Evaluation of a Color-coded Landsat 5/6 Ratio Image for Mapping Lithologic Differences in Western South Dakota

by

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Abstract

From analysis of a color-coded Landsat 5/6 ratio image, a map of the vegetation density distribution has been produced by Raines of 25,000 sq km of western South Dakota. This 5/6 ratio image is produced digitally calculating the ratios of the bands 5 and 6 of the Landsat data and then color coding these ratios in an image. Bretz and Shurr compared this vegetation density map with published and unpublished data primarily of the U.S. Geological Survey and the South Dakota Geological Survey; good correspondence is seen between this map and existing geologic maps, especially with the soils map. We believe that this Landsat ratio image can be used as a tool to refine existing maps of surficial geology and bedrock, where bedrock is exposed, and to improve mapping accuracy in areas of poor exposure common in South Dakota. In addition, this type of image could be a useful, additional tool in mapping areas that are unmapped.

Introduction

This report summarizes the findings to date of an analysis of a color-coded Landsat 5/6 ratio image as a method for mapping subtle lithologic differences in western South Dakota. The location of the area considered is shown on Plate 1. The Landsat scene used in this study, E-1081-17064, was acquired on October 12, 1972, with a sun elevation of 34^{o} and an azimuth of 153^{o}. This scene was selected primarily for the analysis of linear features.

The rationale for attempting to map subtle lithologic differences is based on previous experience (Raines and others, 1978; Raines, 1974). In similar environments, lithologic differences have been observed to be correlated with vegetation density differences, and these vegetation density differences can be observed and mapped with a color-coded Landsat 5/6 ratio image. The 5/6 ratio is also affected by changes in plant species composition of the area observed, but the significance of such differences is not known. From results in Wyoming (Raines and others, 1978), however, species differences were found to be insignificant. For these two reasons, the affects of vegetal species variation were not considered in this analysis. The details of the digital image processing and the image analysis technique are exactly as presented in Raines and others (1978). Basically, the analysis consists of mapping areas of uniform color as observed in the color-coded image, and, then by comparison with available geologic maps, determining which vegetation-density map units correlate with which mapped lithologic units or subdivision of mapped lithologic units. Generally there is no precise one-to-one correlation; however, similar lithologies have similar vegetation density. The map produced from this analysis is shown in Plate 1. The symbology used to designate the colors is organized from major to minor color components, each rank separated by dashes; where parentheses are used they indicate a lesser component of the indicated rank. For example, Y-G is an area dominantly of yellow with minor green.

In this study Raines was responsible for the digital image processing and the interpretation resulting in Plate 1. Raines then derived a set of questions primarily from correlations between the U.S. Geological Survey map of South Dakota and Plate 1. Bretz and Shurr then responded to these questions and evaluated the resulting map. Shortly after Bretz and Shurr completed their evaluation this research activity was stopped. This report documents the interpretation by Raines and the evaluation by Bretz and Shurr. Therefore, the Evaluation, Summary, and Further Research sections of this report are essentially in the format of the combined correspondences between the authors.

Evaluation

The Landsat ratio image map was compared with the U.S. Geological Survey and South Dakota Geological Survey State geologic maps, available South Dakota Geological Survey 15' geologic quadrangles, the preliminary South Dakota Geological Survey Surficial Quaternary Deposits of Western South Dakota map, the South Dakota State University Soil Association of South Dakota map, and a preliminary map showing outcrop belts of the Mobridge Member and its equivalents of the Pierre Shale.

In order to simplify the comparison of the Soil Associations and Landsat maps, the former map was color coded based on lithologic characteristics only; climatic and topographic variation were ignored.

General Comparison

Maps whose units corresponded closely with the Landsat map of Raines (Plate 1) were, from highest to lowest degree of correspondence: South Dakota University Soil Association of South Dakota, U.S. Geological Survey and South Dakota Geological Survey state geologic maps, and Preliminary map of Surficial Quaternary Deposits of Western South Dakota. The 15' geologic quadrangles and the preliminary outcrop map of the Mobridge and its equivalents were not referred to in this general comparison.

Since both the Landsat and soil association maps are based on lithology, it was expected that they would give the best correspondence, but the high degree of correspondence to be found in most places was surprising. Some things were noticed in this comparison. There is fair to good correlation between the loamy/silty and friable/claypan area and the Y-G category in the northwestern corner of the scene. In general, there is good correlation between most of Y-G and Y-R-G categories at lat. 45° N. and long 101° W. and loamy/silty and loamy areas. Good to excellent correlation between the moderately deep and deep over gravel loamy terrace and the Y-R arm extending northwest near the mouth of the Cheyenne River. Good correlation between loamy area and Y-G category in vicinity of Red Owl and White Owl Creeks. Fair to good correlation between soil categories 44 through 51 (see Appendix) and R-Y category and between categories 176, 180, and 62-68 and G-Y-B category in the Elk Creek-Boxelder Creek area. The G-Y-B and R-Y contact is essentially the contact between the terrace levels and shale exposures along Boxelder and Elk Creeks. Good correlation between gray clay and shale breaks and most of M category. Fair correlation between Y-G category and silty area just east of Cheyenne River. Good to excellent correlation between the soil association and Landsat map in the extreme southwestern corner. The line between the C and G-Y-B categories separates the Black Hills soil assemblages from the cool dry plains assemblages. The principal vegetation component of the Black Hills to the eastern edge of the outer hogback is Ponderosa pine, which gives the C signature.

The degree of correspondence of the U.S. Geological Survey and the South Dakota Geological Survey state geologic maps with the Landsat map was much the same, and these comparisons, with the addition of field observations, were used to answer Raines' suite of questions.

Two items that were noticed with respect to the South Dakota Geological Survey map and Landsat map are: R-Y area between Elk and Boxelder Creeks corresponds somewhat to a remnant of Oligocene-Miocene on drainage divide. Squiggly marker bed in the R area in the northeastern part of Plate 1 corresponds to Virgin Creek-Mobridge contact (both members of the Pierre Shale) and probably represents a well defined ledgy marl bed in the lower Mobridge.

Correspondence was lowest with the Quaternary deposits map; this is due to the preliminary nature of the map and the limited areal extent of the deposits. Some observations: Good correlation between some of Y-R category and loess/fluvial deposits near mouth of the Cheyenne River. Most of loess mapped between Cheyenne and Moreau Rivers falls within Y-G area (1st) and Y-R-G (2nd), and the large area of loess southeast of Cheyenne-Belle Fourche confluence occurs mostly in Y-G area. Bretz and Shurr interpret these small loess occurrences as locally derived from the Fox Hills Sandstone. Most of loess mapped between the Cheyenne and the Bad Rivers falls within G-Y area; some of it falls into Y-R, R-Y, and Y-G-R area. Reasonable correlation at boundary between the nonloess Y-R and R and the loess G-Y areas in east central section. Reasonable correlation at boundary between loess G-Y and the nonloess Y-G-R area in northeastern corner of south central section. Correlation was not good between loess and Landsat units in area between Bad and White Rivers; most of the loess occurs in G-Y area but several of the loess blankets cross-cut G-Y and Y-G-R, G-Y and MR-Y, and MR-Y and Y-G-R. Bretz and Shurr interpret these large loess blankets as glacially derived material.

Ideas on Questions

In this section from the correspondence between the authors, a question was developed by Raines from the image analysis, and a response given by Bretz and Shurr. Each numbered entry is Raines' question, followed by the response of Bretz and Shurr.

1. The Y-G category correlates well with the Fox Hills Sandstone lithology, but what is the explanation of the Y-G area in the extreme northwest corner? Is it a lithology in the upper part of the Hell Creek Formation similar to the Fox Hills Formation? Also, is the Y-G area, 20 km north of Cherry Creek in the center of the map, Fox Hills-type lithology in the Hell Creek Formation? Are these facies changes within the Hell Creek?

Comparison of the Landsat image and the U.S. Geological Survey Geologic Map of South Dakota suggests that Y-G category in the northwestern corner may be related to Ludlow Member of the Fort Union Formation and the upper part of the Hell Creek Formation. Both of these units contain a fair amount of siltstone and sandstones, i.e., a lithology quite like that of the Fox Hills. Comparing this area with the 15' geologic quadrangles, there is an even better agreement between Y-G and Ludlow. The marker beds in this corner of the map may represent calcareous cemented ledge and caprock forming sandstones in the Hell Creek.

In Y-G area 20 km north of Cherry Creek in the center of the map, the Faith and Red Elm 15' quadrangles reveal that the Fox Hills outcrops along Moreau River. While most of the Y-G category is the Hell Creek, a fair amount of it would be the lowermost part of the Hell Creek; it is sandier because the Fox Hills-Hell Creek contact is both transitional and unconformable, both locally and regionally. A marine sandstone tongue is known in the Hell Creek in Sioux County, North Dakota, and extends into Corson County, South Dakota. Similar tongues may exist throughout the area, but little detailed work on the stratigraphy has been done in South Dakota except that done in conjunction with quadrangle mapping.

The R-Y, Y-R, Y-R-G, Y-G-R, and Y-G categories, especially in the Fox Hills-Hell Creek outcrop area in the north-central area between the Moreau and Cheyenne Rivers, due to their poor to fair correlation with U.S. Geological Survey map, suggest that the complex facies relationships, coupled with subtle structure and the topography, make the geology more complex than it has been mapped on any scale (including our 15' quadrangles). This possibly accounts for a large portion of the discrepancies between Plate 1 and published maps, but see section on Further Research.

2a. Are the M and R categories the black shale facies of the Pierre Shale?

2b. Is the G-Y category the calcareous shale facies of the Pierre Shale?

2c. Is the G-Y-B category something between the black shale and the calcareous shales?

2d. Does the Y-R area in the south center (along the south edge of the map) correlate with the White River Group?

With regard to question 2a, Bretz and Shurr agree to some extent with the following comments. In the R area, a look at the Rousseau Creek, No Heart, Standing Butte, and Fort Bennett quadrangles, shows Virgin Creek Member of the Pierre Shale as a dark gray to black shale. Agreement between Landsat map and quadrangles is good to very good for the Standing Butte and Fort Bennett quadrangles, but poor for the Rousseau Creek and No Heart quadrangles. A possible reason for breakdown of agreement over such a short distance is that Stevens did the Rousseau Creek and No Heart quadrangles, whereas Petsch did the Standing Butte and Fort Bennett quadrangles. See also Further Research, number 3. The northeasterly projecting portion of the dogleg-shaped R category in the extreme northeastern corner of the map probably represents the Virgin Creek Member. The easterly projecting portion presents a problem as it does not closely follow the drainage pattern. If it does represent the Virgin Creek Member, we would expect a similar signature (color) along the Virgin Creek drainage, but this falls within the Y-G category.

Concerning the M area, there are some thin black shale units and some extensive areas of very dark gray shale in this area, some of which the authors saw in the Bridger area. However, the interpretation of the M signature as wholly representing a black shale lithology is questionable. An alternate explanation is that the general topographic relief is affecting plant associations. See Further Research, number 4, and the G-Y-B, and the G-Y-B, R-Y, and M contacts discussion in the General Comparison section.

Bretz and Shurr disagree on question 2b. Probably the extensive G-Y area in the eastern part of the map is the Elk Butte Member of the Pierre Shale and not the calcareous Mobridge Member. This interpretation is based upon a preliminary outcrop map of the Mobridge and its equivalents. This map was prepared comparing surface elevations with elevations of a subsurface marker believed to be the base of the Mobridge (Bretz, oral communication, 1978). The unit is assumed to be a uniform 200 feet thick throughout the area.

The Elk Butte Member is sandy and silty due to its transitional nature with the overlying Fox Hills. This agrees with the grain size interpretation of the G-Y category. There may be little contrast in grain size between the surficial terrace material and the Elk Butte Member. This may account for the lack of expression for the extensive terraces along the Cheyenne.

Areas of Y-R and R-Y correlate with the Mobridge and its equivalents outcrop pattern along the Bad River and along the Cheyenne River south of the Cheyenne-Belle Fourche confluence. In other areas these color units are Elk Butte-Fox Hills transitions. See question 4. below.

Bretz and Shurr disagree on question 2c. The G-Y-B category is the widespread terrace levels that are particularly well developed in the vicinity of the Black Hills. See the soil associations map discussion of the G-Y-B category in General Comparison section.

On question 2d Bretz and Shurr agree. There is a good agreement between the Y-R category and the White River Group as mapped by the U.S. Geological Survey and the South Dakota Geological Survey.

3. What are the Y-R, MR-Y, and Y-G-R areas between the White River and the Bad River and just north of the North Fork of the Bad River? From this interpretation they appear to be finer grained material (more heavy clay) than the calcareous shale (G-Y) of the Pierre Shale, thus ruling out that they are related to the gravel terraces.

Bretz and Shurr are pretty sure that they do not represent gravel terraces because the larger, more extensive ones along the Cheyenne River (as well as the ones along the White, Belle Fourche, and Moreau Rivers) do not have a signature, so it seems unlikely that those along the Bad River would be recognized. Considering the Y-G-R area, reconnaissance in this area suggests that this category may represent a mishmash of Y-G (Fox Hills) and Y-R (White River) plus Y-R (Mobridge). Bretz (oral commun., 1978) has seen Fox Hills just southwest of Philip and there are numerous outcrops of White River Group, especially in the southern portion of the area. The Y-G-R area just southeast of the Belle Fourche-Cheyenne confluence is probably a Fox Hills and Pierre transition. This also applies to the Y-G-R area just north of the

Cheyenne in the center of the map. Eagle Butte-Fox Hills are highly transitional and the Y-G-R probably represents this transition, particularly in the two Y-G-R areas near the Cheyenne. However, see question 4 in Further Research.

Y-R and MR-Y areas near the Bad River may represent Mobridge or similar lithology. Affinities of the MR-Y signature to the dark shale units, M and R, suggest dark gray shale. There are some rather dark shale cuts on the Bad River in the area between Midland and Philip. South Dakota Geological Survey and U.S. Geological Survey maps do not show Virgin Creek Member of the Pierre shale this far upstream, but the preliminary outcrop map of the Mobridge and its equivalents suggest that MR-Y corresponds with gray shales below the Mobridge.

4. Could the Y-R and R-Y areas around the M and R areas be transitional areas like between M and G-Y, for example? Also note that there is possibly no difference between Y-R and R-Y that surround M and R areas.

Comparing Plate 1 with U.S. Geological Survey maps and field observations, the Y-R and R-Y areas around the M and R areas probably represent an Eagle Butte Member of the Pierre Shale-Trail City Member of the Fox Hills transition unit in the eastern area and an upper unnamed Pierre-Trail City transition unit in the western area.

5. Markers mapped suggest that the "Skylab structure" (large structure at 103° W., 44°30' N.) is highly faulted on its west flank.

Most of the marker beds bounding or within the M area are probably the thick and associated thinner bentonite beds that were seen in this area; some of the markers, especially in the northwestern part of the "Skylab structure", may be cuesta or hogback ridges. The authors have seen relatively bare linear ridges in a flyover of the north and middle part of this structure, highly suggestive of hogbacks.

There is not much evidence to support the postulated fault or the structural configuration. A future project is to make a plane table map to show the configuration. Bentonite beds, drilling, and electric logging, etc., can be used to determine closure and possible faulting.

Additional comments:--Marker bed in northwestern corner R area, as shown on the Rosseau Creek quadrangle, may be resistant marl bed in Mobridge. The two marker beds in the extreme southwestern corner of the map, one farthest up in Black Hills, corresponds with Spearfish, Minnekahta, and Opeche formations, but probably mostly Minnekahta outcrop. The outermost one corresponds to the outer hogback Inyan Kara Group and Newcastle Sandstone.

Summary

Correlation is good between Plate 1 and existing maps of surficial geology. It seems that the Landsat 5/6 ratio image can be used as a tool to refine existing maps of surficial geology and enhance their accuracy in areas of poor exposures. In addition, it is one of several tools that can be used as an aid to map areas that are unmapped or only partially mapped. Used in conjunction with aerial photography and Skylab photography, it should make geologic mapping much easier and more efficient. It is hard to imagine, however, that these methods will ever totally replace older mapping tools or eliminate the need for ground observation of the geology.

The table below is a first attempt to build a geologic legend for Plate 1.

Terrace deposits	G-Y-B in southwest part of map, Y-R near mouth of Cheyenne River
Loess	Y-G local sources related to Fox Hills Sandstone, G-Y blanket deposit between Cheyenne and Bad Rivers
White River Group	Y-R along White River
Ludlow Member, Fort Union Formation	Y-G in northwest corner of the scene
Hell Creek Formation	Complex Y-R, Y-G, Y-R-G
Fox Hills Sandstone	Y-G
Pierre Shale, Elk Butte Member	G-Y extensive in southeast
Pierre Shale, Mobridge Member	Y-R/R-Y transitional areas between R and G-Y, along Cheyenne and Bad Rivers
Pierre Shale, Virgin Creek Member	R at mouth of Cheyenne River and MR-Y on Bad River

Plate 1 has very little utility in the recognition of facies relationships within the Pierre. This is probably due to the nature of Pierre outcrop belts, surficial deposits (such as loess and terrace materials), slope effects, and complications in the plant associations. Stratigraphic position of members within the Pierre seemed to be recognizable (see table above), but lateral facies changes are apparently too subtle to be "seen" through complexities of surface geology.

Further Research

In some areas there seems to be good to very good agreement between the map derived from the 5/6 image and all of the other maps. However, it breaks down somewhat in other places, even over a distance of twenty miles.

Based on this, some questions and ideas:

1. How much effect on the spectral properties of an area will the changing rainfall regime from the Black Hills to the far plains have considering associated changes in plant associations?

2. Raines' other works of this nature (Raines, 1974; Raines and others, 1978) seemed to be restricted to western plant associations (Sonora-southwest and Powder River Basin). Has similar work been done in eastern South Dakota plant associations on their spectral properties with respect to lithology; i.e., how much effect will the intermixing of eastern and western prairie/rangeland plant associations in the present area have on the color-coded image?

3. What about aspect effect on plant associations? There was discrepancy in agreement between the Standing Butte/Fort Bennett Quadrangles (good agreement - north-facing slopes, generally) and the Rousseau Creek/No Heart quadrangles (poor to fair agreement - south-facing slopes, generally).

4. What about the variation of plant associations with respect to general topographic relief? Observations by the authors show that the same lithologic unit in the Pierre Shale may have different plant associations and a different degree of cover depending on whether it is found in the steep breaks or on the gentler uplands. The steep slopes in the breaks have a greater number of, and better exposures of, shale and less vegetation than the uplands due to slumping, greater erosion,

and better rainfall drainage. This combination of factors seems to prevent the establishment of the same plant associations (or at least creates lesser density in the same association) in the same unit in the breaks as compared to the uplands.

5. What about seasonal variation? Do the same spectral patterns occur on images from the same area taken in early spring, late spring/early summer, and late summer?

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Appendix

44. Clay soil from shale

45. Clay soil from shale

46. Clay soil from shale

47. Clay soil from shale

48. Clay soils and shale breaks

49. Clay soils and shale breaks

50. Clay soils and shale breaks

51. Clay soils and shale breaks

62. Alluvial, loamy

63. Alluvial, loamy

64. Alluvial, loamy

65. Alluvial, sandy

66. Alluvial, clayey

68. Alluvial, clayey

176. Alluvial, loamy

180. Alluvial, clayey