Clay), it is more difficult to change the background (give it a try if you wish). To change to background color for a non-line geologic pattern click the symbol once in the main pattern viewing window, then click on the 'Preview' window for that pattern. This will take you to the 'Symbol Property Editor,' where you will see a selection for the background color of the pattern. This way you can have a limestone polygon fill pattern and a particular color. Using properties/labels, turn labels on, using the unit_code field. Adjust the 'placement properties' until the labels look right.
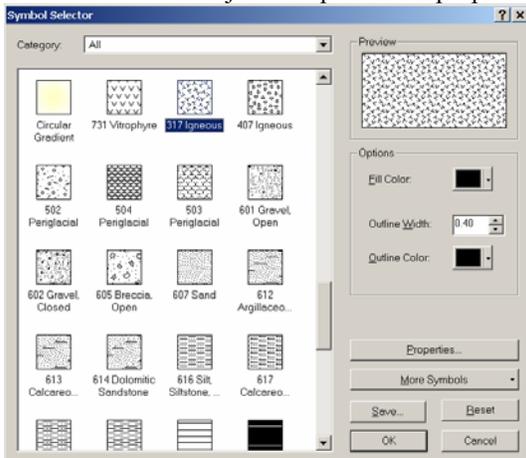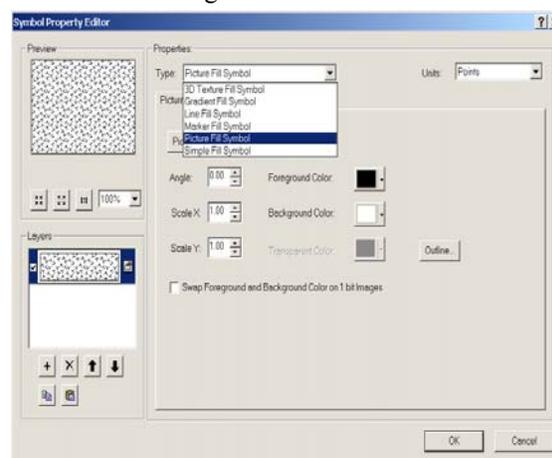
    c) **Contact** Line Shapefile
- a. The procedure for the contacts is exactly the same as for the faults. In the Symbol Selector window, instead of typing 'fault,' type 'contact' and again I used 'certain' 'inferred' and 'concealed.' I left the lines black and went with the thinner line (0.43).
- b. When you add all values in the categories window, don't forget to check for line segments with labels that don't match up with your intended attributes.

    d) **Structure** Point Shapefile
- a. For this one you will use the Properties/Symbology/Unique values window and choose chose the Value Field for 'structure type.' 'Add all values', and select the proper symbology from the Symbol Selector window. Type 'inclined' for the strike and dip (s/d) symbol, 'photo' for the s/d of a contact. I'll leave it to you to find the overturned bed, the vertical bed and other structural point symbols.
- b. Now in the Properties/Symbology window, click the 'advanced' tab and select 'rotation'. Select Azimuth from the pull-down menu. Make sure 'geographic' is selected. All your s/d data should now be rotated correctly. Compare it to the scanned map!
- c. In order to have the dip value labels display appropriately next to symbols, we will create a new column in the structural_point_data attribute shapefile. To do this, stop all editing, open the attribute properties for the structural point data and use the options button to create a new column. Name it labelloc and set it as short-integer. Next right click in on header for the new column and select 'calculate values.' In the work area you will see that it already says 'labelloc ='. Double click on the field '[Azimuth]' to add it to the equation then add a '+' and type 90. This math will add 90 degrees to all the azimuth values and place that product in the labelloc column.
- d. Now that we have good locations for the labels, go to the Properties/Labels tab and click the box to 'label all features'. For the label, select the 'text string' dip_plunge. Next click on 'placement properties' and change the 'point settings' to 'Place label at an angle specified by a field.' Then click the 'Rotation Field…' button and select 'label loc', geographic and do not check the box to 'place label perpendicular to the angle.' This should now display your dip values in appropriate locations.

12. Prepare the Map for Printing Using 'Layout View'.

Layout view is how we configure our map sheet for printing. There you add a legend, a title, a north arrow a scale and any other necessary notes. Though Layout View works just like the Data View window, it is slower and more clunky. To speed things up, I have written instructions to maximize processing power.

    a) Preparing to go to Layout view
- a. Make sure the symbology and display properties (transparency, etc.) of your layers are set to look the way your want them to. Though you can change things in layout view, it is slow to redraw. The following layers should be used in your final map:
  - i. the geologic polygons with units labeled
  - ii. the faults and contacts
  - iii. the structural data with the dips labeled
  - iv. the Shaded Relief of the region (final_hlshd)
  - v. the 2 DRG's (make sure all large regions are set to null (there is one region in the northern part of the map). To do this, use the info tool to find the numeric value of the particular color. Then click on that color in the TOC. On the second tab in the new color chooser window, select the color as null.
- b. Use the zoom tool to zoom as close as possible to extent of your geologic map.
- c. Go to file, page and print set-up. Select the printer 'Langtang/raindrops.' Under paper size, select Tabloid and click the landscape button. Click ok and close the window.
- d. Now, turn OFF all the layers except the contacts. They will be your layout guide.

    b) Layout View
- a. Use the pull-down menus at the top to select View/Layout View.
- b. Allow you map to fully draw. It should be enclosed in a selected box. Position and change the size of the box on the paper so that you have room to place a legend and other information. Use the ruler surrounding the work area to make sure that the paper is the

right size (11'' x 17''). If your map is not displayed correctly in the selected box, use the standard zooming tools that you use in Data View to get the map in the right position.

c. Around the edge of the map box, add the following items. They in the 'Insert' menu
   i. scale bar
   ii. north arrow
   iii. legend: I'd include: point data, contacts, faults, polygons
   iv. Text: the scale (on the top toolbar), projection info, data sources, your name
   v. Title (no need to add one! Use the Title at the top of the legend for this!)

d. Once it looks good, turn on all the layers that you want to show (I think the DRG and shaded relief look good when included…your choice). Select file/print and make sure the image looks right on the page (nothing over the edge), and select print! It will go to the 9th floor copier across the hall from the Education office. **You are done!**

Qal

Alluvium

(Recent — QUATERNARY)

Tfg

Fan gravel and pediment gravel
*Unconsolidated or weakly consolidated fan deposits
and gravel veneer on pediments*

(Pliocene (?))

Ttg

Tuff and gravel
*Light-colored rhyolitic tuff with a few interbeds of
stream gravel*

(Miocene (?) — TERTIARY)

UNCONFORMITY

Kcm
Kcl

Colorado formation
*Upper black shale unit not mapped. Middle sili-
ceous mudstone and sandstone unit, Kcm, is inter-
tongued marine and nonmarine sandstone, mud-
stone, and siliceous mudstone, in part of volcanic
origin. Lower black shale unit, Kcl, is a basal
tan-weathering quartz sandstone, drab and olive-
gray blocky siltstone, very dark gray to black shale,
and an upper dark-gray carbonaceous, limonitic
speckled to mottled sandstone*

(Lower and Upper Cretaceous — CRETACEOUS)

EROSIONAL UNCONFORMITY

Kk

Kootenai formation
*Comprises three units. Upper unit is 10 to 25 ft of
gastropod-bearing limestone overlain by a few
feet to 80 ft of drab mudstone; middle unit is red
and green mudstone and shale with concretions
and lentils of limestone; lower unit is crossbedded
"pepper-and-salt" sandstone and interbedded shale
and mudstone*

(Lower Cretaceous)

Ju

Morrison and Swift formations
*Morrison formation: varicolored nonmarine shale,
mudstone, and siltstone, with thin beds of limestone
and sandstone, and near the top a unit of black
shale. Upper hundred feet locally contains thick,
lenticular "pepper-and-salt" sandstone and grades
into overlying Kootenai formation
Swift formation: grayish-brown punky calcareous
marine sandstone, 20 to 35 ft thick, with a basal
chert-pebble conglomerate*

(Upper Jurassic — JURASSIC)

EROSIONAL UNCONFORMITY

Pp / **PPq**

Phosphoria formation
*Brown and gray chert and sandstone, in part phos-
phatic; may locally contain one or two thin beds of
phosphate rock, Pp. In places mapped with the
Quadrant formation, PPq*

(PERMIAN)

Pq

Quadrant formation
*Light-colored quartzitic sandstone and interbedded
light-gray sugary-textured sandy dolomite*

(PENNSYLVANIAN)

PMa

Amsden formation
*Red to grayish-red mudstone, shale, and subordinate
amounts of carbonate rock with interbeds of gray,
brown, or yellow argillaceous sandstone in upper
and lower parts; middle part of medium- to dark-
gray thick-bedded dolomite*

EROSIONAL UNCONFORMITY(?)

br / **Mmc**

Mission Canyon limestone
*Medium-gray to light-gray medium-grained thickly
and indistinctly bedded limestone, with a few thin
siliceous layers in lower 200 ft and sparse gray
chert nodules and lentils in upper half. A breccia
unit, br, about 200 ft below top of formation has
been mapped locally*

(Madison group — MISSISSIPPIAN — CARBONIFEROUS)

Ml

Lodgepole limestone
*Upper part of medium-gray fine- to medium-grained
limestone in distinct beds as much as 3 ft thick
alternating with zones of much thinner beds con-
taining rare mudstone partings; lower part of
medium-gray limestone in beds 1 in. to 1 ft thick
with partings and interbeds of yellow to red cal-
careous mudstone; grades into Mission Canyon
limestone through a 150- to 200-ft zone*

MDt

Three Forks shale
*Predominantly greenish-gray and brown shale with
subordinate amounts of interbedded sandstone and
limestone. Dolomitic siltstone at top. Locally
a 10- to 25-ft fossiliferous limestone unit, li, has
been mapped*

(Upper Devonian and Mississippian — DEVONIAN AND MISSISSIPPIAN)

Dj

Jefferson dolomite
*Dark-gray granular-weathering fetid well-bedded
dolomite with subordinate amounts of dark-gray
limestone and light-gray dolomite*

(Upper Devonian — DEVONIAN)

EROSIONAL — — — UNCONFORMITY

DC

Maywood and Red Lion formations undifferentiated,
*Varicolored, generally in shades of red and yellowish-
brown, argillaceous, dolomitic, and calcareous
rocks; poorly exposed*

(Upper Cambrian and Upper Devonian)

Cpi

Pilgrim dolomite
*Comprises three units. Upper unit is light-gray
thick-bedded dolomite commonly mottled medium-
gray near base. Middle unit is light- to medium-
gray crystalline limestone irregularly ribboned
with yellowish-gray silty dolomite. Lower unit is
mottled light- and dark-gray dolomite with sparse
intraformational conglomerate; locally, basal 8
to 10 ft is bluish-gray limestone*

(Upper Cambrian)

Cpa

Park shale
*Olive-gray, gray, and light-brown shale with minor
amounts of argillaceous limestone, siltstone, and
sandstone*

(Middle Cambrian)

Cm

Meagher limestone
*Comprises three units. Upper and lower units are
medium-gray limestone irregularly ribboned or
mottled with yellowish-orange, yellowish-brown,
and yellowish-gray dolomite. Middle unit is
thickly and indistinctly bedded medium-gray lime-
stone, commonly with oolitic beds*

Cw

Wolsey shale
*Upper half is interbedded gray argillaceous limestone
and greenish- and yellowish-gray calcareous mud-
stone and shale. Lower half is greenish-gray and
drab shale with some interbeds of sandstone and
limestone; many beds are micaceous, some are
glauconitic*

(Middle Cambrian — CAMBRIAN)

Cf

Flathead quartzite
*White to pale shades of gray, pink, brown, and purple
medium- to thick-bedded homogenous even-grained
quartz sandstone; most beds are cemented to
vitreous quartzite; thin, discontinuous sparse
pebble zones in lower part; crossbedding common
Cross*

UNCONFORMITY

pCe

Empire shale
*Gray, greenish-gray, and brown, siliceous mudstone
or argillite with interbeds of quartzite sandstone
and shale. Intertongues with Spokane shale*

pCs

Spokane shale
*Grayish-red mudstone, shale, and sandstone, with a
few thin beds of limestone near base*

pCg

Greyson shale
*Gray and brown mudstone or shale alternating with
sandstone or quartzite. Base not exposed. Grades
into Spokane shale*

(Upper Precambrian — Belt series — PRECAMBRIAN)

INTRUSIVE ROCKS

YOUNGER INTRUSIVE ROCKS

gd

Granodiorite and
quartz diorite
*In Sagebrush Park
stock*

ic

Composite or hybrid
intrusives
*Small plutons contain-
ing diverse and un-
usual rocks includ-
ing olivine-rich and
quartz-rich types*

(Lower Tertiary (?) — TERTIARY(?))

OLDER INTRUSIVE ROCKS

ba

Basalt and related
rocks
*Dark-gray to greenish-
black fine- to medi-
um-grained rocks,
mainly as sills*

adf

Andesite porphyry,
diorite porphyry, and
related rocks
*Greenish-gray to dark-
gray porphyritic
rocks with pheno-
crysts of plagioclase
and hornblende or
augite, mainly as
sills*

hl

Hornblende lampro-
phyre
*Very fine grained gray
rock with conspicu-
ous hornblende phe-
nocrysts*

(Upper Cretaceous — CRETACEOUS)

aasdf

Devils Fence Geologic Map

type

Strike and Dip
Strike and Dip on a contact
Strike and Dip of Fault Plane
Strike/Dip of Overturned Contact
Vertical Bedding

Contacts

certainty
—— Certain
– – – Approximate
.... Inferred

Faults

fault_type
—— Certain
–·–·– Approximate
.... Inferred

Geologic Units

unit_code
Cf
Cm
Cpa
Cpi
Cw
DC
Dj
Ju
Kcl
Kk
MDt
Ml
Ml
Mmc
PMa
PPg
PPq
Pq
Qal
Tfg
Ttg
ad
ba
gd
hl
ic
pCe
pCg
pCs
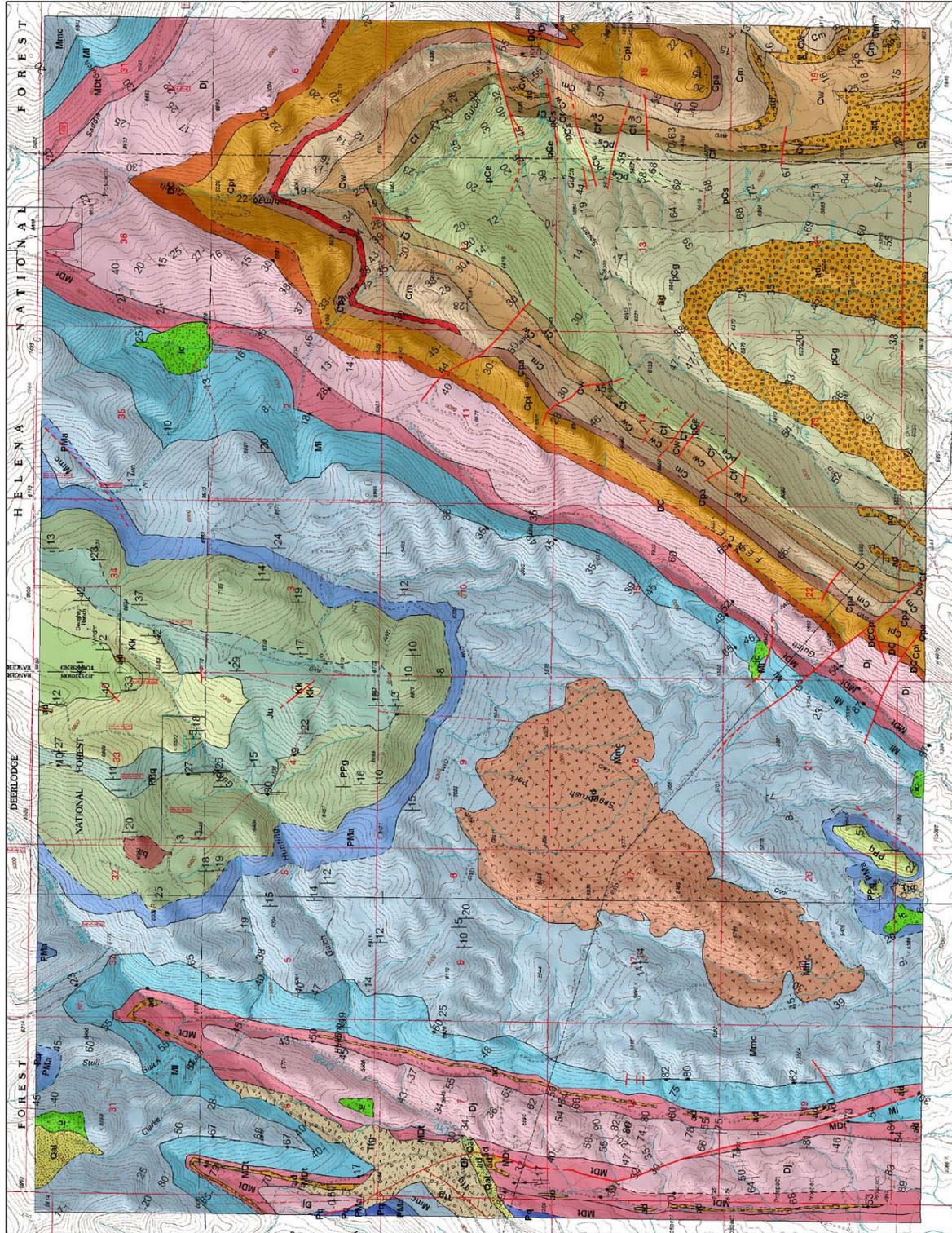
Map Scale: 1:35,000
Projection: Universal Transverse Mercator, Zone 14, NAD 27
Topographic Data: USGS DRG sheets and 10m DEM

Kilometers
0   0.5   1   2   3   4   5