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RATIO MAPS OF IRON ORE DEPOSITS ATLANTIC CITY DISTRICT, WYOMING

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ABSTRACT

Preliminary results of a spectral ratioing technique are shown for a region at the southern end of the Wind River Range, Wyoming. Digital ratio graymaps and analog ratio images have been produced for the test site, but ground truth is not yet available for thorough interpretation of these products. ERTS analog ratio images were found generally better than either ERTS single-channel images or high altitude aerial photos for the discrimination of vegetation from non-vegetation in the test site region. Some linear geological features smaller than the ERTS spatial resolution are seen as well in ERTS ratio and single-channel images as in high altitude aerial photography. Geochemical information appears to be extractable from ERTS data. Good preliminary quantitative agreement between ERTS-derived ratios and laboratory-derived reflectance ratios of rocks and minerals encourage plans to use lab data as training sets for a simple ratio gating logic approach to automatic recognition maps. Empirical atmospheric corrections indicate that atmospheric corrections are needed to make the ratio method, and possibly other types of data processing, consistent over large geographical and temporal displacements. The ratio method, designed for geochemical prospecting and geologic mapping, should also be useful for other scientific applications from satellite data as well.

1. BACKGROUND

The primary objectives of this ERTS investigation are to develop a generally applicable method for mapping large exposures of iron compounds, to use this method for mapping iron compounds in the Wind River Range, Wyoming vicinity, and to estimate the usefulness of this method for limited geochemical prospecting from ERTS data in this and other (geologically well-exposed) regions of the world. The method involves empirical corrections for atmospheric effects, spectral ratioing of reflected radiances of selected pairs of ERTS multispectral channels, production of analog ratio images, and production of automatic recognition maps of as many rock classes as possible, using laboratory data as training sets whenever possible.

The data processing steps used to correct for atmospheric and illumination effects in this ratio method have been described in an earlier paper [1]. In brief, the radiance detected for the darkest object (usually shadow or water) in a given scene is subtracted from the detected radiance of all other points for each MSS channel. The resulting radiances in two of the MSS channels are ratioed. The ratio for all points is then divided by the ratio of a known point in the scene (ratio normalized) and multiplied by the reflectance ratio (determined from laboratory data) of the known point. This yields a ratio of reflectances in the two selected spectral channels for every point in the scene. To a first approximation, it is hypothesized that most atmospheric and illumination effects are removed from this ratio of reflectances by this procedure. As a qualitative example, typical reddish rocks (high reflectance in channel 5 and lower reflectance in channel 7) will have an R_{75} ratio less than 1.0; vegetation, which exhibits the opposite spectral behavior, will have an R_{75} ratio much greater than 1.0. Further processing involves inputting the ratio of reflectance into digital and analog computers to produce digital ratio graymaps and analog ratio images, respectively. Later processing is planned in which automatic recognition maps of various rock classes will be produced, using two to four of the above reflectance ratios as a basis for automatic decision making.

The four months since ERTS data were first obtained have been spent primarily on development of the data processing techniques to be used, some of which are presented here. Initial interpretative efforts have been based on comparisons of aerial photography, geologic maps, and expected ratio values calculated from laboratory data. All of the data processing to date has been done on parts of ERTS frame E-1013-17294, collected on 5 August 1972. Once satisfactory results have been obtained for the primary test site, the rest of the ERTS frame will be "prospected" for unusual concentrations of iron oxides. A field trip to Wyoming to check anomalies and to collect samples for laboratory spectral measurements will be made this coming summer.

2. GEOLOGIC DESCRIPTION OF THE TEST SITE

The primary test site chosen for this investigation is the Atlantic City District, at the southern end of the Wind River Range, Wyoming. In this district, which has been mapped by R.W. Bayley [2], the Goldman Meadows Formation consists of schist, quartzite, and metasedimentary iron-formation. The iron-formation member, which contains on the average of 35% iron, is composed mainly of magnetite and quartz, with small amounts of chlorite, garnet, and amphibole. It is in this region that the U.S. Steel Corporation has an operating iron mine.

Just south and east of the Goldman Meadows Formation is the Roundtop Mountain Greenstone Formation, consisting of ellipsoidal greenstone (derived from basalt) and green schist. Just southeast of that formation is the Miners Delight Formation, composed primarily of graywacke (turbidites), schist, conglomerate, and ellipsoidal greenstone (derived from andesite). To the west of the iron mine is the Louis Lake batholith, which is primarily biotite-hornblende quartz diorite and granodiorite, bordered by migmatite and gray gneiss. Interlaced within the batholith are diabasic gabbro dikes of widths on the order of 60 to 100 meters and lengths up to 10 kilometers. All formations previously listed are Precambrian in age. Due north of the Goldman Meadows Formation lies a sedimentary series of beds from Precambrian to Mesozoic in age. These beds lie unconformably on the metamorphic and igneous rocks previously mentioned and dip northeastward, exposing Precambrian sandstone adjacent to the metamorphics.

3. AIR PHOTOS AND ERTS SINGLE-CHANNEL IMAGES OF THE TEST SITE

Figure 1 shows an aerial photo taken from a high-altitude, October, 1971 flight of the NASA U-2 aircraft [3] and a MSS channel 5 ERTS image of the test site. Both photo and image encompass the red portion of the visible spectrum and are the same scale, although the ERTS image is inadvertently shifted slightly northward in comparison of the aerial photo. The iron mine, which is the one-km-wide bright region (shaped somewhat like an extracted molar) in the lower right of the ERTS image, seems more distinct in the ERTS image, probably due to film-saturation of the image for even moderately bright targets. On both photo and ERTS image, intersecting diabasic gabbro dikes (on the order of one ERTS spatial resolution element) are visible west of the iron mine in the Louis Lake batholith. For future reference, note three things: (1) the iron mine does not appear unique, or even distinctive, from other areas in the scene; (2) the sedimentary strata in the upper right corner of the ERTS image appear similar to one another; and (3) vegetation (dark) in the channel-5 ERTS image is easier to distinguish from non-vegetation than in the aerial photo (probably because of the time of year). Dark shadows (in the northeast trending valley) appear similar to vegetation in both ERTS image and photo.

Figure 2 shows the same scene as in the previous figure. The aerial photo was taken in the 0.51 - 0.90μm wavelength range and the ERTS image is for MSS channel 7 (0.8 - 1.1μm wavelength region). Although the iron mine is darker than its surroundings, in contrast to a brighter-than-average reflectance in the visible red region, it is not distinct from the surrounding terrain in the reflective infrared region of either the aerial photo or the ERTS channel 7 image. Note further that the diabasic gabbro dikes in the Louis Lake batholith are virtually undetectable in the ERTS channel 7 image, the sedimentary strata in the upper right corner appear similar to one another in both photo and image, and vegetation (bright) in the upper right corner of the channel 7 ERTS image is more discriminable from non-vegetation than in the false color aerial photo, again possibly because of time of year differences between the data collections.

4. RATIO MAPS OF THE TEST SITE

Two forms of ratio maps have been produced thus far for the test site; one is a digital ratio graymap and the other form is an analog ratio image.

The digital graymap is used as a research tool for quantitative analysis, to examine the accuracy of the ratio method. Figure 3 shows an R_{75} (ERTS channel 7 divided by channel 5) digital ratio graymap. (Note: This figure and figure 4 were originally in color. See Figure 4 for color interpretations). Green represents vegetation, violet is primarily a mixture of rock and vegetation, blue is rock outcrop, and red represents magnetite, possibly some greenstone, and other possible iron-rich outcrops. The darkest red occurs only in the iron mine and along pond edges, where muds or tailings may be present.

The atmospheric path radiances obtained from the dark object subtraction were about 12% of the mean signal level in channel 5 and less than 4% of the mean level in channel 7 in the hilly Atlantic City District, which is approximately 2.5 km above sea level. At two other points, approximately one-half and three-fourths of the ERTS frame to the east, in flat, open plains that are about 0.3 km lower in elevation, path radiance percentages determined by dark object subtraction in channels 5 and 7 were 22% and 4%, respectively, of the mean signal levels. Without these corrections large errors in the ratio would have been made for objects which are dark in channel 5 within a given scene, and the errors would have been substantially different in the two parts of the ERTS frame. Since this ERTS frame was collected on a clear, dry day for a high mean elevation test site, atmospheric corrections would appear to be more necessary for less favorable observing conditions over lower test sites, if consistent data processing results are desired.

Figure 4 shows some R_{75} reflectance ratios calculated from a subset of laboratory data contained in the NASA Earth Resources Spectral Information System at the Johnson Spacecraft Center in Houston, Texas. Not all of the categories displayed here are represented in the test site. The values corresponding to the graylevels of the ratio graymap in figure 3 are also shown here. For calculation of these laboratory spectra reflectance ratios, square filters were assumed for the ERTS MMS channels; this assumption makes the calculated vegetative R_{75} ratio lower than that calculated from ERTS data because of the rapidly rising reflectance of vegetation longward of 0.67μm. The other ratios should be close to the ERTS-drived ratios, and they are to the best of our current estimation. All of the obviously exposed rocks (granite, limestone, greenstone, magnetite, hematite, grey sand) in the Atlantic City District have ERTS-derived R_{75} ratios that are within the R_{75} ratio ranges calculated from corresponding lab samples. However, only lab spectra of rock samples from the test area will yield a final answer as to the absolute accuracy of the ratio method.

There are two comments concerning figure 4 that should be made here. First, the lab-derived ratio ranges represent the extreme (highest and lowest) in R_{75} for each given rock category, and most categories include specimens as small as 0 - 5μm in particle diameter. This is a worst case. Secondly, this is only one ratio, and final decisions concerning rock classifications will be made on the basis of two to four ratios. Further work using laboratory data to derive ratio limits for these rock categories is planned, such that a ratio gating logic can be derived for the production of automatic recognition maps with an AND gate for each of the two to four ratios.

The other form of ratio map produced thus far is an analog ratio image. This yields a continuous display of ratio values, as if the ratio were a single channel of information. Figure 5 is an R_{75} analog ratio image which includes the whole Atlantic City District and more of the surrounding region. Note the enhanced iron mine (dark) discrimination from most of the immediately surrounding background. Note also that the sedimentary strata in the upper right of the R_{75} ratio image (not as near the corner as in Figures 1 and 2) are still indistinct. The diabasic gabbro dikes in the Louis Lake batholith are distinctive, however. Finally, note that the discrimination between vegetation (brighter) and non-vegetation (darker) is better in this ratio image than in either aerial photos or single-channel ERTS images.

An analog R_{74} ratio image of the same area (Fig.6) shows the iron mine (dark, but brighter than water) to be unique from all other points in the scene. The Jurassic sediments (relatively bright) and thin, dark beds of some sedimentary origin are discriminated from adjacent sedimentary strata in the upper right of the R_{74} ratio image. In no other photos or images shown in Figures 1 through 5 are there sediments discriminated this well. Vegetation is easily discriminated from non-vegetation; shadows, which are minimized, are not mistaken for vegetation here, as they were in the channel 5 ERTS imagery of Figure 1.

These analog ratio images focus the attention of the geologist or other scientist on areas in the scene where chemical properties of a target are different from its surroundings. The ratio images contain information which, when interpreted by the human eye, is either not available or difficult to distinquish in aerial photos or single channels of ERTS imagery. Furthermore, the ratios are dimensionless numbers with which laboratory data and points in the scene of interest can be compared. The data shown here only prove that geochemical data exist in ERTS data. Further data processing and ground truth investigations are necessary to permit the organization of these data into as many meaningful classifications as it possible.

5. CONCLUSIONS

The following general conclusions are made from the foregoing discussions:

1. Ratio images of ERTS data appear to be better than either aerial photos or ERTS single channel images for discrimination between vegetation and non-vegetation.
2. Some geological features smaller than the publicized spatial resolution of ERTS, such as the diabasic gabbro dikes in the

Louis Lake batholith, are seen as well in ERTS single-channel images and ERTS ratio images as in high altitude aerial photos.

3. Geochemical information definitely is contained in ERTS images and ratio images, which are generally superior to aerial photos because of the limited spectral range of the latter. Iron oxides are more easily discriminated from ERTS ratio images than from ERTS single-channel images or from high altitude aerial photography. This is useful in mineralogical exploration because exposures of several types of metallic ores are often associated with iron oxides. The differing relationships between rock type and iron-bearing minerals may also be useful in general geologic reconnaissance mapping, due to the resultant variability of ferric and ferrous compounds present. Satellite geologic reconnaissance would be much cheaper than aerial data collection over most large, remote sites.

4. On the basis of the ERTS ratio images, it seems plausible that an automatic recognition map can be made on the basis of selected spectral ratios of ERTS data which will distinguish rock and soil exposures from all other materials in the scene (within the limits of the ERTS spatial resolution) and discriminate two to four meaningful rock groups (each consisting of one or more rock types).

5. The agreement observed thus far on absolute ratio numbers between ERTS ratio maps and laboratory spectra encourages efforts to use laboratory data as training sets for geologic targets, which if successful, would enable the same automatic discrimination over unknown geologic terrain throughout the world, with reasonable atmospheric conditions.

6. Early quantitative analysis indicates that consistent results for this or other data processing techniques over large geographical distances or large time periods over a given test site will require some type of atmospheric corrections. The empirical atmospheric corrections used in this ratio method appear to be effective for high-elevation test sites, but have yet to be tested with areas near sea level.

7. The method being developed for this investigation would appear to be useful for scientific applications other than geology. Soil mapping and biomass estimation are two such applications.

REFERENCES

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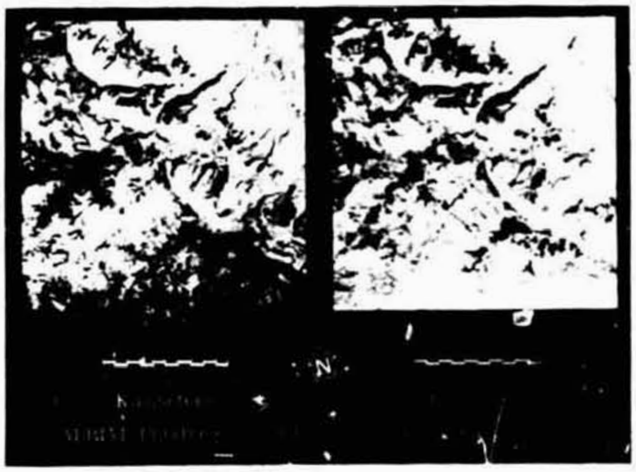


Figure 1. Aerial Photo and ERTS Image in the Visible Red of the Southern Wind River Range, Wyoming

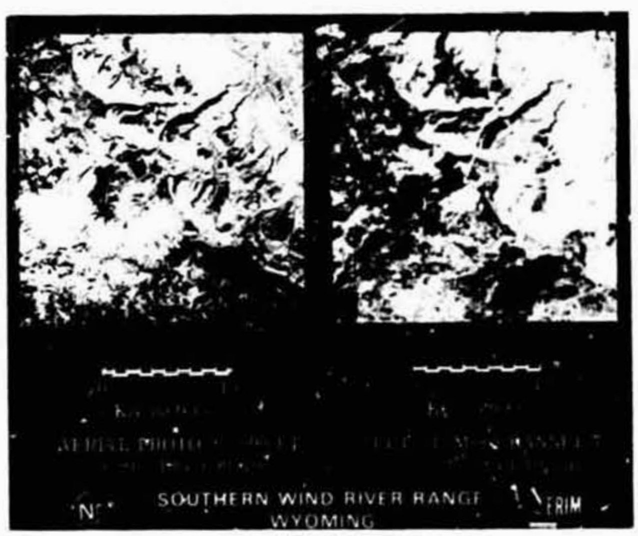


Figure 2. Aerial Photo and ERTS Image in the Reflective Infrared of the Southern Wind River Range, Wyoming

Figure 3. ERTS Digital R_{75} Ratio Graymap of Southern Wind River, Wyoming

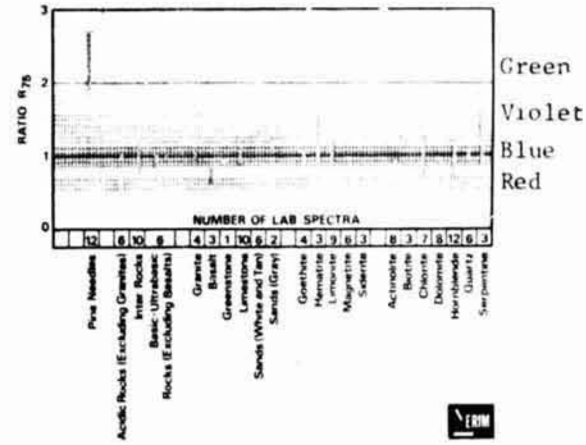
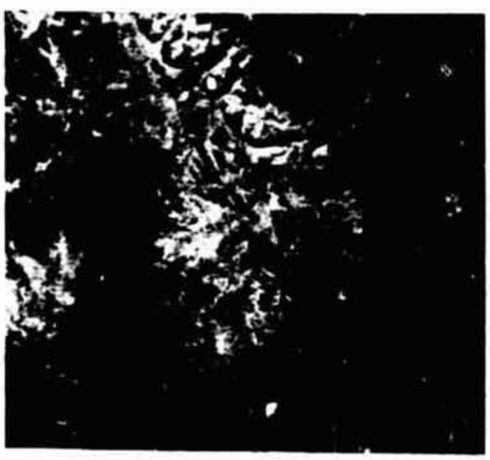
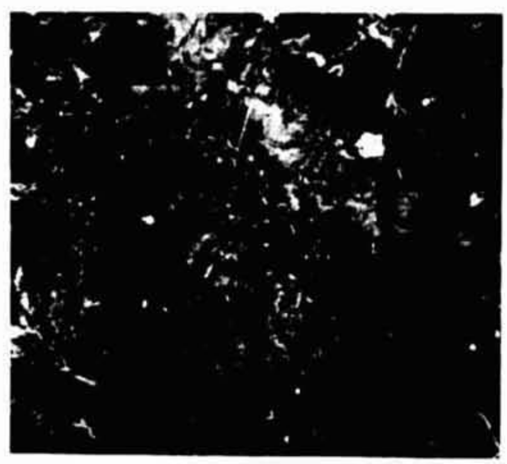


Figure 4. Expected R_{75} Ratios Calculated from Laboratory Data



0 5 10
Kilometers

Figure 5. ERTS Analog R_{75} Ratio Image of Southern Wind River Range, Wyoming



0 5 10
Kilometers

Figure 6. ERTS Analog R_{74} Ratio Image of Southern Wind River Range, Wyoming