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Preliminary report on the use of LANDSAT-1 (ERTS-1) reflectance data in locating alteration zones associated with uranium mineralization near Cameron, Arizona

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This report is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards and nomenclature.

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PRELIMINARY REPORT ON THE USE OF LANDSAT-1 (ERTS-1) REFLECTANCE DATA IN LOCATING ALTERATION ZONES ASSOCIATED WITH URANIUM MINERALIZATION NEAR CAMERON, ARIZONA

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Abstract

LANDSAT-1 (ERTS-1) multispectral reflectance data were used to enhance the detection of alteration around uranium deposits near Cameron, Ariz. The technique involved stretching and ratioing computer-enhanced data from which electronic noise and atmospheric haze had been removed. Using present techniques, the work proves that LANDSAT-1 data are useful in detecting alteration around uranium deposits, but the method may still be improved. Bluish-gray mudstone in the target area could not be differentiated from the altered zones on the ratioed images. Further experiments involving combinations of ratioed and nonratioed data will be required to uniquely define the altered zones.

Introduction

The Cameron uranium district is located in northeastern Arizona about 80 km (50 mi) north of Flagstaff (fig. 1); it lies between Black Mesa basin on the northeast and the Kaibab uplift on the southwest. Structurally the area is simple. The regional dip of 2 or 3 degrees to the northeast is only locally interrupted by a few minor faults and folds and several collapse features. The low dips, along with the low relief and the structural simplicity of the area, result in broad exposures of the formations. The climate is arid and, to a great extent, the area is devoid of vegetation. Consequently many of the easily eroded silty and clayey parts of the stratigraphic section have been carved into a badlands topography, which is brilliantly colored and named the "Painted Desert". These broad, barren, colorful exposures make the Cameron area an excellent site for experiments involving LANDSAT, formerly ERTS, reflectance data.

Mining activity

Currently no mines are active in the Cameron area, but the increased demand for uranium has revived interest in the district. Economic factors have restricted mining near Cameron to shallow depths; however, more ore is likely to be obtained from greater depths. Ores in the area contain uranium oxides that are low in vanadium (Austin, 1964) and can easily be leached. Thus, ores that were previously too deep or of too low a grade to be economical might now be profitably recovered because of the higher price of uranium and the development of _in situ_ leaching techniques.

Objective

The purpose of this investigation is to produce a map of the altered zones near Cameron that will be useful in further prospecting of the area and to develop techniques for detecting color alteration from LANDSAT reflectance data that may be applied in other uranium districts.

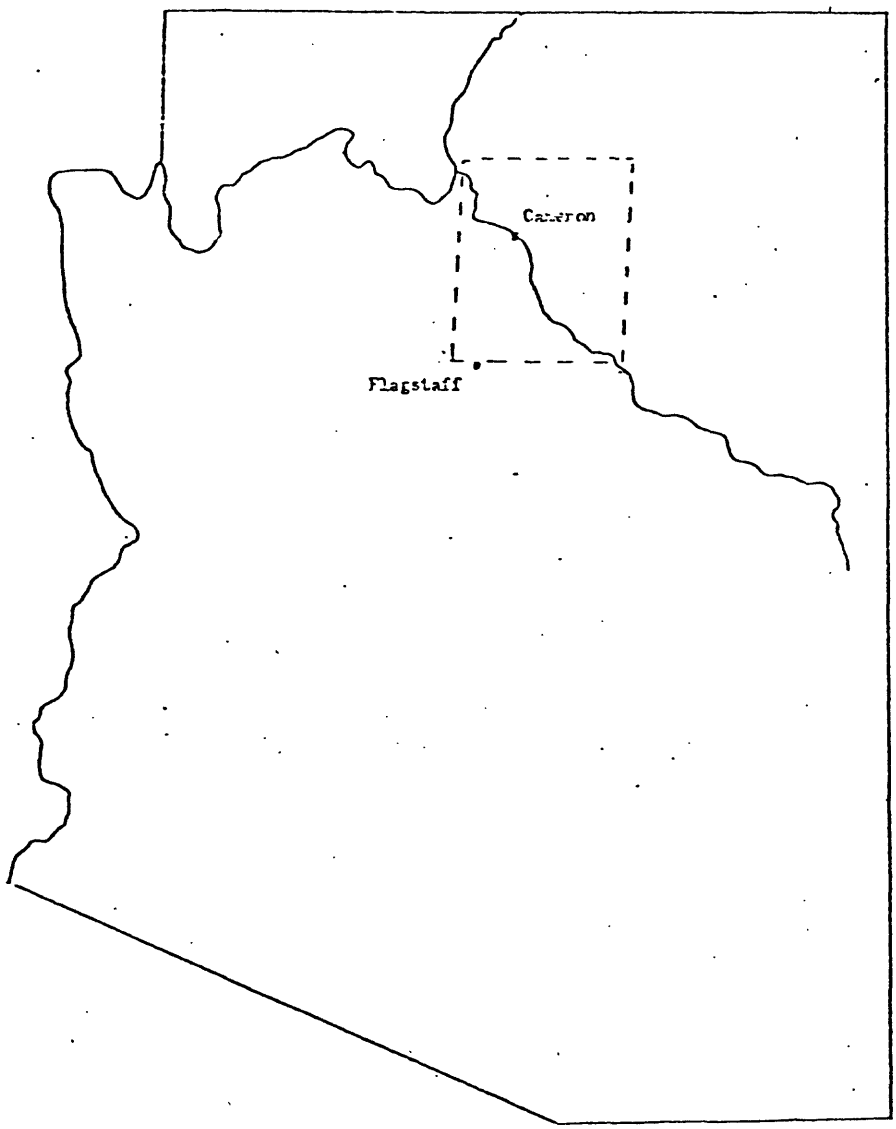

Figure 1.--Location of the southwest quarter of LANDSAT-1 frame #1463-17300 Images shown in figures 4-6.

Stratigraphy

The oldest of the exposed sedimentary rocks in the Cameron area is the Permian Kaibab Formation. The Kaibab is a yellow-gray limestone that is exposed on the Kaibab Plateau in the southwest part of the study area and in the Little Colorado River Gorge (Akers and others, 1962).

Above the Kaibab Formation lies the Moenkopi Formation of Early Triassic age. In the Cameron area, the Moenkopi Formation is nearly 120 m (400 ft) thick and is characterized by reddish-brown siltstones and sandstones and minor gypsum beds. Where the overlying Chinle Formation is mineralized, the upper few metres of the Moenkopi Formation is commonly bleached (R. A. Cadigan, oral commun., 1975).

The Chinle Formation of Late Triassic age unconformably overlies the Moenkopi and contains most of the ore in the Cameron district. The Chinle is the primary target of this investigation. Locally, four members of the Chinle Formation are recognized (Repenning and others, 1969). Lowest is the Shinarump Member, which is composed of 15-30 m (50-100 ft) of yellowish-gray to pale-red, lenticular sandstones and conglomerates and minor mudstones. Above the Shinarump, Repenning, Cooley, and Akers (1969) recognized an informal transitional sandstone and siltstone member. In the Cameron district, the sandstone and siltstone member is predominantly a fine- to coarse-grained, poorly sorted, multicolored sandstone from 30-50 m (100-160 ft) thick. Colors within the sandstone and siltstone member range from very light gray and pale-reddish-purple to grayish-red-purple and moderate-yellow-brown (Repenning and others, 1969). The sandstone and siltstone member grades into the overlying Petrified Forest Member of the Chinle Formation. In the study area, the lower 60 m (200 ft) of the Petrified Forest Member is dominated by bluish mudstones; the middle portion consists of 120 m (400 ft) of gray mudstone and sandstone, and the upper 75 m (200 ft) is composed of red sandstone and mudstone. The Owl Rock Member is the uppermost member of the Chinle Formation. It consists of approximately 90 m (275 ft) of mottled, pale-blue or grayish-pink limestone interbedded with orange-pink siltstone.

An erosional surface showing minor relief separates the Chinle Formation from the overlying Glen Canyon Group. Included in the Glen Canyon Group, in ascending order, are the Wingate Sandstone, which is a reddish-brown, crossbedded, fine-grained sandstone; the Moenave Formation, composed of lenticular, orange-red sandstone; the Kayenta Formation, consisting of reddish-brown to reddish-purple siltstone and sandstone; and the Navajo Sandstone, which is characterized by pale-reddish-brown, well-sorted sandstone with large-scale crossbedding.

Alteration associated with the ores

Most of the ore in the Chinle Formation occurs in the upper part of the Shinarump Member, in the sandstone and siltstone member, and in the lower part of the Petrified Forest Member. Within the formation, uranium is associated with organic material and concentrated in permeable channel sands. Apparently the mineralizing solutions redistributed iron in the vicinity of the ores and oxidized pyrite and marcasite, forming sulfuric acid and ferrous sulfate. Oxygen dissolved in the mineralizing solutions converted ferrous sulfate to ferric sulfate, which hydrolized to limonite and jarosite;much of the sulfuric acid reacted with calcite to form gypsum and with aluminous rocks to form alunite (Austin, 1964). As a result of this alteration, most of the ores in the Cameron district are surrounded by a light-brown-yellow alteration halo characterized by the following minerals: limonite, jarosite, gypsum, and alunite. These haloes contrast markedly with the typical purple to gray color of most of the unmineralized parts of the Chinle Formation (Isachsen and Evensen, 1956). The alteration haloes are generally elongate and as much as 0.4 km (0.25 mi) in length (Birdseye, 1958). Thus the larger alteration haloes are within the resolution of the LANDSAT system.

Although alteration colors are useful as a guide to ore deposits in the Cameron area, these colors are not uniquely related to ore deposits for the following reasons: some unmineralized parts of the Chinle Formation have a color that resembles the altered zones; uranium may have been remobilized and removed since the alteration occurred; and alteration is the effect of the oxidation of sulfides that may be present without uranium ore (Austin, 1964).

Acknowledgments

We would like to express our gratitude to R. A. Cadigan for suggesting that LANDSAT be investigated as a potential uranium exploration tool and for giving us the responsibility of designing and conducting this experiment. We also appreciate the assistance we received from L. A. Soderblom and P. S. Chavez of the U.S. Geological Survey in Flagstaff, Ariz.

LANDSAT multispectral-scanner reflectance data

The LANDSAT satellite orbits the Earth at an altitude to 910 km (570 mi). On board the satellite are six four-channeled, spectral scanners that collect spectral reflectance data from four discrete parts of the electromagnetic spectrum, each of which is referred to as a channel or band. The wavelength ranges of the four bands are: band 4, 0.5 to 0.6 um (micrometres)--green light; band 5, 0.6 to 0.7 um--red light; band 6, 0.7 to 0.8 um--infrared; band 7, 0.8 to 1.1 um--infrared.

Information from each band is stored as one data set, which represents a digitized image. A digitized image may be thought of as a two-dimensional array of the intensity of reflectance detected by the scanners and of the picture element ("pixel") from which the reflectance was received. A LANDSAT image contains about 7.5 million "pixels". Each "pixel" represents (after geometric corrections) an area on the Earth's surface of about 6,240 m^2 (67,140 ft^2).

The intensity of reflectance for each band from each "pixel" is recorded as a binary digital number. For bands 4, 5, and 6, digital numbers are presented as 7-bit information according to the binary system of numbers with values ranging from 0 to 127. The digital numbers of band 7 are recorded as 6-bit information (values of 0 to 63).

By applying image-processing techniques to these data in the form of digital numbers, it is possible to convert the reflectance data to imagery that may be interpreted in terms of semiquantitative geochemical information about rock types within the LANDSAT image, to a resolution of a unit area of about 6,240 m^2 (67,140 ft^2) (79 m by 79 m (260 ft by 260 ft)).

Image-enhancement techniques

Rowan and others (1974) have shown that geochemical information is contained in the reflectance data obtained from the LANDSAT system and that stretched-ratioed images are more useful for detecting and presenting subtle geochemical information than are images of single LANDSAT bands or composites of bands. Prior to ratioing and stretching, noise and atmospheric back-scattering effects (haze) must be removed from the data.

Noise

A type of noise in the LANDSAT data that must be removed is due to differences in calibration among the six scanners. These differences cause a series of west-to-east scan lines to appear on the images. A first step in the removal of this "six-line scanner noise" is the generation of a series of histograms of the digital numbers versus their frequency of occurrence for each band of each of the six scanners. Then a computer program entitled "histogram noise" forces the mean value of the histograms to coincide by shifting the histograms along the digital-number axis. As the mean values of the histograms shift positions, each datum point moves by an equal amount. The effect is an equalization of the histograms that compensates for the imprecision of the calibration of the scanners and eliminates the "six-line scanner noise". In studies where this type of noise was not removed (as in Rowan and others, 1974), the "six-line scanner noise" could limit the resolution and therefore the usefulness of the ratioing technique, especially for small targets.

Haze

Haze, which is caused by the backscattering of light in the atmosphere, is removed from the data with the aid of histograms of the digital numbers versus the frequency of occurrence of each digital number. On these histograms (fig. 2), low frequencies are observed for the lowest digital numbers, followed by an abrupt change to higher frequences beyond some point on the digital-number axis. All values below the abrupt change are attributed to haze above a nonreflecting (black) object, whereas values above the abrupt change are considered as ground reflectance plus haze. Haze is removed by subtracting the digital number attributed to haze for each band from each of the picture elements within the frame (P. S. Chavez, oral commun., 1974).

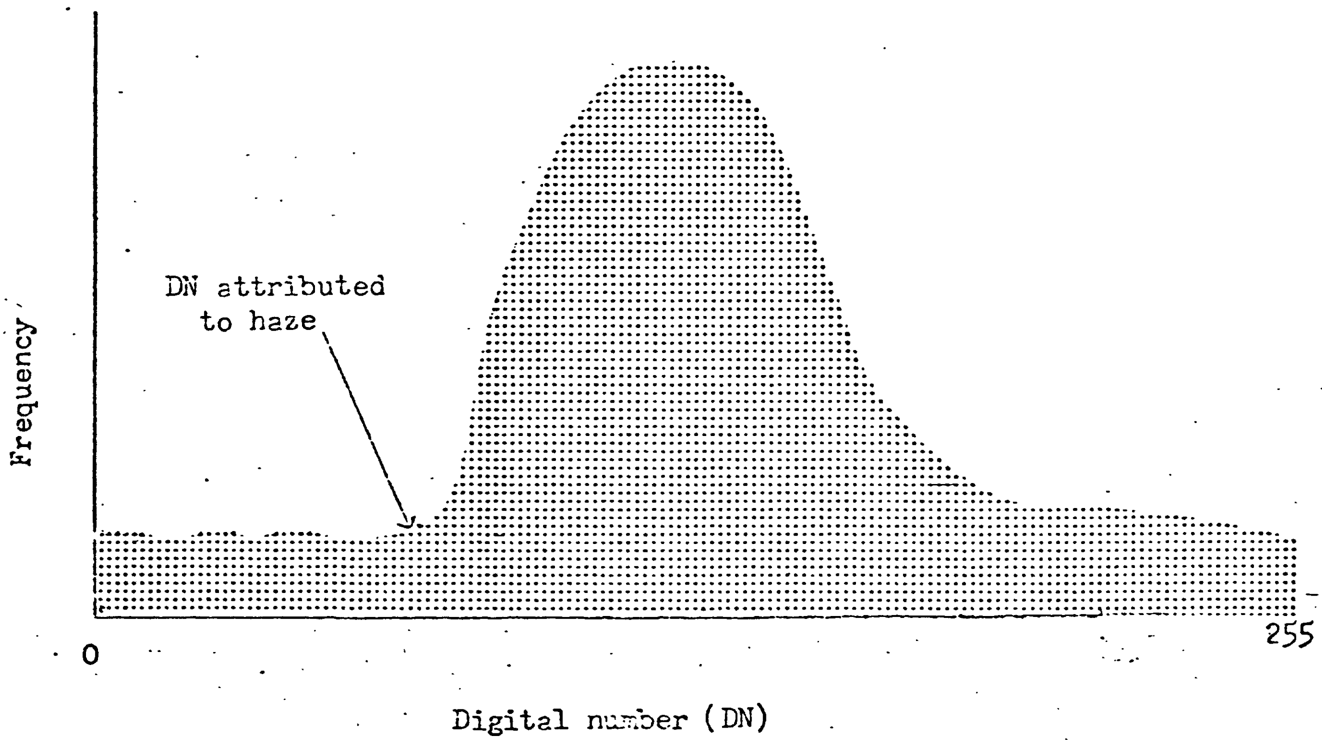

Figure 2.--Example of a frequency-of-occurrence versus digital-number histogram.

"Enhanced natural color" image

Once "six-line scanner noise" and haze are removed, the data are ready to be used to produce an "enhanced natural color" image (Eliason and others, 1974) and to ratioed. In order to produce an "enhanced natural color" image, the blue component of the ground reflectance must be approximated. (Because of the large degree of backscatter (haze) for the blue wavelengths of light, blue was not included as one of the LANDSAT bands.) The blue component is generated by plotting the digital numbers for each picture element for all four of the LANDSAT bands versus the wavelengths of each LANDSAT band and extrapolating to an approximated digital number for the blue component of each picture element. The generated blue component, the green component (band 4), and the red component (band 5) are composited as an "enhanced natural color" image.

Ratioing

Ratioing is the division of one band by another for each picture element. The technique accentuates subtle differences in reflectance and eliminates differential lighting effects caused by topography. Generally, the ratioed data occupy only the central portion of the range of digital numbers. Thus, in order to maximize the contrast, the data must be "stretched". Stretching systematically redistributes the data to fill the entire digital-number range. In the case of a linear stretch, each datum receives a new value at a constant percentage farther from the mean of the original ratioed data. Thus the complete range of digital numbers is used, and the contrast is enhanced. Another type of linear stretch, termed an "autostretch", sets the mean value of the data at the center of the digital-number range and maps data contained above and below preselected percentages of the total data to the extreme values of the range of the digital numbers. The remaining data are systematically redistributed as in a linear stretch. Rowan and others (1974) presented a more detailed description of stretching techniques.

Presentation of the data

Stretched-ratioed pairs of LANDSAT bands are generally produced in the form of black and white negatives. Commonly, three stretched-ratioed pairs are composited by printing each in a different color onto the same piece of photographic film. Colors in these images serve to amplify the boundaries between areas of contrasting characteristics. They do not depict true ground reflectance; instead, they relate to changes in reflectance.

Methods

Approximately one-fourth of a LANDSAT-1 digitized image (#1463-17300), which centered in the Little Colorado River Valley, was preprocessed from computer-compatible tape obtained from the EROS Data Center in Sioux Falls, S.D. This preprocessing included reformating the magnetic-tape data, removing atmospheric haze, removing "noise," standardizing the sun angle, and correcting systems distortions to rectify the magnetic-tape data into an orthoimage. (See fig. 3.) This data base was then processed through an "enhanced natural color" program to obtain an initial image similar to a color aerial photo (fig. 4). The original data base was then reused as input for a "ratio" routine that resulted in three output data sets: one representing the result of dividing the reflectivity value (as recorded on a scale of 0 to 255) for band 4 of each "pixel" into the reflectivity value for band 5 of each "pixel," another for the division of band 6 by band 4, and a third for the ratio of band 7 to band 4. Because the ratioed data occupied only a small portion of the range of digital numbers, it was necessary to stretch the ratioed data to increase the contrast. A large variety of stretches could have been used. Fortunately, even without prior knowledge of the reflectance of an altered area, it is possible to choose the stretch parameters that are likely to be near the optimum for enhancing alteration by defining a sample area in which alteration is known to occur and choosing stretch parameters that yield the maximum spectral discrimination within the area. In order to do this, a technique known as "cluster analysis" was employed to generate histograms of the ratioed data of just the sample area. From an evaluation of these histograms, the stretch parameters were chosen; they are presented in table 1.

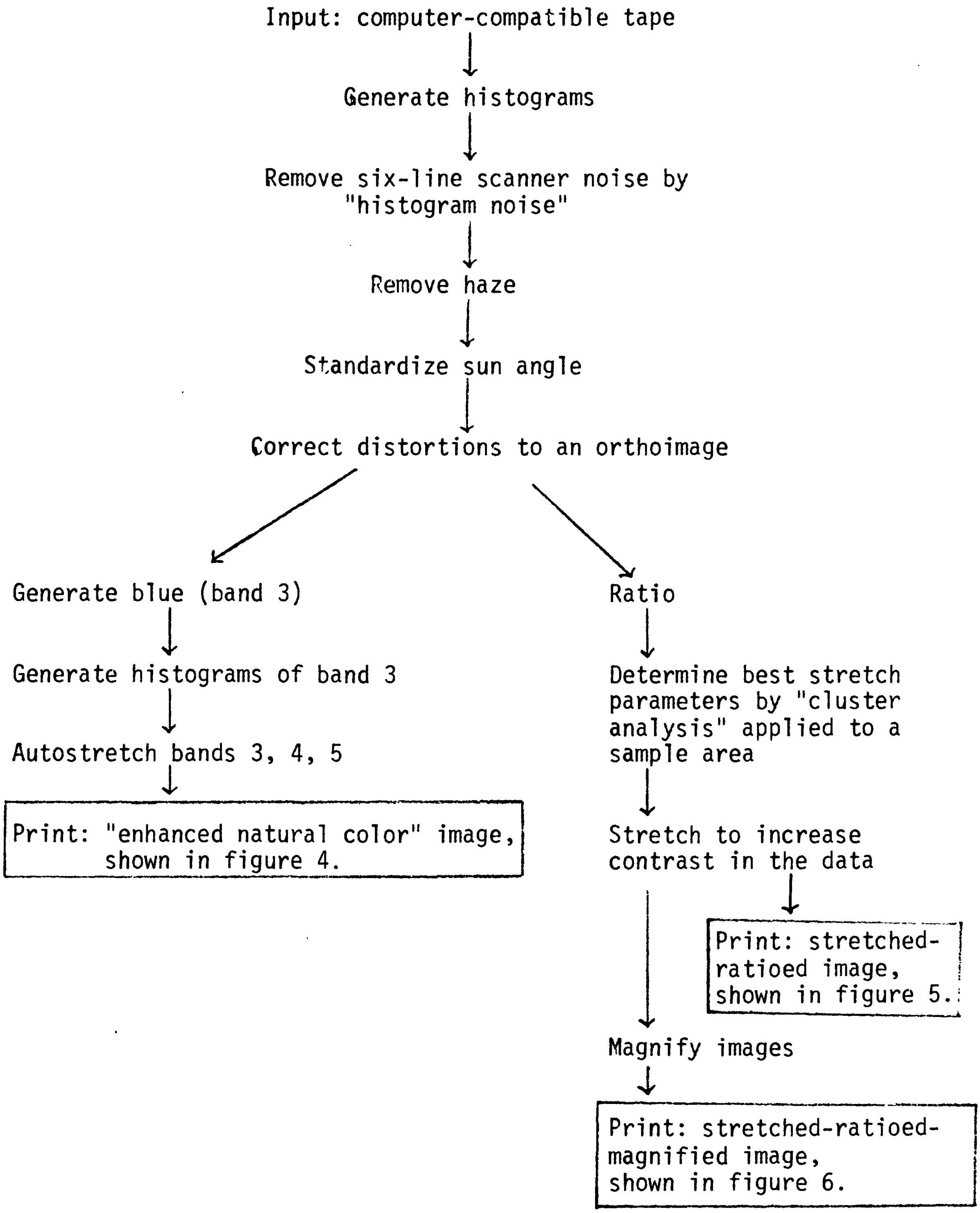

Figure 3.--Flow chart of computer-enhancement techniques.

Figure 4.--"Enhanced natural color" image of the Cameron area.

Table 1.--Stretch parameters and printing colors

Original ratioed value	Contrast-stretched value	Color component in image
	IMAGE 2 (fig. 5)	
	Band 5 (0.6 to 0.7 um)/Band 4 (0.5 to 0.6 um)	
120	0	No blue.
145	127	Intermediate blue.
173	255	High blue.
	Band 6 (0.7 to 0.8 um)/Band 4 (0.5 to 0.6 um)	
58	0	No green.
71	127	Intermediate green.
89	255	High green.
	Band 4 (0.5 to 0.6 um)/Band 7 (0.8 to 1.1 um)	
174	0	No red.
193	127	Intermediate red.
205	255	High red.
	IMAGE 3 (fig. 6)	
	Band 4 (0.5 to 0.6 um)/Band 7 (0.8 to 1.1 um)	
174	0	No blue.
193	127	Intermediate blue.
205	255	High blue.
	Band 6 (0.7 to 0.8 um)/Band 4 (0.5 to 0.6 um)	
58	127	Intermediate green
71	255	High green.
89	127	Intermediate green
	Band 7 (0.8 to 1.1 um)/Band 4 (0.5 to 0.6 um)	
50	0	No red.
62	127	Intermediate red.
81	255	High red.

The reflectance of the altered rocks is similar throughout the mining district. Therefore, by applying the stretch parameters chosen on the basis of the analysis of the sample area to the entire one-fourth frame, altered areas in other parts of the one-quarter frame were accented. In order to present all of this information on one image, each of the three stretched-ratioed data sets was equated to one of the three primary colors (red, green, or blue) and printed on the same piece of photographic film. The result is an easily interpretable single data set derived from the information contained in all four LANDSAT bands. (See fig. 5.) Figure 6 was constructed in a similar manner; however, in this case, emphasis was placed on bands 4 and 7 by using both the ratio of 4 to 7 and its reciprocal. (See table 1.)

Figure 5.--Stretched-ratioed, false color image of the Cameron area. Band 5/band 4, printed in blue; band 6/band 4, printed in green; band 7/band 4, printed in red.

Figure 6.--Stretched-ratioed-magnified, false color image of the Cameron area. Band 4/band 7, printed in blue; band 6/band 4, printed in green; band 7/band 4, printed in red.

Interpretation of the Images

The "enhanced natural color" image (fig. 4) proved to be quite informative. Most of the formations and some of their members can be recognized on this image. A number of grabens, faults, collapse structures, volcanic cones, and basalt flows are also discernible. Areas tentatively identified as altered areas around the uranium deposits appear as a light-gray or light-brown color on the "enhanced natural color" image. The light color (high albedo) cannot be used as the sole criterion for identifying altered areas because much of the surface of the target area is also light colored.

Stretched-ratioed images (figs. 5 and 6) were more effective in accenting the alteration zones within the Petrified Forest and sandstone and siltstone members of the Chinle Formation. Approximately 75 percent of the mines in the Petrified Forest and sandstone and siltstone members that were not obscured by alluvium or vegetation are located in the accented parts of the images, the red areas of figure 5 and the blue areas of figure 6. Examination of the area from a low-flying aircraft verified that the altered areas are indeed contained within the accented parts of the images. The fact that most of the mines are located at the edges of the altered areas is consistent with the interpretation that the mineralizing solutions altered rocks along their path. Unfortunately, the bluish-gray mudstone near the base of the Petrified Forest Member was also accented and presented in these ratioed images in the same color as the altered areas.

Conclusion

Stretched-ratioed LANDSAT images may be used within limits to identify surficial alteration associated with uranium mineralization in the Cameron area. The usefulness of these images is limited by the fact that a bluish-gray mudstone in the area was not differentiated from the altered zones by the imaging. Further refinement of the imaging techniques will be required to accomplish this. The higher albedo of the altered zones compared with that of the mudstones is likely to be critical in differentiating areas of alteration from mudstone areas. Future experiments involving the combination of nonratioed data (which preserves albedo differences) with ratioed data on the same image are likely to succeed in uniquely defining the alteration.

For the present, the final product of this experiment, figure 6, greatly reduces the size of the exploration target areas to be tested by field exploration methods.

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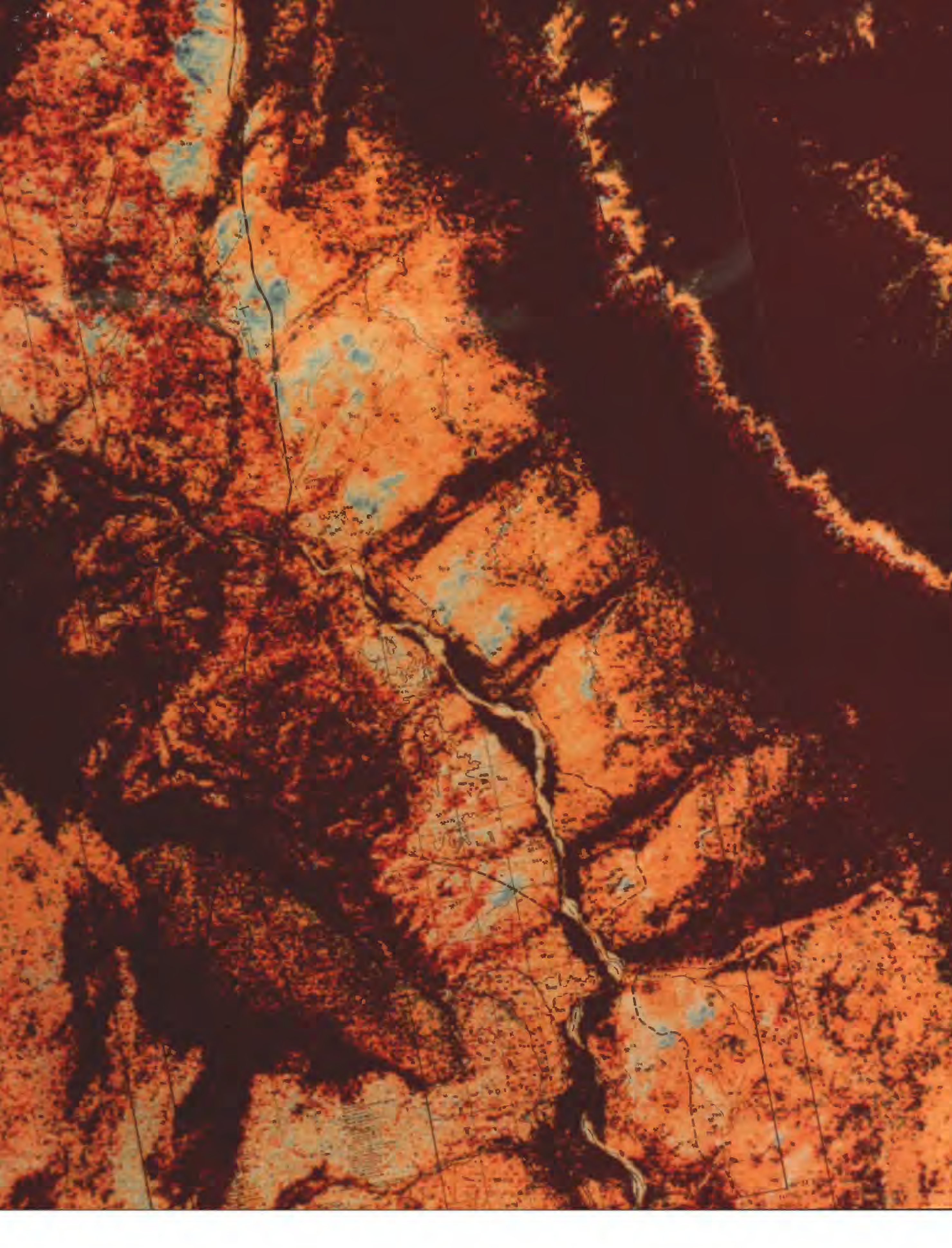
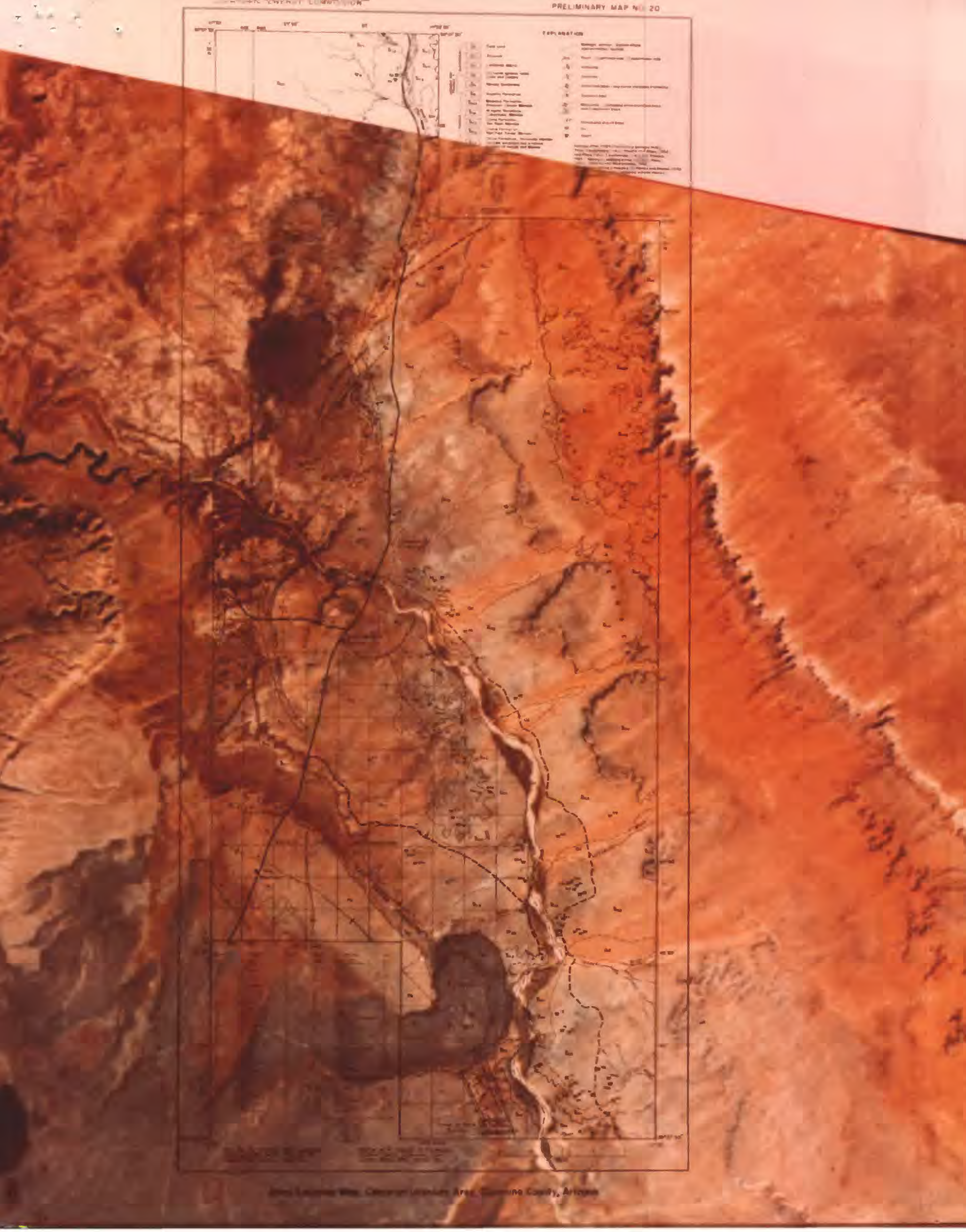
Mine Location Map, Cameron Uranium Area, Coconino County, Arizona

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