Thematic Mapper-derived mineral distribution maps of Idaho, Nevada, and western Montana

By Gary L. Raines[1]

Data Series 185

2006

Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY
[1] U.S. Geological Survey, Reno, NV 89557

Table of Contents

Abstract

This report provides mineral distribution maps based on TM spectral information of minerals commonly associated with hydrothermal alteration in Nevada, Idaho, and western Montana. The product of the processing is provided as four ESRI GRID files with 30 m resolution by state. UTM Zone 11 projection is used for Nevada (grid clsnv) and western Idaho (grid clsid), UTM Zone 12 is used for eastern Idaho and western Montana (grid clsid_mt). A fourth grid with a special Albers projection is used for the Headwaters project covering Idaho and western Montana (grid crccls_hs). Symbolization for all four grids is stored in the ESRI layer or LYR files and color or CLR files. Objectives of the analyses were to cover a large area very quickly and to provide data that could be used at a scale of 1:100,000 or smaller. Thus, the image processing was standardized for speed while still achieving the desired 1:100,000-scale level of detail. Consequently, some subtle features of mineralogy may be missed.

The hydrothermal alteration data were not field checked to separate mineral occurrences due to hydrothermal alteration from those due to other natural occurrences. The data were evaluated by overlaying the results with 1:100,000 scale topographic maps to confirm correlation with known mineralized areas. The data were also tested in the Battle Mountain area of north-central Nevada by a weights-of-evidence correlation analysis with metallic mineral sites from the USGS Mineral Resources Data System and were found to have significant spatial correlation. On the basis of on these analyses, the data are considered useful for regional studies at scales of 1:100,000.

Introduction

In the fall of 1998, the U.S. Geological Survey initiated a project to develop regionally consistent digital geoscience data and interpretations that could be used by the U.S. Forest Service (USFS). The project area included all National Forests in Idaho north of the Snake River Plain, western Montana, and part of northeastern Washington. Two regional science needs were identified through discussions with USFS Geology and Minerals Management Program staff in Regions 1 and 4. First, the USFS wanted digital themes derived from geologic maps in order to address topics ranging from land use to resources to ecosystem function. Second, they requested an assessment of where minerals exploration and development activities may take place in the near future. In both cases, it was emphasized that science products would be most useful if the data and information (1) directly addressed requirements specified in planning regulations, (2) were readily available and consistent to everyone throughout the region in the USFS, (3) were at a scale appropriate for regional planning (1:100,000), and (4) could be incorporated in the GIS used by the USFS.

In response to these needs, this report provides mineral distribution maps based on Landsat Thematic Mapper (TM) spectral information of minerals commonly associated with hydrothermally altered rocks in Idaho, western Montana, and Nevada. Some overlap of data into adjacent states occurs. The mineral distribution products are provided in the following ESRI GRID files: **clsnv** for Nevada, **clsid** for western Idaho, **clsid_mt** for eastern Idaho and western Montana, and **crccls_hw** for the Headwaters project covering Idaho and western Montana. TM data as summarized in Lee and Raines (1984) and Knepper (1989) can be used to map general classes of minerals with Al-OH absorption bands such as alunite, kaolinite, montmorillonite, and sericite, with CO_3 absorption bands such as limestone and dolostone, and with ferric absorption bands such as hematite, goethite, and limonite. Individual mineral species cannot be identified within these classes, nor can Al-OH minerals be differentiated from CO_3 minerals. The high carbon content of many carbonates rocks conceals the carbonate minerals in the widespread limestones and dolostones lacking hydrothermal alteration, but the bleaching of the carbonate rocks commonly associated with hydrothermal alteration emphasizes the Al-OH and CO_3 absorption bands. Consequently, areas of hydrothermal alteration are easily identified using TM and many unaltered carbonate rocks are not included.

The objectives of the analyses presented here were to map a large area quickly and to provide results that could be used at a scale of 1:100,000 or smaller. Thus, the processing was standardized to speed the processing while achieving the desired resolution. Some subtle mineral occurrences may not be detected, but the results are still useful for regional analyses at a scale of 1:100,000. More careful, scene-specific processing could provide additional information for a local area of interest.

The scheme for processing the data is summarized in figure 1. The details of the grid processing are discussed below and repeated in the metadata. Because of the objective to quickly process large volumes of data, the user-interactive process of masking clouds and snow may be incomplete or locally more extensive than required. Similarly, labor-intensive processes to calibrate and scale the data were replaced with fixed calibration and scaling parameters. The general processing scheme is based on Knepper (1989) and was programmed in an extension for the ESRI ArcView3 Image Analyst Extension. To minimize atmospheric effects and problems with snow, which can mimic Al-OH absorption, high sun-angle scenes acquired as early as practical to minimize snow cover were selected. Furthermore, scenes with the least cloud cover were selected. The masking of vegetation was automated based on the identification of areas of dense vegetation as red hue in color-infrared composite images (bands 4, 3, and 2 as red, green, and blue, respectively) as discussed in Raines (1977). Similarly, the identification and mapping of mineral classes was automated based on the same hue-mapping concept as discussed in Raines (1977). These automated processes are not perfect, but inspection of the results in known areas of hydrothermally altered rocks indicates that the mapping is quite acceptable for a regional analyses.

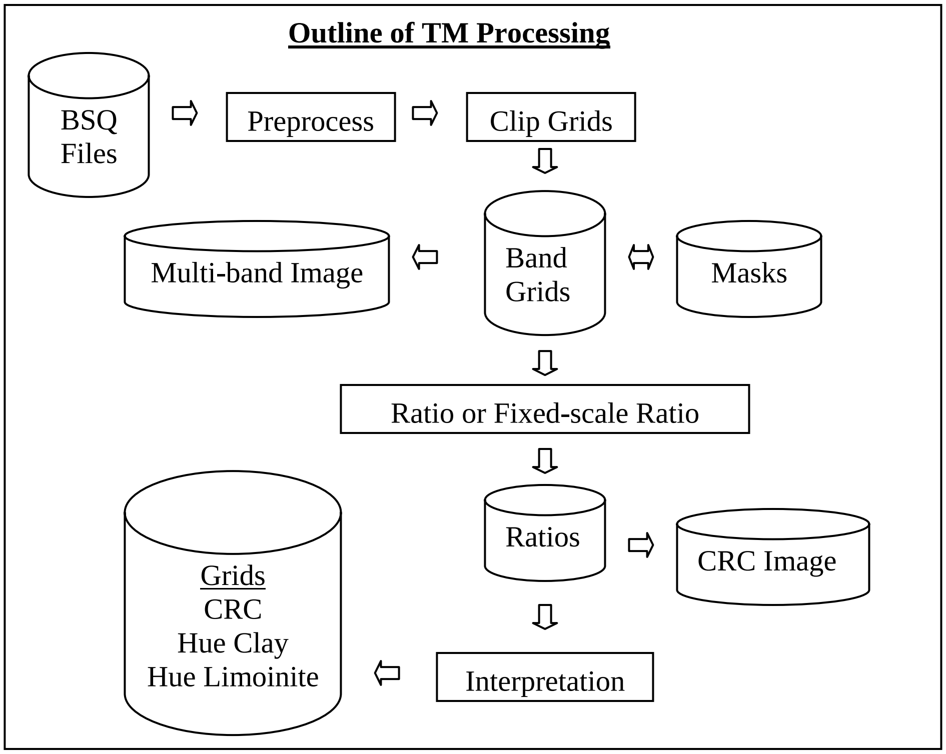

Figure 1: Summary outline of the processing steps. Rectangles indicate processes and oval boxes indicate grid products or sources. The source grid labeled Mask defines areas that were not processed based upon user input to define areas of clouds, cloud shadows, water bodies, and snow combined with automatically defined areas of heavy vegetation. These masked areas are places where no information on the rocks was accessible to the TM. Intermediate products are multi-band color and color infrared images (Multi-band Images) and color ratio composite (CRC) images. The product released by this report is the mineral interpretation grid.

Processing

There are several decisions involving various parameters and manual processing that are required to adequately process the TM data. The first decision was to use data that were georeferenced by the USGS EROS Data Center. This georeferencing can cause some minor distortions in the spectral information. Tests of the distortions due to georeferencing the data before spectral processing showed that the distortions were not significant, especially with the objective of covering such large areas. Data were georeferenced to UTM zone 11 for Nevada and western Idaho and zone 12 for eastern Idaho and western Montana. The data were preprocessed, clipped, masked, calibrated, and mosaiced before the spectral processing of ratioing and final mineral interpretation to produce a mineral map. Three grid products were mosaiced from the individual TM scenes: Nevada (grid **clsnv**, UTM Zone 11), western Idaho (grid **clsid**, UTM Zone 11), and eastern Idaho with western Montana (grid **clsid_mt**, UTM Zone 12). In addition, Idaho and western Montana TM scenes were mosaiced in a customized Albers projection (grid crccls_hw) to register with the other data prepared by the USGS for the USFS for this region.

Preprocessing and Clipping

The preprocessing and clipping involved reformatting the data from the single band formats of the georeferenced data, which were provided by the EROS Data Center, to the BSQ format required by the ESRI Image Analysis extension. A clipping mask was prepared to remove the no-data areas from the EROS data frame. The clipping masks were typically made manually by inspection to reduce the data overlap and volume in order to create separate grid mosaics for Nevada, Idaho, and western Montana.

Masking

Vegetation densities varied widely from minimal in many parts of Nevada to very dense in the high ranges of Nevada and large areas of Idaho and Montana. In these areas of dense vegetation, rocks and soils cannot be observed by satellite. Consequently, vegetated areas need to be masked from the analyses. It is widely recognized that vegetation can be identified on TM color-infrared images as red areas. These red areas can be easily identified by transforming the three bands of the color-infrared image to Munsell space and selecting the red hues (Raines, 1977). Such transformations to Munsell hue, saturation, and brightness or value are commonly implemented in image processing and GIS systems. In preparing the mask in figure 1, a color-infrared image using TM bands 4, 3, and 2 were used as input to create a hue image from which the areas of the red hues (vegetation) were identified and incorporated into the mask of areas to be excluded from the mineral mapping.

In addition, areas of clouds, cloud shadows, water bodies, and snow were manually masked by photointerpretation methods in the GIS. This involved defining polygons that surrounded the areas of clouds, cloud shadows, and water bodies, and then converting these polygons into a grid format. Because snow occurs in the best available scenes in the Rocky Mountains in Idaho and western Montana and appears the same as the AL-OH and CO_3 classes of minerals in the processed TM data, it is important to mask out the snow. In the summer to late-summer images, the snow occurs in small patches at high elevation on north-facing slopes. Some of the TM data come with digital elevation data (DEM) and a thermal infrared band; so bright areas (high value in the Munsell space) in the color-infrared composite images at high altitude on north slopes (calculated from the DEM) and cold (where the TM thermal infrared band was available) are generally snow. Areas meeting these criteria are readily identified in the GIS and easily incorporated into the mask. Potentially, small areas of hydrothermal alteration with minerals such as kaolinite could also be mistakenly masked out by this process.

Ratios: Calibration and Atmospheric Backscatter Corrections and Scaling

On the basis of the experience summarized in Knepper (1989), four ratios of TM bands were used in these analyses: band 5 divided by band 7 (57 ratio), 3 divided by 1 (31 ratio), 3 divided by 4 (34 ratio), and 2 divided by 3 (23 ratio). The 57, 31, and 34 ratios were combined as red, green, and blue, respectively, to make a color ratio composite image, referred to as CRC Clay image. The 31, 23, and 34 ratios were combined as red, green, and blue respectively, to make a CRC Limonite image. These two images are included in the CRC images in figure 1.

To calculate valid ratios, the TM data numbers need to be calibrated into radiance units and a correction for atmospheric backscatter is necessary. The standard calibration parameters were used as suggested in the Landsat users manual (Markham and Baker, 1985). On the basis of testing in the Battle Mountain area, a standard correction for atmospheric backscatter was selected (see table 1). This value was tested at several places in Nevada and Idaho and found to be acceptable.

Table 1: Calibration and atmospheric backscatter values used for calibrating the data. The source of the minimum and maximum calibration parameters are Markham and Barker (1985). The backscatter values were found empirically using data from the Battle Mountain, Nevada, area and tested in other areas in Nevada and Idaho.

Band	Minimum	Maximum	Backscatter
1	-0.15	15.21	20
2	-0.28	29.68	14
3	-0.12	20.43	8
4	-0.15	20.62	3
5	-0.037	2.719	1
7	-0.015	1.438	1

To combine the ratios into a color ratio composite image (CRC), it is necessary to scale the real valued ratios to 8-byte integer data. On the basis of testing primarily in the Battle Mountain area, various scaling parameters were tested and are summarized in figure 2. The acceptable median values shown in figure 2 and summarized in table 2 were used for all processing. These scaling parameters were tested in several areas of known hydrothermal alteration around Nevada (including Goldfield, Tonopah, the Comstock, and Battle Mountain), southern Idaho, and western Montana (including Butte) and were found to produce acceptable definition of known areas of hydrothermally altered rocks. One simple test was to digitally overlay the 1:100,000-scale topographic maps over the processed images and look at areas around known mines.

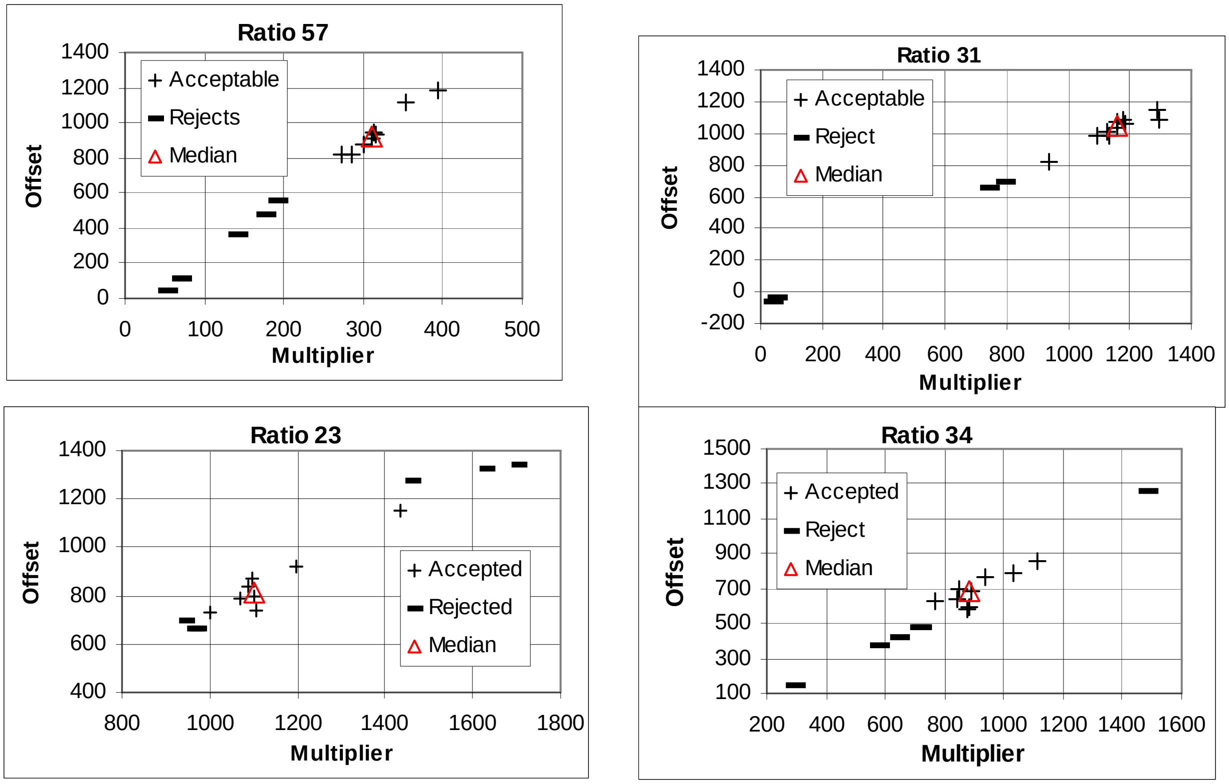

Figure 2: Calibration graphs showing selection of the scaling parameters, multiplier and offset, for fixed-scaling the ratio data.

Table 2: Scaling parameters selected for fixed-scale ratioing. These selections are based on the analysis shown in figure 1. The 23 ratio was not used.

Ratio	Multiplier	Offset
57	312	923
31	1162	1045
34	883	685
23	1101	817

Interpretation

The interpretation process (fig. 1) uses the Munsell transform of the CRC Clay and CRC Limonite images (Raines, 1977) to automate the application of the color classifications in Knepper (1989, tables 1 and 2) that identify the mineral classes defined in table 3. The color classification of the two images is summarized in table 4 and explained in the following If-Then logic.

The logic of table 4 can also be stated in an If-Then logic structure shown below. In this logic, M = magenta, R = red, Y = yellow, G = green, C = Cyan, and B = blue as defined by the Munsell hue circle.

If CRC Clay = M then Class = 0 (Strong 2.2 absorption)
If CRC Clay = R then Class = 1 (Strong 2.2 absorption probably due to vegetation)
If CRC Clay = Y and CRC Lim. = M then Class 2 (2.2 absorption + jarosite or hematite)
If CRC Clay = G or C and CRC Lim. = M then Class 3 (hematite)

If CRC Clay = Y and CRC Lim. = R or Y then Class 4 (2.2 absorption and goethite)
If CRC Clay = G or C and CRC Lim. = R or Y then Class 5 (goethite)
If CRC Clay = B and CRC Lim. = C then Class 6 (iron gel)
Otherwise Class 7 (none of above)

The Al-OH minerals include alunite, kaolinite, montmorillonite, sericite, and phyropholite. Gypsum can also have similar spectral features in the Tm data. The iron gel refers to poorly crystallized iron minerals that can include ferrihydrite. See Lee and Raines (1984) for a summary of the spectral properties and references for more detailed information.

As a part of the processing in preparing the mineral grids, the hue-classified data from the CRC Clay and CRC Limonite grids are filtered to smooth the color classes. The filter used is a 3x3 majority filter that was sequentially applied twice. This causes isolated cells to be changed to the same value as the majority of their neighbors and causes boundaries of color classes to be smoother. Testing of this process seems to produce generalized boundaries and less noisy maps and is more similar to decision making in field mapping for the desired product scale of 1:100,000.

Table 3: Definition of classes in preliminary CRC classification.

Mineral Class Value	**Mineral Class Name**	**Definition**
Value	Desc	Attribute names in the grid attribute table.
0	Strong 2.2	Magenta in clay CRC that is masked for vegetation. Carbonate and Al-OH-bearing minerals. Commonly associated with hydrothermally altered areas.
1	Strong 2.2, probably vegetation	Red in clay CRC that is masked for vegetation. This can be carbonate and Al-OH-bearing minerals but, more likely, is vegetation.
2	Strong 2.2 + Hematite or Jarosite	Jarositic limonite associated with carbonate or Al-OH-bearing minerals.
3	Hematite	Hematitic limonite.
4	Strong 2.2 + Goethite	Goethitic limonite associated with carbonate or Al-OH-bearing minerals.
5	Goethite	Goethitic limonite.
6	Iron Gel	Poorly crystallized iron minerals that can include ferrihydrite.
7	None of Above	None of the above.

Table 4: Preliminary classification of CRC clay and limonite derived from tables 1 and 2 in Knepper (1989). Only the portions of each scene that lack vegetation, as defined by red areas in the color-infrared-composite image, are used for this calculation. The resulting mineral class, as identified by the numbers defined in table 3, is the combination of hues indicated by the column and rows from the CRC clay and limonite images.

	Hue CRC Clay						
Hue CRC Limonite	Magenta	Red	Yellow	Green	Cyan	Blue	Neutral
Magenta	0	1	2	3	3	7	7
Red	0	1	4	5	5	7	7
Yellow	0	1	4	5	5	7	7
Green	0	1	7	7	7	7	7
Cyan	0	1	7	7	7	6	7
Blue	0	1	7	7	7	7	7
Neutral	0	1	7	7	7	7	7

Mineral-Interpretation Grids

The product of the processing is provided as an ESRI GRID in three geographic projections. The mineral maps of Nevada and western Idaho are provided in UTM Zone 11 projection (Figure 3, grids **clsnv** and **clsid**) and eastern Idaho and western Montana in UTM Zone 12 (Figure 4, **clsid_mt**). These UTM projections are convenient for local studies at a scale of 1:100,000. For Idaho and Montana the data were combined in a special Albers projection (Figure 5, grid crccls_hw) designed for regional use by the USFS for registration with the regional large-scale geology, geochemistry, and geophysical data.

The interpreted-mineral grids were not field checked but were checked by overlaying the results with 1:100,000 scale topographic maps to confirm correlation with known mineralized areas. The grids were also tested in the Battle Mountain area of north-central Nevada using a weights-of-evidence correlation analysis with metallic mineral sites from the USGS Mineral Resources Data System (MRDS). In the Battle Mountain area, the following units that were more that 69% by area composed of one mineral class were defined on the Nevada state geologic map: Quaternary unconsolidated materials, Gabbroic Complex (Jgb), Cambrian limestone and dolomite (Cc), Devonian Slaven Chert (Dsl), Silurian shale and chert (Ss), Cretaceous and Jurassic Diorite (KJd), and Mississippian siliceous and volcanic rocks (Msv). If these units are excluded because the TM analysis indicates this mineral class is part of the lithology of these units and does not indicate hydrothermal alteration, then spatial correlations between mineral classes and MRDS metallic mineral sites, as measured by contrast varied from 0.2 to 1.3 with Studentized confidence greater than 93% (see Bonham-Carter, 1994, for discussion of weights of evidence). These spatial correlations are weak to moderately strong and statistically significant. On the basis of the inspection of areas of known mineralization and the weights-of-evidence correlation test, the data are considered useful for regional studies at scales of 1:100,000 or smaller.

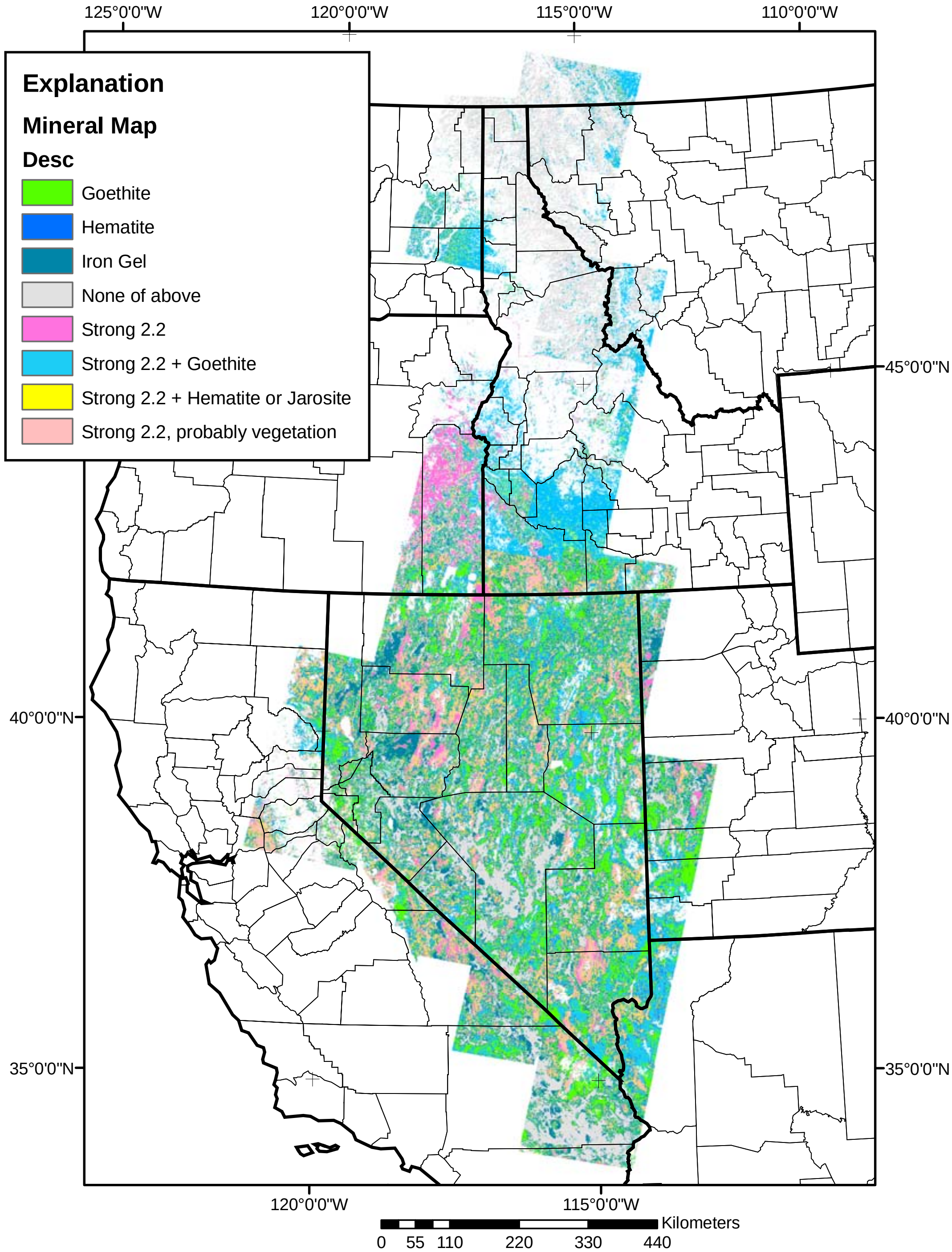

Figure 3: Coverage for the UTM Zone 11 mineral-interpretation grid for Nevada and western Idaho. The data sets for Nevada and western Idaho are shown together here. This display is simply to show the coverage; the actual resolution of the grid is 30 m, suitable for use at 1:100,000 scale. The boundary between the Idaho and Nevada data sets is an irregular boundary defined by the limits of the individual TM scenes, thus data near the Idaho-Nevada boundary south of the Snake River Plain are covered in the Nevada data set.

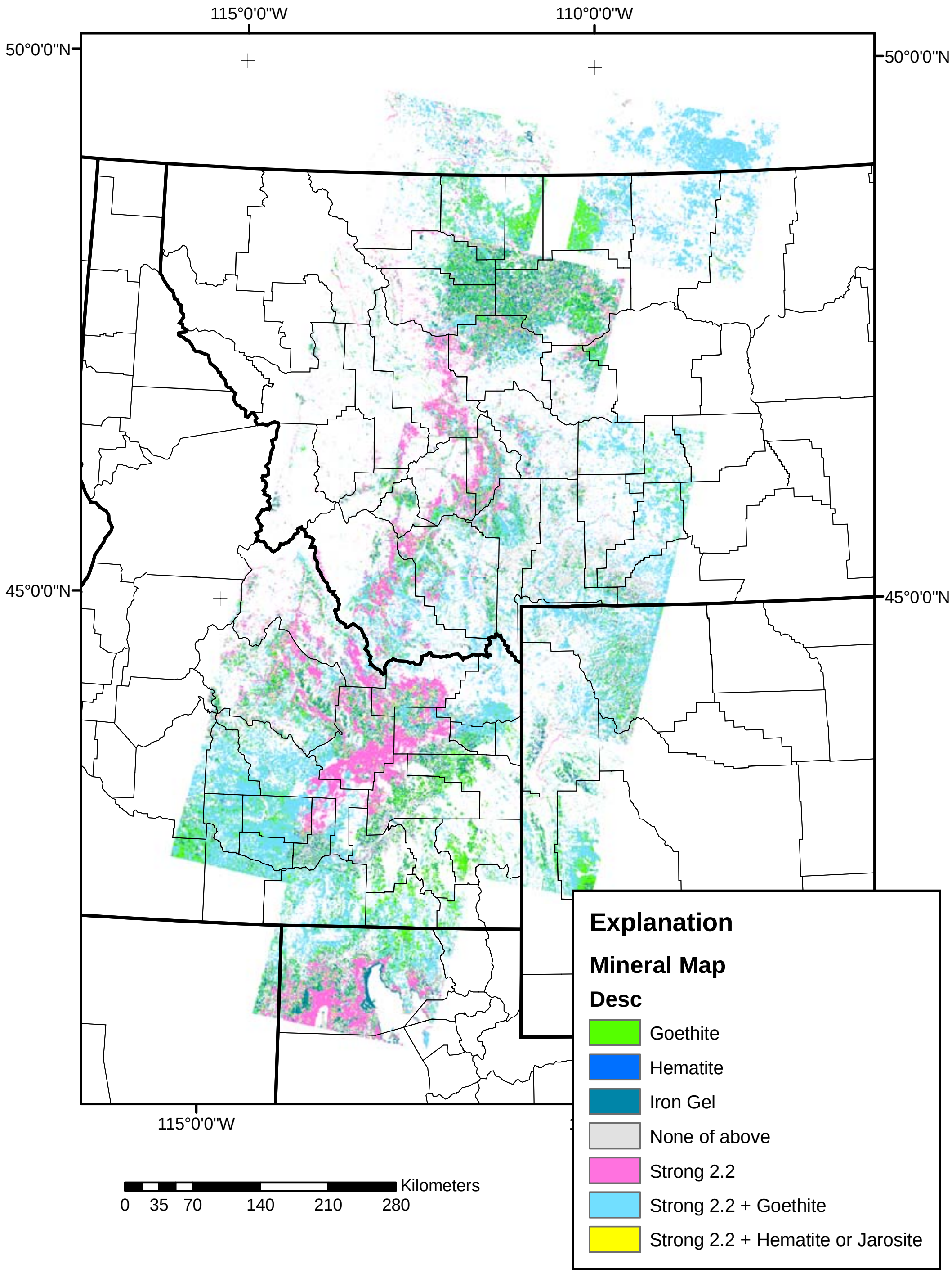

Figure 4: Coverage for the UTM Zone 12 mineral-interpretation grid for eastern Idaho and western Montana. This display is simply to show the coverage; the actual resolution of the grid is 30 m, suitable for use at 1:100,000 scale.

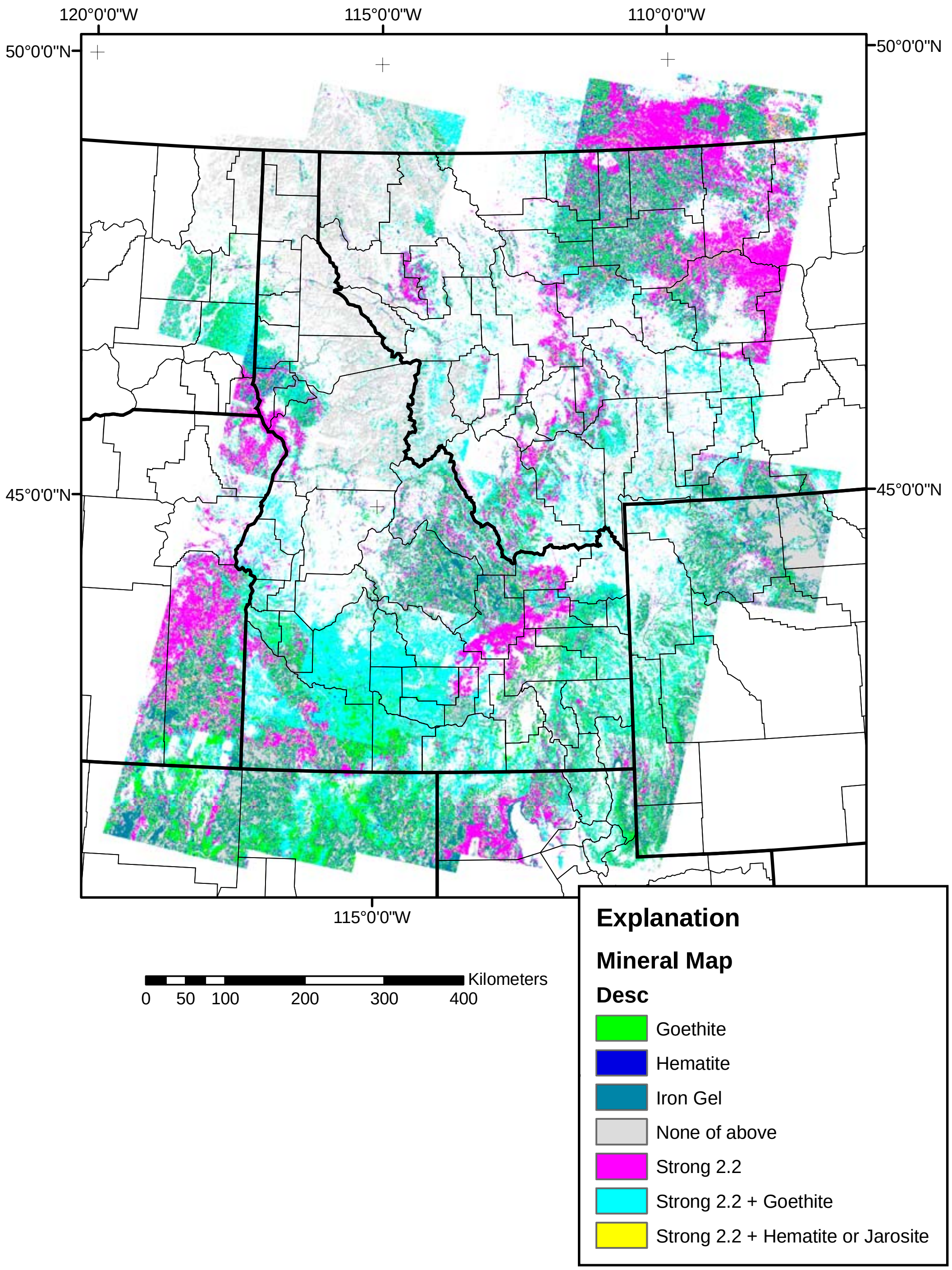

Figure 5: Coverage of the Albers-projection mineral-interpretation grid for Idaho and western Montana. This display is simply to show the coverage; the actual resolution of the grid is 30 m, suitable for use at 1:100,000 scale.

References Cited

Bonham-Carter, G.F., 1994, Geographic Information Systems for geoscientists; modelling with GIS: Oxford, Pergamon, 398 p.

Knepper, D.H., 1989, Mapping hydrothermal alteration with Landsat Thematic Mapper data *in* Lee, Keenan, Kruse, F.A., Marrs, R.W., and Milton, N.M., Remote sensing in exploration geology: 28th International Geological Congress, Washington, D.C., Field Trip Guidebook T182, p. T182-13 – T182-21.

Markham, B.L., and Barker, J.L., 1985, Landsat MSS and TM post calibration dynamic ranges, exoatmospheric reflectance, and at-satellite temperatures: Lanham, Maryland, Earth Observation Satellite Company, EOSAT Landsat Technical Notes, p. 3-8.

Raines, G.L., 1977, Digital color analysis of color-ratio composite LANDSAT scenes: Proceedings Eleventh International Symposium Remote Sensing of Environment, Michigan, p. 1463-1472.