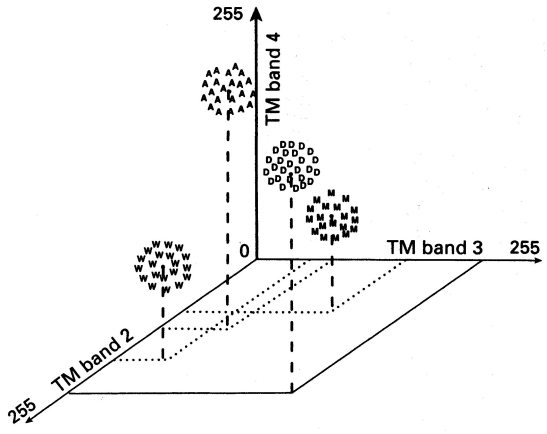
Remote Sensing 4113
Lab 7: Unsupervised Classification
March 21, 2018

Part I Introduction

Unsupervised classification is used to cluster pixels in a data set based on statistics only, without any user-defined training classes. Even so, the operator must specify certain parameters for the classification to produce good results. ENVI provides two options for unsupervised classification of multi-spectral data: "K-Means" and "ISODATA". Today we will begin with K-Means because it requires less user input – but for that reason it may provide less than optimum results.

Suppose we have N pixels of data, with B different spectral bands for each pixel. If this was a supervised classification scheme we might have ground-truth which told us the "correct" spectra for every different class. Each of those "know type" spectra would plot as a point in this B dimensional space. (If we had three bands we could plot band 1 as X, band 2 as Y, and band 3 as Z.) To classify an unknown pixel we would just compute the distance (in B dimensions) from that pixel to each of the known type of spectra and assign that pixel to the type to which it was closest. With an unsupervised classification scheme we don't know in advance the correct spectra of the different classes – we need to find that from the way the data is clustered.



B. Three-dimensional cluster diagram for classification.

Figure 8-32 Landsat data used to classify image of the Salton Sea and the Imperial Valley, California.

From Sabins: Remote Sensing

The K-Means classifier takes its name from the fact that it will divide the data into a specified number of classes (denoted by K) and take as the "correct" spectra the Mean (center point) of each class of points. However finding the Means will be an iterative process because initially we can't know which pixels really belong to which classes.

To begin, the program starts with a random guess for the "center" of each of the K clusters, then iterates as follows. It assigned each pixel to whichever cluster is closest, then once it has assigned all the pixels it recomputes the center of each cluster from the mean of all of the pixels currently in each cluster. Once it has finished it begins a new iteration, reassigning pixels and recomputing means. It keeps track of how many pixels are reassigned to a new cluster during an iteration, and also how much the cluster centers move. If the number reassigned is above some specified threshold or a cluster center moves by more than a specified amount then the iteration repeats. If not the classification is assumed to have "converged". In ENVI only the number-of-pixels test is used to check convergence. ENVI does also offer one final option, related to the size of clusters. If pixels are beyond a certain distance from a cluster center they can be left unassigned – however we will not use those limits. The parameters we therefore need to specify are:

1) which bands to use in the classification,
2) how many classes (K) to use,
3a) the maximum percent of pixels which can be reassigned and
3b) the maximum number of iterations to allow before forcing the process to stop.

Because K-Means simply accepts the number of classes we request, over or underestimating the actual number of distinct classes present in the data can produce unwanted results – either splitting regions which should really be in the same class, or grouping together pixels which are clearly different. The simplest procedure (which we'll follow) is to repeat the classification using an increasing number of classes till one clearly has specified slightly too many classes, then use "post-classification tools" to combine the different classes which should not have been split. (Although we won't use ISODATA today because of its complexity, it has an advantage in that it can automatically combine or split classes.)

There are two serious failure modes with K-Means which requires some understanding of the mathematics to recognize. 1) It can get stuck at an "OK", but not ideal classification. 2)It can have trouble recognizing unusually shaped clusters.

Mathematics:

You can think of each pixel as forming a vector in a B dimensional space, where B is the number of bands used in the classification. For B=2 each pixel can be plotted in a 2-D plane – for B=3 each pixel can be plotted in a 3-dimensional space. The above figure from Sabins assumes B=3.

Each pixel in effect forms a vector in this B dimensional space, with components (i_1, i_2, i_3, ... i_B). The cluster center (or mean) is also specified by a vector: (c_1, c_2, c_3, ... c_B). In this B dimensional space the distance of each pixel from the cluster center is just

$$\text{Sqrt}[\ (i_1-c_1)^2 + (i_2-c_2)^2 + (i_3-c_3)^2 + \ldots (i_B-c_B)^2].$$

The ultimate goal of K-Means is to find cluster centers and cluster assignments so as to minimize the sum of the squares of all of the distances of all pixels from their centers. Put another way, if C(x) is the center of the cluster to which a pixel is assigned then K-Means is trying to minimize

$$SS_{distance} = \sum [\ x - C(x)]^2$$

where the sum is over all pixels and all bands.

However iterative procedures can get stuck at a "local" minimum in this function. That is, no small readjustment of cluster centers and assignments is better – but there is no guarantee we have found the "global" minimum – that is the best of all possible choices. Restarting the system with a different initial guess and seeing if it produces a lower $SS_{distance}$ or a vastly different classification, can be used to see if you really have found that global minimum.

Because K-Means treats all the bands identically, K-Means works best when the clusters are approximately spherical in n-dimensional space, and have similar sizes (variances). However if one band varies by an amount much larger than the others, then the clusters will be elliptical and K-Means can get confused. Often it will try to break a long skinny cluster up into a string of smaller spherical ones. Ideally, before applying K-Means one should "rescale" the data so that clusters are spherical. However, even when the instrumental characteristics are similar for the different bands – different targets can produce elliptical clusters. For example desert scenes tend to have similar variances in the different bands, which tend to produce spherical clusters. However forest scenes tend to have much more variance in some bands then others, producing elliptical clusters. Therefore one has to examine carefully the results of the classification process, and also, if possible, examine the statistics of the input data. We'll ignore most of these complications in today's lab.

Part II: Specific Lab Instructions

We will use an ASTER image of Como Bluffs, just east of Medicine Bow. For this exercise we will use only the Visible, Near-IR, and Short-Wavelength IR data, but not the Thermal IR data. Because ENVI requires all pixels be the same size, the lower-resolution SWIR data have been resampled to have the same 15-m resolution as the VNIR data. Use the Como Bluffs image file contained in the **`lab_08_data.zip`** file on the class website. As usual, download it and unzip it to a directory you create within your local **`c:\tmp .`** dAgain, be sure to save any files you want to retain on your H: drive.

The steps below outline what you should do in this lab. Specific ENVI directions on how to use the K-Means classifier and also the required annotation functions is given on the last page. Refer to them and also the ENVI **`Help`** menu item for detailed instructions.

1) Open the image file and display bands 3,2,1 as an RGB image (in "Display 1"), to use as a guide. Note that ASTER does not have a Blue band, so these will be NIR, Red, and Green, creating an "IR Color Image." If possible enlarge the main display enough that the **`Scroll`** window disappears. It may take a couple tries to make this happen. Save a jpg copy of the full image for inclusion in your lab report.

2) Construct 3 different K-means classifications using the Aster sub-scene provided Start with 5 classes, checking your classification as explained in the instructions below. Include copies of the classification images in your report. You will probably decide that 5 is too few and your eye can distinguish regions which are mistakenly being classified the same. Describe in a few sentences what problems you see with the classification. You might want to include a jpg copy of the image showing just the problem classes, as well as the full classification one. Next try 10 classes, include a copy of it and discuss any improvements or remaining problems, finally try a version with 15 classes, and again include a copy and describe how well it works. In the end you will probably decide that 10 is the best number of classes to request. *(NOTE: When requesting 15 classes you may want to set the tolerance (threshold) to 5% pixels to keep the program from running for a long time. You can "cancel" a classification if it is taking too long.)*

3) Return to the 10 classes result obtained above for the following. Select it as the classification overlay for your Display #1 Color-Infrared Image. It will most likely have failed to split some regions your eye can differentiate, but will also have split some regions that are so highly intertwined you would like to see them combined. For example because K-Means uses intensities rather than band ratios it may break up a given unit into slopes facing towards the sun (brighter) and those facing away from the sun (darker), but a geologist would want them classified the same. We will use the "Post Classification Tools" to fix that. Go through your 10 classes and decide on at least two "excessive" classes you want to combine with other classes. Write the numbers of the classes down in your report. Use the "Post Classification" instructions given below to combine those classes. Save the result as a new file.

4) Using the computer instructions below produce a final classified image with a classification key in the corner. The class names should be more useful ones than "Class 1" ... for example: "Vegetation + Water", "Red Beds", Rock Unit #2", etc. Save that image including the classification key as a jpg file for inclusion in your report. Compare your results to the "Wyoming Geological Map" by Love and Christiansen (1985) included at the end of the lab. You may also want to compare it to the older but higher resolution map from Robert Dunbar's 1942 thesis, which is also attached. However when possible use the more modern names for the units, from Love and Christiansen. Discuss in a few paragraphs the success of the classification and any problems with confusion between different types of terrain. In particular, address the following points.

   Discuss the expected "apparent" color of red rocks in your "IR Color Image" which shows as RGB bands (#3,#2,#1). The Chugwater and Goose Egg formation are Triassic/ Permian red beds. Do you see a class which roughly corresponds to them?

   The unit labeled "Kmt" (Mowry and Thermopolis Shales) should be evident as one of your classes. The exposure at the western nose of the anticline should occur near the highway. Do you see this class? In places does K-Means confuse it with another type of material?

   What other group of rock units is at least crudely recognized by K-Means?

   What other non-rock classes are detected? Are these every confused with rocks?

Summary: Your report should contain:

1. A copy of the original color-IR image of the Como Bluffs region

2. A set of classification images using 5, 10, and 15 classes, as well as a brief discussion of how well each classification has worked. You may want to include additional images showing just the problem classification layers superposed on the original color-IR image.

3. A list of what classes you decided to combine from the 10-class result, and why you decided to combine those particular classes..

4. The revised classification image, including a superposed key giving classes with reasonable names and colors.

5. A paragraph or two discussing the quality of the final classification, the relationship to the geological map, and any problems with your classification. In particular note dissimilar pixels it was unable to split, and similar pixels it mistakenly split.
   Be sure to describe:
   a)What other group of rock units is at least crudely recognized by K-Means?
   b)What other non-rock classes are detected and are these ever confused with rocks?

Part III: Computer Procedures

Procedure for K-Means Classification:

1. From the main ENVI menu select **Classification->Unsupervised->K-Means**.

2. When the Classification Input File dialog appears, select the desired input file. Leave **Spatial Subset** at the default **Full Scene**, **Spectral Subset** at the default **9/9 Bands**, and **Select Mask Band** at the default **None Selected**. (You could choose just to use a subset of the available bands.) Click **OK**. That will bring up the **K-Means Parameters** window.
   a. Select the desired **Number of Classes**.
   b. For this exercise select a pixel **Change Threshold %** of **1%**.
   c. Set the **Maximum Iterations** to **50** (which should be more than enough for "convergence").
   d. Leave the optional distance thresholds (**Max. Stdev From Mean** and **Max. Dist. Error**) blank.
   e. Choose an output file in your directory. (You could output to memory for testing.)

3. Click **OK** to start the K-Means classification. Statistics are calculated for each band of the image, and a status displays the progress of the operation. The status bar cycles from 0 to 100% for each iteration of the classifier.

4. After classification ends the results will appear as a "band" in the **Available Bands List**. On the **Display #1** color-infrared image's menu click **Overlay->Classification**, and select the classification file from the file or memory menu then click **OK**. A key will appear with an on/off button for each of the K different classes you have created, plus an "Unclassified" category. Turning the buttons on or off will overlay the classification values on your display, allowing you to judge how well the automated classification has done. Besides stepping through overlays of the different classes, you may also want to load different bands into Display One to understand what spectral characteristics the classification program has used. (RGB = #9, #4, #1 is one useful combination.) If your eye can detect clear differences in the image which the classifier has not recognized, you may want to specify more classes. If it is splitting up regions which look identical (in all the relevant bands) then you may want to specify fewer classes. To dismiss the classification overlay, close the classification key window.

   Note: To compare images you can also load your classification results as a **Gray Scale** image on a **New Display** – then use the **Tools->Link->Link Displays** menu of that new display to link it to the original color-infrared image, or to another classification image. Holding down the left mouse button within one image causes the other one to momentarily appear.

Procedure for post-classification combination of classes

From the main ENVI menu select **Classification->Post Classification->Combine Classes** then when the **Input file** window appears, select the correct classification file. For the following example, assume you wanted to merge classes 1 and 2 into a single class 1. First select 1 as the input class, select 1 as the output class, then click **Add Combination**. Next select 2 as the input class, 1 as the output class, then again click **Add Combination**. If you wanted to combine other groups, you could also enter them here. Finally, once you have entered all the "input" to "output" mappings you need, click **OK**. An output file box will appear. Choose a name for the output file. By default the system will not eliminate the discarded classes – it will simply leaving them empty. It is usually simpler if you do eliminate those empty classes. Change that option to **Yes** then click **OK**. The file will be created and will appear in the available bands list. To display the new classification close the old classification key window then use **Overlay->Classifications** and select the new one.

Procedure for renaming and re-coloring classes.

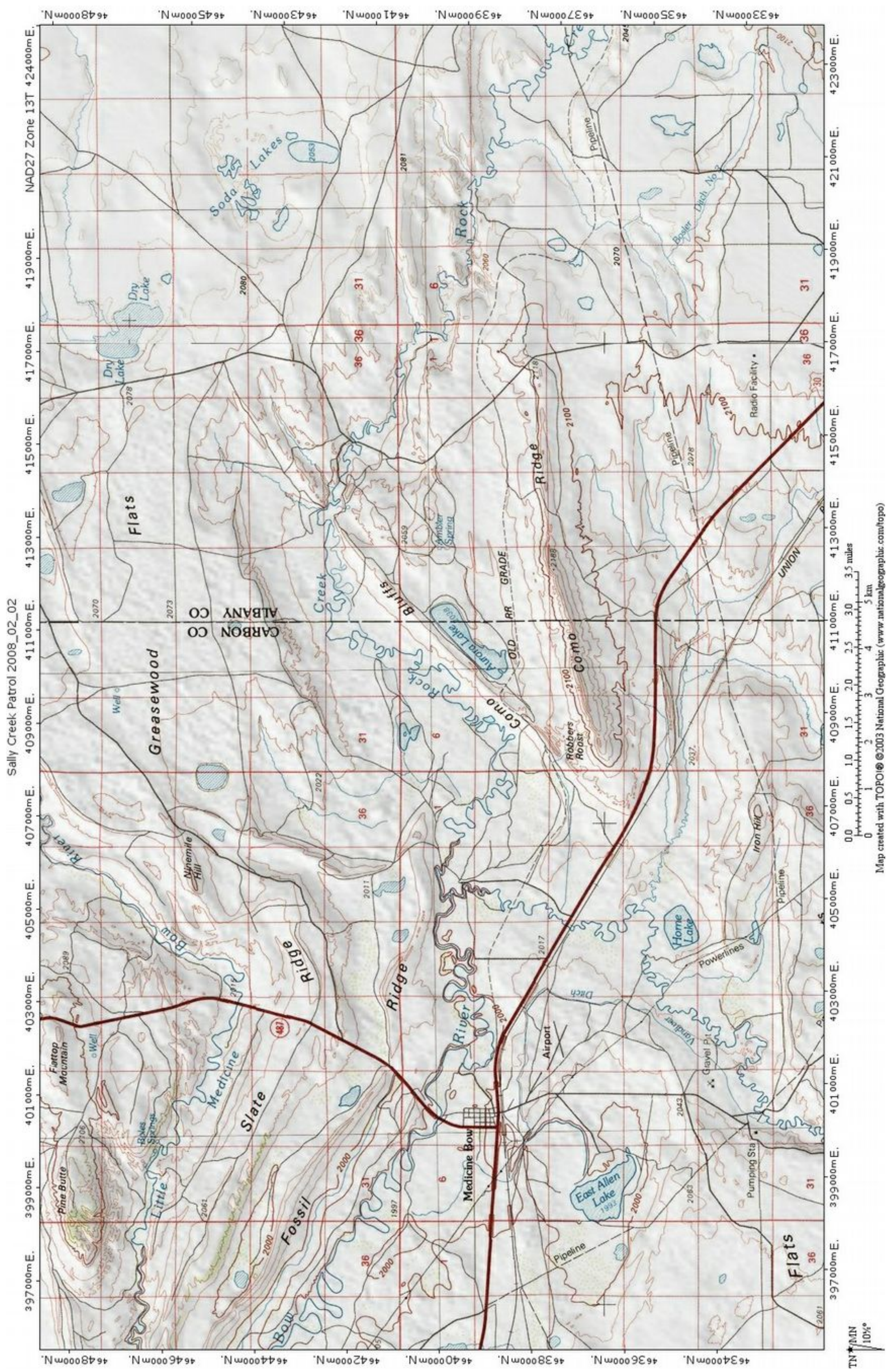
In the class key window – probably titled **#1 Interactive Class Tool**, click **Options->Edit Class Names/Colors** then make the modifications to the names and colors. Ideally you should use similar colors for similar types of features. When done use **File->Save Changes to File** to save the changes you have made. Keep a list of your final names and color choices.

Procedure for adding a classification key to your image.

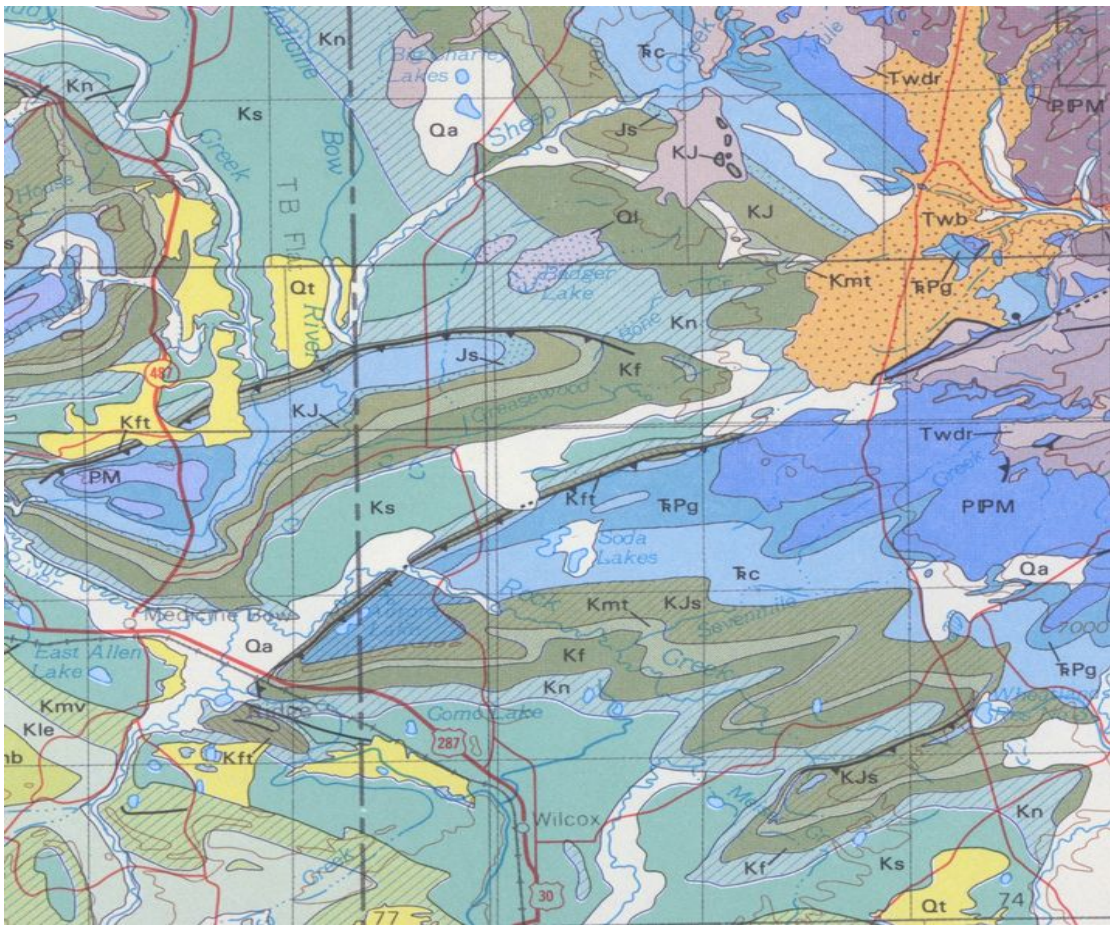
1) Open a new display showing your classification image if you haven't already done this, and enlarge it enough to make the **Scroll** window disappear. On this display's menu select **Overlay->Annotation** then from the menu of the Annotation Window which will appear select **Object->Rectangle**. Set **Fill** to **Solid**. Draw a white rectangle on the classification image, in an "unimportant" corner, by "dragging" with the left mouse button. Click the right mouse button when finished. This will give you a blank area to place a key

2) Select **Object->Map Key** in the annotation window. Select black color so the characters stand out against the white rectangle. Left click on the map to place the key – right click to make it "permanent". You may have to manually change key colors and names in your key to match the image.

3) In the "Annotation Window" menu select **File->Save Annotation** then enter a file in which to save this. The annotation can then be reapplied to the window later by going to the Display Window's menu, selecting **Overlay->Annotation**, then when the "Annotation Window" appears, selecting **File->Restore Annotation** from the menu.


Sally Creek Patrol 2008_02_02
NAD27 Zone 13T
Greasewood
Flats
Soda Lakes
Dry Lake
Rock Creek
Como Bluffs
Aurora Lake
OLD RR GRADE
Como Ridge
Robbers Roost
ALBANY CO
CARBON CO
Medicine Bow
Medicine Bow River
Little Medicine Bow River
Slate Ridge
Fossil Ridge
Ninemile Hill
Flattop Mountain
Pine Butte
Airport
East Allen Lake
Home Lake
Iron Hill
Radio Facility
Pumping Sta
Gravel Pit
Powerlines
Pipeline
UNION
Map created with TOPO!® ©2003 National Geographic (www.nationalgeographic.com/topo)

Wyoming Geological Map by Love and Christiansen (1985)



Partial Legend of units

Qa Quaternary alluvium, colluviums

Qt Quaternary gravel, pediment, and fan deposits

Twb Wagon Bed Formation

SOUTH

Kl LANCE FORMATION
Kmb MEDICINE BOW FORMATION
Kfh FOX HILLS SANDSTONE
Kfl FOX HILLS SANDSTONE AND LEWIS SHALE
Kle LEWIS SHALE
Kp PIERRE SHALE
Kmv MESAVERDE GROUP—On Rawlins uplift includes Almond Formation, Pine Ridge Sandstone, Allen Ridge Formation, and Haystack Mountains Formation. In Laramie Basin includes Pine Ridge Sandstone and Rock River Formation
Rock Springs uplift
Kal Almond Formation
Ke Ericson Sandstone
Kr Rock Springs Formation
Kbl Blair Formation

Kba BAXTER SHALE
Kc CODY SHALE
Kcf CODY SHALE AND FRONTIER FORMATION
Ks STEELE SHALE
Ksn STEELE SHALE AND NIOBRARA FORMATION
Kn NIOBRARA FORMATION
Knt NIOBRARA AND FRONTIER FORMATIONS, AND MOWRY AND THERMOPOLIS SHALES
Kf FRONTIER FORMATION
Kft FRONTIER FORMATION AND MOWRY AND THERMOPOLIS SHALES
Kmt MOWRY AND THERMOPOLIS SHALES
KJ CLOVERLY AND MORRISON FORMATIONS
KJs CLOVERLY, MORRISON, AND SUNDANCE FORMATIONS
Js SUNDANCE FORMATION

TRc CHUGWATER FORMATION OR GROUP—Includes overlying Jelm Formation in Shirley and Seminoe Mountains and at northern end of Laramie Basin
TRPcg CHUGWATER AND GOOSE EGG FORMATIONS
TRPjs JELM AND CHUGWATER FORMATIONS, FORELLE LIMESTONE, AND SATANKA SHALE
TRPg GOOSE EGG FORMATION
MzPz MESOZOIC AND PALEOZOIC ROCKS—Shown in small areas of complex structure
South side of Granite Mountains north of Green Mountain—Nugget Sandstone, Chugwater and Goose Egg Formations, Tensleep Sandstone, and Amsden Formation (Jurassic? through Upper Mississippian)
South flank of Ferris Mountains—Nugget Sandstone and Chugwater and Goose Egg Formations (Jurassic? through Permian)
Northeast flank of Seminoe Mountains—Cloverly, Morrison, Sundance, Chugwater, and Goose Egg Formations (Lower Cretaceous through Permian)
West flank of Sierra Madre—Chugwater, Goose Egg, Casper, and Fountain Formations (Upper Triassic through Middle Pennsylvanian)
East flank of Laramie Mountains—Cloverly, Morrison, Sundance, Chugwater, and Goose Egg Formations, and, east of fault in T. 19 N., Casper Formation (Lower Cretaceous through Middle Pennsylvanian)
Pfs FORELLE LIMESTONE AND SATANKA SHALE
PIPc CASPER FORMATION
PIPcf CASPER AND FOUNTAIN FORMATIONS
PIPM CASPER FORMATION AND MADISON LIMESTONE
PM TENSLEEP SANDSTONE AND AMSDEN FORMATION
Mm MADISON LIMESTONE
Pzr MADISON LIMESTONE AND CAMBRIAN ROCKS
Cr CAMBRIAN ROCKS

Older but more detailed map from Robert Dunbar's MS. Thesis 1942