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Remote Sensing Study in Support of Mineral Resource Appraisal of Wilderness Study Areas near Moab, Utah: Dolores River Canyon Wilderness Study Area, Montrose and San Miguel Counties, Colorado; Lost Spring Canyon Wilderness Study Area, Grand County Utah; Behind the Rocks Wilderness Study Area, Grand and San Juan Counties, Utah; Indian Creek Wilderness Study Area, San Juan County, Utah; and Butler Wash Wilderness Study Area, San Juan County, Utah

Keenan Lee
Denver, Colorado

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REMOTE SENSING STUDY IN SUPPORT OF MINERAL RESOURCE APPRAISAL OF WILDERNESS STUDY AREAS NEAR MOAB, UTAH:

Dolores River Canyon Wilderness Study Area, Montrose and San Miguel Counties, Colorado; Lost Spring Canyon Wilderness Study Area, Grand County, Utah; Behind the Rocks Wilderness Study Area, Grand and San Juan Counties, Utah; Indian Creek Wilderness Study Area, San Juan County, Utah; and Butler Wash Wilderness Study Area, San Juan County, Utah.

By

Keenan Lee

ABSTRACT

A regional remote sensing study was conducted to assist in evaluating the mineral resource potential of five wilderness study areas in western Colorado and eastern Utah, centered on Moab, Utah. Numerous Landsat Multispectral Scanner (MSS) images were used as the basis for a lineament analysis, and two Landsat MSS images were processed for limonite mapping. No Landsat Thematic Mapper data were available for this study.

The Behind the Rocks, Indian Creek, and Butler Wash Wilderness Study Areas are on or along major lineaments that reflect basement faults. One of these lineaments is part of the much longer Colorado Lineament.

Mapping of limonite was based on Landsat MSS color-ratio-composite images. No limonite concentrations were found that would indicate hydrothermal alteration. Likewise, no reverse limonite anomalies were found that could be related to either hydrocarbon seepage or uranium deposition, but narrow outcrop widths, vegetation cover, and variable initial iron content in the sedimentary rocks may preclude their recognition.

CONTENTS

INTRODUCTION

The Federal Land Policy and Management Act (Public Law 94-579, October 21, 1976) requires the U.S. Geological Survey and the U.S. Bureau of Mines to conduct mineral surveys on certain areas to determine the mineral values, if any, that may be present. Results must be made available to the public and be submitted to the President and the Congress. This report presents the results of a remote sensing study of an area that includes the Dolores River Canyon Wilderness Study Area (CO-020-290), Montrose and San Miguel Counties, Colorado; Lost Spring Canyon Wilderness Study Area (UT-060-131B), Grand County, Utah; Behind the Rocks Wilderness Study Area (UT-060-140A), Grand and San Juan Counties, Utah; Indian Creek Wilderness Study Area (UT-060-164), San Juan County, Utah; and Butler Wash Wilderness Study Area (UT0060-169) San Juan County, Utah.

Landsat Multispectral Scanner (MSS) data (available from the EROS Data Center, Sioux Falls, SD) covering a large part of western Colorado and eastern Utah were processed for a regional lineament analysis. Linear features mapped on the images were interpreted to derive longer linear trends of parallel linear features called lineaments (Sawatzky and Raines, 1979). Lineaments were interpreted, along with geophysical surveys and deep drilling data, for possible basement structures.

Landsat MSS images were also used to map variations in limonite content of surface rocks. The images were used to target hydrothermal alteration associated with mineralized rocks or limonite anomalies associated with either uranium depositon or hydrocarbon seepage. Limonite anomalies interpreted to be significant were subsequently checked in the field.

METHODS

LINEAMENT ANALYSIS

A lineament analysis was conducted in a region covering several U.S. Bureau of Land Management wilderness study areas in western Colorado and eastern Utah. The area incorporated in the analysis is bounded by 107° - 111° West Longitude and 37° - 40° North Latitude.

Linear features were interpreted from Landsat MSS images processed specifically for this purpose. Individual images were processed from single band data, using contrast enhancement and edge enhancement. Gary L. Raines (USGS) interpreted the Utah portion of the area and Keenan Lee interpreted the portion of the area in Colorado. Because several separate Landsat MSS scenes were required to cover the study area, the linear-feature data were digitized and compiled onto a single basemap (both Lambert and UTM projections).

This data compilation was then interpreted visually for long trends or strings of aligned linear features, which were combined into lineaments called visual lineaments (VL). Similarly, drainages were inspected on the images for anomalous linear reaches that were mapped as drainage lineaments (DL).

Lineaments were then correlated with published geological and geophysical data. Surface faults were determined from geologic maps at scales of 1:500,000 and 1:250,000. Basement structures were interpreted from the correspondence of lineaments with Bouguer gravity maps and aeromagnetic maps at a scale of 1:1,000,000, and with deep drilling data.

MAPPING OF LIMONITE FOR DETECTION OF HYDROTHERMAL ALTERATION

Landsat Multispectral Scanner (MSS) images are used to map the distribution of limonitic materials, which may act as guides to mineralized areas. The objective is to locate limonitic, hydrothermally altered rocks.

"Limonite" is used in this report as defined by Blanchard (1968) "to denote the undifferentiated ferric oxide precipitates as a group. By common consent the word has become accepted as a collective term designating all of the reddish, yellowish, brownish, and blackish-brown supergene ferric oxide or ferric oxide hydrate precipitates...which have not been more specifically identified".

"Limonitic hydrothermal alteration" refers to areas of hydrothermally altered rocks that contain limonite. Exposed sulfide mineral deposits commonly have limonitic surfaces derived from the oxidation of pyrite to goethite, hematite, or jarosite. A gossan may form, or more commonly, a limonite staining occurs. This limonite can be sensed remotely, even in small quantities that incompletely stain grain surfaces (Lee and others, 1983). Limonite minerals have absorption features in the blue region of the visible and near 0.9 micrometers in the infrared part of the electromagnetic spectrum. Both of these regions are sensed by the Landsat MSS. Areas of hydrothermally altered rocks that lack limonite minerals will not be found using this technique, and areas of limonitic rocks not related to hydrothermal alteration may be included. Limonite cannot be mapped reliably in areas where vegetation cover exceeds about 30 percent nor in shaded areas.

The study area was imaged by the Landsat 1 MSS on 25 June 1973 (image 1337-17314) and by the Landsat 2 MSS on 9 October 1975 (image 2260-17124). Computer-compatible tapes of these images were processed to reformat the images, to destripe them (that is, to compensate for variations in sensitivity of the six detectors by equalizing the means of their signals), and to correct them geometrically for skew effect of the earth's rotation (Raines and others, 1978). The images were contrast enhanced using parameters based on statistics of rock surfaces only--that is, the effects of vegetation and shadows were masked out by procedures developed by Knepper and Raines (1985).

Individual bands were ratioed to maximize spectral variations and to minimize illumination differences (commonly from topography). These band ratio images were combined to produce color-ratio-composite (CRC) images (Rowan and others, 1974) on which limonitic rocks appear distinctive. The CRC images were interpreted to locate those areas of limonitic rocks that may be associated with hydrothermal alteration (Lee, 1985).

LIMONITE MAPPING FOR REDOX ALTERATION RELATED TO HYDROCARBON SEEPAGE

Preliminary studies at Elaterite Basin, about 60 km south-west of Moab, show that migrating hydrocarbons produce distinctive alteration effects in the enclosing redbeds. Suggested changes caused by the alteration process include the development of kaolinite, the introduction of or increase in calcite, and changes in iron oxides. The latter change is the most obvious; ferric iron in hematite is reduced to the ferrous state, which allows removal of the iron as aqueous ferrous ion and retention of only trace amounts of hematite. Migrating hydrocarbons may also provide sulfur that combines with the reduced iron to form pyrite and marcasite in local concentrations. Thin films of ferrihydrite form on rock surfaces if the altered redbeds are exposed to weathering.

Red mudstones have reflectance spectra that show hematite and traces of kaolinite. The altered beds have spectra that show ferrihydrite, kaolinite, illite/smectite, and an overall increase in reflectance, or albedo. These spectral features are capable of being sensed by the Landsat satellite; the MSS can detect changes in iron mineralogy and albedo, whereas the Thematic Mapper (TM) also can sense the combined occurrence of clay minerals.

LIMONITE MAPPING FOR REDOX VARIATIONS ASSOCIATED WITH URANIUM DEPOSITS IN SEDIMENTARY ROCKS

Uranium ions in solution frequently precipitate in sedimentary rocks at sites where reductants occur. These sites commonly show limonite variations as well, because the ferric iron in hematite and goethite will be replaced by ferrous iron. The effects will be the same as described above: redbeds will appear limonitic whereas the reduced beds will not.

Uranium in the Triassic Chinle Formation in the Paradox Basin is associated with limonite anomalies. According to Chenowith (1975), in the vicinity of some of the deposits the color of the sandstone has been altered from reddish purple to greenish gray. Similar effects are associated with uranium deposits in the Permian Cutler Formation (Chenowith, 1975), although some uranium in this formation apparently is concentrated in hematite grain coatings in the absence of reductants (Campbell, 1981).

Limonite mapping, as described above, could show these redox variations in iron compounds and perhaps be a guide to those uranium deposits that display reduction of limonite. Both Landsat scanners, the MSS and TM, have the capability to image these differences, especially using CRC images in combination with any single band image or color-infrared composite.

RESULTS

Results of the lineament analysis are shown in figure 1, and the correlations of these lineaments with Bouguer gravity maps, aeromagnetic surveys, Precambrian structure as determined from deep drilling, and recent geologic maps at a scale of 1:500,000 are listed in table 1.

DOLORES RIVER CANYON WILDERNESS STUDY AREA

The Dolores River Canyon Wilderness Study Area lies near the southeastern end of a major lineament (lineament VL 5, fig. 1 and table 1). This lineament coincides with a typical salt anticline structure to the northwest - an elongate, northwest-trending anticline with a crestal graben. Although the surface expression of this structure is interrupted by the Laramide intrusions of the La Sal Mountains, the lineament continues southeastward and terminates just outside the Wilderness Study Area.

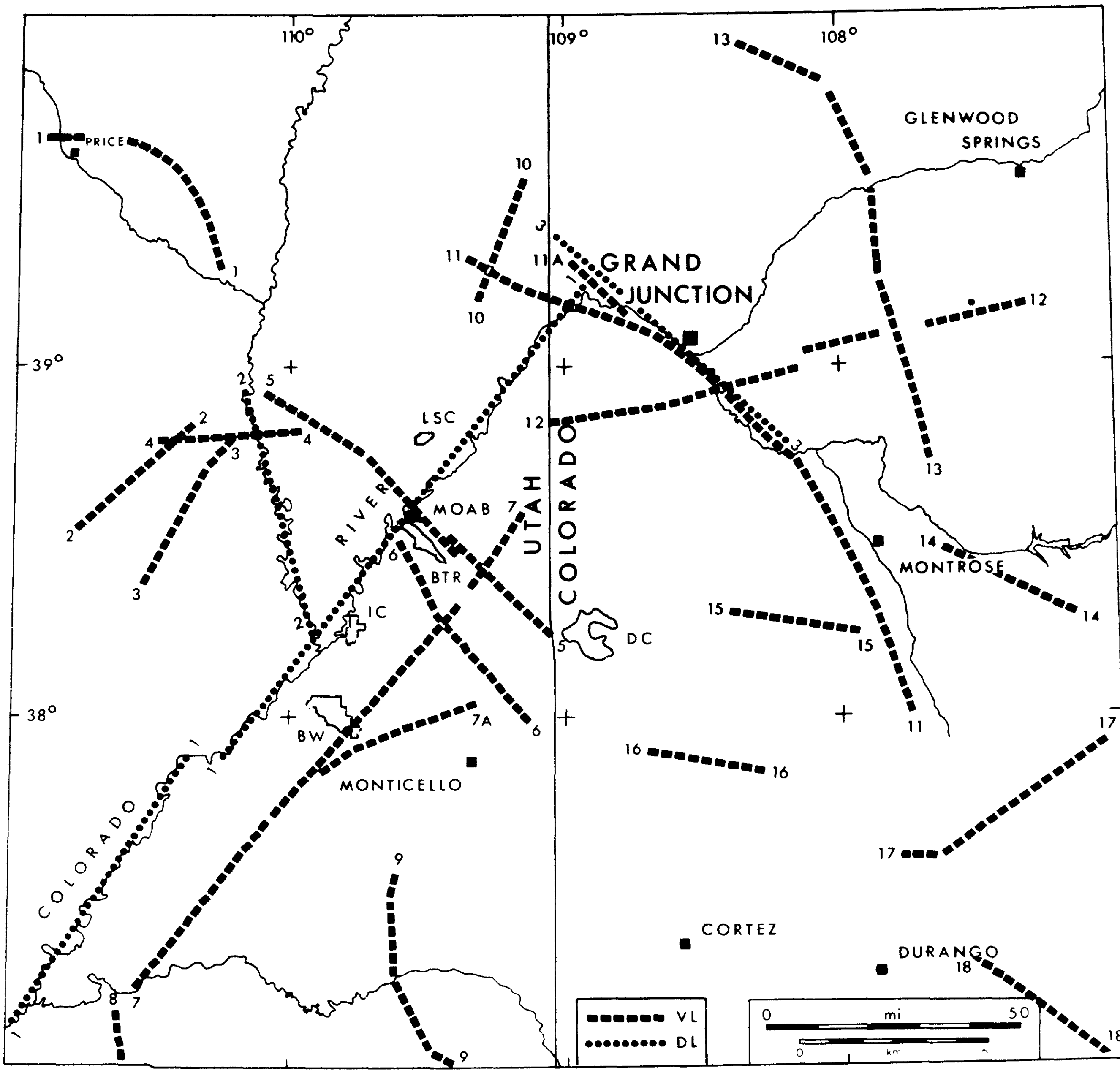

Figure 1.--Lineament map of southwestern Colorado and southeastern Utah showing location of wilderness study areas.
BTR, Behind the Rocks Wilderness Study Area;
BW, Butler Wash Wilderness Study Area;
DC, Dolores River Canyon Wilderness Study Area;
IC, Indian Creek Wilderness Study Area; and
LSC, Lost Spring Canyon Wilderness Study Area.
Visual lineaments (VL) are shown by dashed pattern, and drainage lineaments (DL) are dotted.

Table 1.--Correlation of lineaments in southwestern Colorado and southeastern Utah with geological and geophysical data

Lineament	Correlation with: Gravity[1]	Aeromagnetics[2]	Surface Faults[3] and Precambrian Basement Structures[4]
VL1	WEAK nose of high	WEAK SW flank of high	None apparent
VL2	GOOD gradient on SE flank of high	GOOD gradient on SE flank and in saddles	Reef Monocline, fault with 3000 ft offset, down-to-SE
VL3	GOOD (as VL2 above)	GOOD (as VL2 above)	East of and parallel to Reef Monocline fault
VL4	None apparent	None apparent	None apparent
VL5	STRONG parallels elongate highs and lows; coincides with a low	WEAK subparallel to anomalies	Coincides with Moab-Spanish Valley-Gypsum Valley Anticline, faulted
VL6	GOOD parallels elongate lows	WEAK subparallel	NW end coincides w/Kane Springs Fault; correlates w/"basement fault"[5]
VL7	GOOD lies on truncations of NW-trending anomalies	WEAK coincides with few small highs	Coincides with three separate surface fault systems; VL7A is Shay Graben, a probable Quaternary fault system[6]
VL8	UNKNOWN (at edge of map)	UNKNOWN (at edge of map)	None apparent
VL9	GOOD along gradient; SE end coincides w/NW-trending high	WEAK along NE flank of several highs	N end coincides with Comb Ridge Monocline, basement offset >3000 ft on down-to-east fault; SE end on Boundary Butte Anticline
VL10	WEAK subparallel to contours	None apparent	None apparent
VL11	GOOD subparallel to long high; bends along w/bend in high	GOOD parallel to several anomalies	NW end coincides with surface fault; in Colo. Nat'l. Mon. coincides with surface monoclines and basement faults, down-to-NE; coincides with surface fault on Log Hill Mesa near Ridgeway, CO, down-to-west; "Olympic - Wichita Lineament"[5]
VL12	GOOD coincides w/kink in high and w/several flexures	None apparent	None apparent
VL13	GOOD parallels contours, even through a sharp bend, on SW flank of low	GOOD parallels contours on strong gradient, truncates anomalies	Northern bend coincides with down-to-south surface faults along Piceance Creek

Table 1.--Correlation of lineaments in southwestern Colorado and southeastern Utah with geological and geophysical data (continued)

Correlation with:

Lineament	Gravity[1]	Aeromagnetics[2]	Surface Faults[3] and Precambrian Basement Structures[4]
VL14	WEAK complex gravity pattern	WEAK coincides w/high	Coincides exactly with surface Cimarron Fault (even where buried), down-to-south offset of basement
VL15	WEAK subparallel to contours	None apparent	Corresponds to series of down-to-SW normal faults that are part of Laramide Uncompahgre boundary fault
VL16	None apparent	WEAK subparallel to anomalies	Coincides with long, down-to-SW surface fault along Disappointment Creek
VL17	None apparent	None apparent	Truncates fault in Needle Mtns.; SW end on small Tertiary intrusion
V18	None apparent	None apparent	None apparent
DL1	WEAK NE end lies on truncation of anomalies	WEAK lies on saddles	Coincides with series of long basement faults; numerous basement terranes are truncated along these faults; Colorado Lineament[5]
DL2	WEAK N end parallel contours	WEAK lies on saddles	None apparent
DL3	GOOD subparallel to long high	GOOD parallel to several anomalies	Along surface monoclines and basement faults, parallel to VL11

1 Behrendt and Bajwa, 1974; Cook and others, 1975
2 Zeitz and Kirby, 1972, 1976
3 Williams, 1964; Cashion, 1973; Tweto, 1979; Hintze, 1980
4 Case and Joesting, 1972
5 Baars and Stevenson, 1981
6 Kitcho, 1981

Limonite mapping in the Dolores River Canyon Wilderness Study Area was based on Landsat MSS data, utilizing color-infrared (CIR) composite image and color-ratio-composite (CRC) images. Variations in limonite content were sought that might be related to either uranium deposition or hydrocarbon leakage.

Hydrocarbon occurrences were considered possible resources in the area, despite dry holes along structural trend both to the northwest and southeast, because of updip fault closure in the northeast part of the area and because of gas shows in three wells to the southeast. Bleaching of limonite in the Triassic Wingate Sandstone occurs over oil and gas accumulations at the Lisbon Field, about 30 km to the southwest (Segal and others, 1984), so similar limonite anomalies were sought in the Wingate Sandstone of the study area, as well as in the overlying Triassic Kayenta Formation. No such anomalies were found.

Resolution of the MSS instrument is about 80 m, however, so limonite anomalies smaller than this might well go undetected with this system. Because the sedimentary rocks in the area have low dips, and because the topography is dominated by mesas and canyons, outcrop widths as seen from the Landsat satellite are very narrow. This is especially true for the Wingate Sandstone, which is a cliff-former.

Limonite anomalies associated with uranium deposits are well known, and the ability to map them on Landsat imagery has also been demonstrated at nearby Lisbon Valley (Segal and others, 1984). Similar anomalies were sought in the wilderness study area because of the extensive uranium deposits surrounding this area on the west, south, and east. No similar anomalies were found.

Limonite bleaching associated with uranium at Lisbon Valley, however, occurs in reducing environments within red beds (Triassic Chinle Formation). The major uranium producer around the study area is the Jurassic Morrison Formation, especially the Salt Wash Member, and there is little limonite in this formation to begin with, so few anomalies would be anticipated.

LOST SPRING CANYON WILDERNESS STUDY AREA

The Lost Spring Canyon Wilderness Study Area is not on trend with any lineament derived from the regional lineament analysis. The area is between two lineaments, VL5 and DL1 (fig. 1), that seem to reflect basement faults, but there is no suggestion of basement faulting under this area.

The Landsat CRC did not show any significant variations in limonite that might be related to hydrocarbon accumulations.

Because of the numerous uranium deposits just outside the area to the north (The Poison Strip), limonite variations were also sought that might relate to uranium deposits. None was found. This result was anticipated, because most of the wilderness study area is covered by the Moab Sandstone Member of the Jurassic Entrada Formation, with the overlying uraniferous rocks (Salt Wash Member of the Jurassic Morrison Formation) removed by erosion.

BEHIND THE ROCKS WILDERNESS STUDY AREA

The Behind the Rocks Wilderness Study Area is bounded by three major lineaments: VL5, VL6, and DL1 (fig. 1 and table 1). VL5 is a northwest-trending lineament that corresponds to a deflection in the regional gravity field. The lineament lies on a strong gravity gradient that drops off into a low corresponding to the Moab - Spanish Valley salt anticline. The surface expression of the lineament is the southern bounding fault zone of the crestal graben of this anticline.

Lineament VL6 (fig. 1) has little expression in the geophysical data (table 1), but corresponds to surface faults just to the southwest of the wilderness study area. These faults are along the axis of the Cane Creek anticline, and some of them controlled deposition of uranium in the Permian Cutler Formation (Chenoweth, 1975).

Lineament DL1, which derives from a remarkably linear reach of the Colorado River, lies on the northwest end of the wilderness study area. This northeast-trending lineament corresponds to a series of Precambrian basement faults (Case and Joesting, 1972) and to the "Colorado Lineament" of Baars and Stevenson (1981).

Hydrocarbon accumulations are considered potential resources of the Behind the Rocks Wilderness Study Area. The area lies on the southwest flank of the Moab - Spanish Valley anticline, with more than 750 ft of updip fault closure (as measured on geologic map of Williams, 1964) . Potential Mississippian-Pennsylvanian sourcebeds exist in the subsurface, and production occurs in the Cane Creek - Big Flat anticline to the southwest. Reverse limonite anomalies (areas of low limonite concentration within limonitic rocks) were sought on the Landsat images that might correspond to hydrocarbon seepage. One such reverse limonite anomaly was identified (north fork of Hunters Canyon, NW 1/4, SE 1/4, Sec. 25, T. 26 S., R. 21 E.), but on field examination it was determined that the lack of limonite was caused by an extensive grass cover.

Uranium was also considered a potential resource of this wilderness study area because of past production and current (March 1987) mining just to the southwest of the area along Kane Springs Canyon. Production in this district is from both the Cutler Formation and the Chinle Formation, and both of these formations extend under the wilderness study area, although at considerable depth. Limonite mapping led to only one anomaly (Hunters Canyon), which was field checked as described above. Several specimens of *Astragalus bisulcatus*, a plant sometimes taken to be a uranium indicator, were seen in this anomalous area, but rock samples collected from the more reduced sandstones of the Kayenta Formation had no anomalous radiation.

INDIAN CREEK WILDERNESS STUDY AREA

The Indian Creek Wilderness Study Area is on one of the major lineaments of the region, DL1 (fig. 1). This very long and remarkably straight lineament coincides with the course of the Colorado River, and it corresponds to a major fault system in the Precambrian basement (table 1). It also forms part of what has been called the "Colorado Lineament" (Warner, 1978).

Hydrocarbons were considered potential resources in this study area because of potential Mississippian-Pennsylvanian sourcebeds in the subsurface. Despite the poor structural position of the area between the Meander anticline and the Rustler Creek and Gibson domes, which would argue against significant accumulations, the Landsat images were interpreted for limonite anomalies that might be related to hydrocarbon seepage. No such anomalies were found, but the very irregular distribution of iron in the main outcropping rocks, the Cedar Mesa Sandstone Member of the Cutler Formation, would make recognition of such anomalies tenuous.

Uranium is known to occur in the Indian Creek Wilderness Study Area, although the deposits are very small (less than 20,000 lb U_3O_8, Williams, 1964). One mapped occurrence was visited (in Rustler Canyon, NW 1/4, NE 1/4, Sec. 18, T. 29 S., R. 20 E.) to investigate possible redox changes in limonite, but no anomalous limonite patterns were noted (other than minor mottling).

BUTLER WASH WILDERNESS STUDY AREA

The Butler Wash Wilderness Study Area lies along one of the longest lineaments in the region, VL7 (fig. 1). This lineament shows strong correlations with both gravity data and surface structures (table 1). Several northwest-trending gravity structures are truncated along this lineament east of Moab. In the southeast part of the wilderness study area, the lineament coincides with the Salt Creek graben, a northeast-trending graben that is the westernmost of three <u>en echelon</u> grabens (Haynes and others, 1972). Southwest of the study area the lineament coincides with the Clay Hills fault zone. This lineament closely parallels the Colorado River lineament, DL 1, about 30 km to the northwest (fig. 1).

Hydrocarbons were considered a possible resource, because the area lies on the northeast flank of the Beef Basin anticline, just off the crest of the structure as defined at the base of the Cretaceous Dakota Formation (Haynes and others, 1972), or possibly including the crest if the axial surface dips to the northeast. Landsat images were studied in an attempt to locate limonite anomalies that might suggest hydrocarbon seepage. No anomalies were found, perhaps in part because of vegetative cover (pinon-juniper).

One small uranium deposit is known in the southern part of the Butler Wash Wilderness Study Area (Haynes and others, 1972). This deposit is in the basal part of the Chinle Formation, where it crops out on an isolated butte, but it is the only occurrence of the Chinle in the study area. No limonite anomalies were noted that might suggest uranium occurrences in the Cutler Formation.

SUMMARY AND CONCLUSIONS

A regional remote sensing study was conducted to assist in evaluating the mineral resource potential of five wilderness study areas in western Colorado and eastern Utah. Numerous Landsat Multispectral Scanner (MSS) images were used as the basis for a lineament analysis, and two Landsat MSS images were processed for limonite mapping. No Landsat Thematic Mapper data were available for this study.

Landsat MSS digital data were processed to provide images from which linear features were interpreted. The linear features were compiled over the region 107° - 111° West Longitude and 37° - 40° North Latitude, and lineaments were interpreted from this compilation.

The Behind the Rocks Wilderness Study Area is bounded by three major lineaments that reflect deep structures, one of which certainly involves Precambrian basement. Two of the lineaments coincide with mapped surface fault zones.

The Indian Creek Wilderness Study Area lies on a northeast-trending drainage lineament that corresponds to a remarkably linear reach of the Colorado River. This lineament reflects Precambrian faulting, and is part of the much longer, continental-scale Colorado Lineament.

The Butler Wash Wilderness Study Area is on a long lineament that trends northeast parallel to the Colorado River drainage lineament, separated by about 30 km. Where the lineament passes through the wilderness study area, it coincides with the Salt Creek Graben.

Landsat MSS images were digitally processed to produce color-ratio-composite images that enhance variations in limonite. The images were studied at each of the wilderness study areas to locate anomalously high concentrations of limonite that might relate to hydrothermal alteration. No anomalous concentrations were found, and no indication of hydrothermal alteration was apparent at any of the sites.

The CRC images were similarly interpreted to locate areas within naturally limonitic rocks that showed anomalously low concentrations of limonite, that is, reverse limonite anomalies. Such limonite anomalies would reflect more reduced zones within highly oxidized rocks. Such reduced zones could be caused by seepage of hydrocarbons, and reducing environments would be favorable sites for uranium deposition.

Only one anomaly was mapped where low limonite concentration occurred within red beds. In the Behind the Rocks Wilderness Study Area an area of low limonite was interpreted in outcrops of the Kayenta Formation. Subsequent field checking, however, showed this to be a false anomaly caused by extensive grass cover. Uranium indicator plants were noted in this area, but samples of the more reduced sandstones showed no anomalous radiation.

Limonite anomalies may exist in the wilderness study areas that went undetected; much of the terrain is mesas and canyons, which produce narrow outcrops, often below the instrument resolution of 80 m. Vegetation also covers some of the area, especially pinon-juniper assemblages on the higher mesas. Some uranium deposits occur in rocks that are not highly limonitic, like the Salt Wash Member of the Morrison Formation, and some deposits occur in rocks with highly variable limonite content, like the Cedar Mesa Sandstone. Because of these constraints, interpretation of Landsat MSS data alone leads to a conservative analysis of mineral potential.

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