Paper G 1

APPLICATION OF THE ERTS SYSTEM TO THE STUDY OF WYOMING RESOURCES WITH EMPHASIS ON THE USE OF BASIC DATA PRODUCTS

Robert S. Houston, Ronald W. Marrs, Roy M. Breckenridge and D. L. Blackstone, Jr., *Department of Geology, University of Wyoming, Laramie, Wyoming 82071*

ABSTRACT

Many potential users (for example, consultants, small companies and independent geologists) of ERTS data products and other aircraft and satellite imagery are limited to visual methods of analyses of these products. Illustrations are presented from Wyoming studies that have employed these standard data products for a variety of geologic and related studies. Possible economic applications of these studies are summarized. Studies include regional geologic mapping for updating and correcting existing maps and to supplement incomplete regional mapping; illustrations of the value of seasonal images in geologic mapping; specialized mapping of such features as sand dunes, playa lakes, lineaments, glacial features, regional facies changes, and their possible economic value; and multilevel sensing as an aid in mineral exploration. Examples of cooperative studies involving botanists, plant scientists, and geologists for the preparation of maps of surface resources that can be used by planners and for environmental impact studies are given. Emphasis is placed on the use of these maps in areas, such as the Powder River Basin of Wyoming, facing critical environmental problems that will result from the development of energy resources.

These various studies illustrate that certain user requirements can be satisfactorily met with ERTS alone, but that others require higher cost (to the user) aircraft and ground data or special data enhancement techniques. However, the ERTS system has given us both complete and sequential regional coverage at a crucial time in our effort to assess the effects of resource development.

INTRODUCTION

The basic goal of investigators of the ERTS-1 imagery in Wyoming as to discover applications of ERTS-1 data to earth resource studies. 1e ERTS standard data products can be used to produce many interrelaons of economic value and there is nothing that competes with the TS synoptic view for regional geologic studies. The system does suf-, however, from resolution limitations and this has led some to stion the utility of ERTS. For example, a recent editorial in *Na-e* (1973, p. 345) states that the ERTS system,

> . . . suffers from one major defect -- it is too generalized. It is not possible simultaneously to please a large constituency and provide each of them with what they need. Furthermore, it is by no means clear that many of the users of the ERTS data can make much of it beyond the 'gee-whizz' stage. When more detailed work is attempted the resolution is too poor (objects less than a few tens of meters across may be invisible), the time of the photograph is unsuitable for the problem or the effect is not suitably sampled in 18-d intervals . . .
>
> . . . Much has been made of the geological uses of ERTS; indeed the publicity has tended to imply that geology is the study of lineations, and lineations can mean metal deposits. One cannot imagine why any geologist would be prepared to make a partial map of his area -- partial because of the finite resolution and because structures not visible at 9:30 a.m. would not be recorded.

This criticism exemplifies the feelings of some, even among the scientific community. At the very least, it seems that such statements are premature, considering that the system has been in operation for just longer than a year and there has been little time in which to realize most tangible benefits. If "gee-whizz" refers to visual analysis of standard image products, certainly many users (private citizens, consultants, independent geologists and representatives of small companies) will be confined to that approach -- for the present. Even so, can they make profitable use of the standard ERTS-1 data products? The investigators at the University of Wyoming remote sensing laboratory have found that visual analysis of ERTS-1 data can produce real benefits. In fact, these studies indicate that visual analysis is the essential step in most earth resources applications.

From the outset, it was realized that any evaluation of ERTS-1 data applications would require thorough checking of the results. Some of the checking must, of course, be done in the field, but the very large areas studied from ERTS-1 cannot be effectively covered on the ground in a few months' time. It was therefore necessary to supplement field reconnaissance with data from the literature wherever possible and with interpretations of high-resolution aerial photography. Color, color infrared, and/or multiband photography is now available for much of Wyoming (Fig. 1) as a result of ERTS- and EREP-support flights flown by NASA aircraft. The aircraft data is, in itself, a valuable product and provides not only a means of checking interpretations of ERTS data, but also an opportunity to approach some problems by a multilevel remote sensing program. Starting with geologic mapping, we hope to illustrate a variety of applications of ERTS and supporting aircraft imagery, that can be made at low cost to the user.

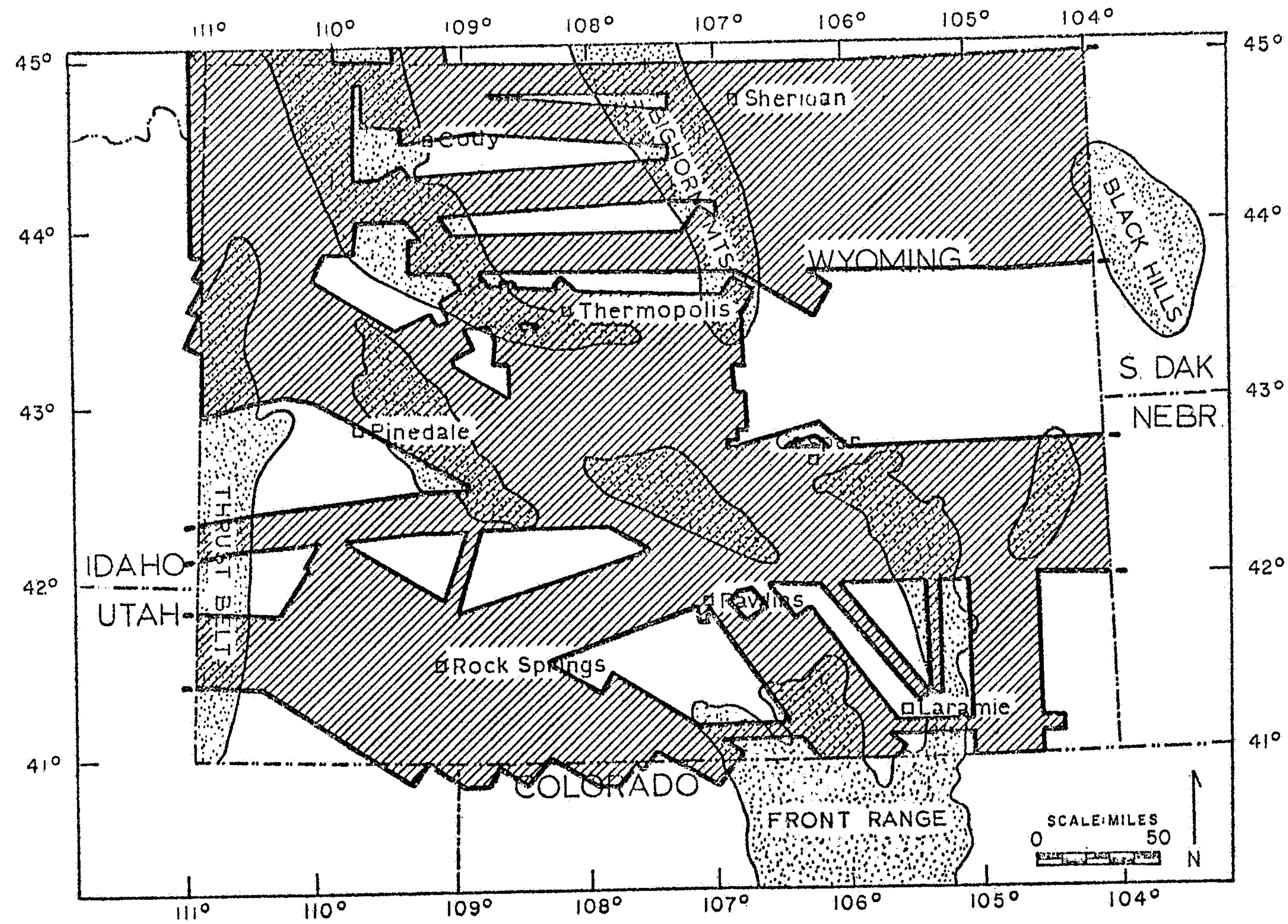


Figure 1. Index map showing current NASA air photo coverage of Wyoming.

GEOLOGIC MAPPING

Figure 2 shows a geologic map prepared from an ERTS color composite (image 1030-17235) of an area northwest of Casper, Wyoming and compares this ERTS map with the best surface mapping (Fig. 3). This area is one of complex geology at the south end of the Owl Creek and Bighorn Mountains where large blocks of Precambrian crystalline rocks have been uplifted and thrust over younger sedimentary successions. Major lithologic units include Precambrian gneisses (pꞒu), Cambrian sandstones (Ꞓf) and limestones and siltstones (Ꞓgl), Mississippian limestone (Mm), Pennsylvanian sandstone (ℙt), Permian dolomite, phosphatic siltstone and shale (Pf), Triassic siltstone with gypsum beds (Trcd), Triassic red siltstone and sandstone (Trc), Jurassic shale and siltstones (Js), Cretaceous sandstone (Kcr), Cretaceous black shale (Kt), Cretaceous sandstone (Kmd), Cretaceous black shale and siliceous shale (Kmr), Cretaceous shale overlain by massive sandstone beds (Kf), Cretaceous shale (Kc), Cretaceous sandstones, shale, and coal beds (Kmv), Cretaceous shales, carbonaceous shales and sandstones (Klml), Tertiary sandstones, siltstones and conglomerate (Tfu), Tertiary dolomitic siltstones (Tlb); Tertiary red beds (Trb), Tertiary units undivided (Tu), Quaternary gravels, Quaternary alluvium, and Quaternary sand dunes.

Twenty-three major lithologic subdivisions were differentiated for this area and many others could be made depending on the detail of mapping desired. Obviously the ERTS photogeologic map cannot compete with surface mapping in an area as complex as this, but note what was achieved. Eighteen subdivisions were made of the exposed units and these subdivisions correspond generally to units mapped by field geologists. Most major faults and many minor faults were mapped although there is a tendency (depending on the interpreter) to over-map lineaments. The distribution of sand dunes (Qs) was defined more accurately than on the geologic map, and some additional mapping was done in R. 88 W., Tps. 39 and 40 N., where no ground mapping had been done previously. Summarizing, then the ERTS image can be used to map the regional geology of complex areas (keeping in mind that limited field checks are necessary for lithologic identification), but the imagery is of little value, except for checking possible errors or filling in gaps, where careful surface mapping has been done previously.

Figure 4a shows a geologic map prepared from the same ERTS color composite (image 1030-17235) of an area north of Casper, Wyoming and compares this ERTS map with the 1955 geologic map of Wyoming (Fig. 4b). Much of this area has not been mapped in detail and no mapping is available in published or open-file form. The geologic map shows nine lithologic subdivisions where as the ERTS photogeologic map shows twenty-five lithologic(?) subdivisions. This area has not been fully field-checked so we cannot be certain that all subdivisions shown on the ERTS photogeologic map correspond to changes in lithology. The large area shown as Cody Shale (Kc) on the geologic map has been subdivided into

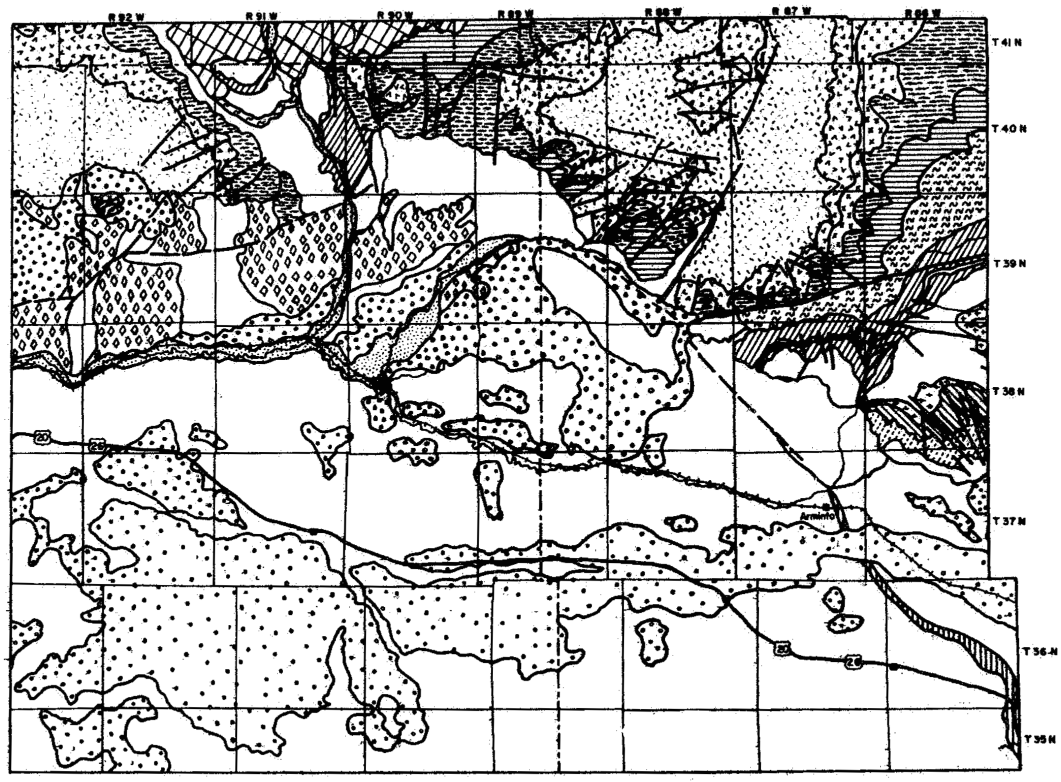


Figure 2. Photogeologic map prepared from ERTS color composite (image 1030-17235) of area northwest of Casper, Wyoming. Patterns of units are keyed to the nearest geologic field subdivision shown on figure 3.

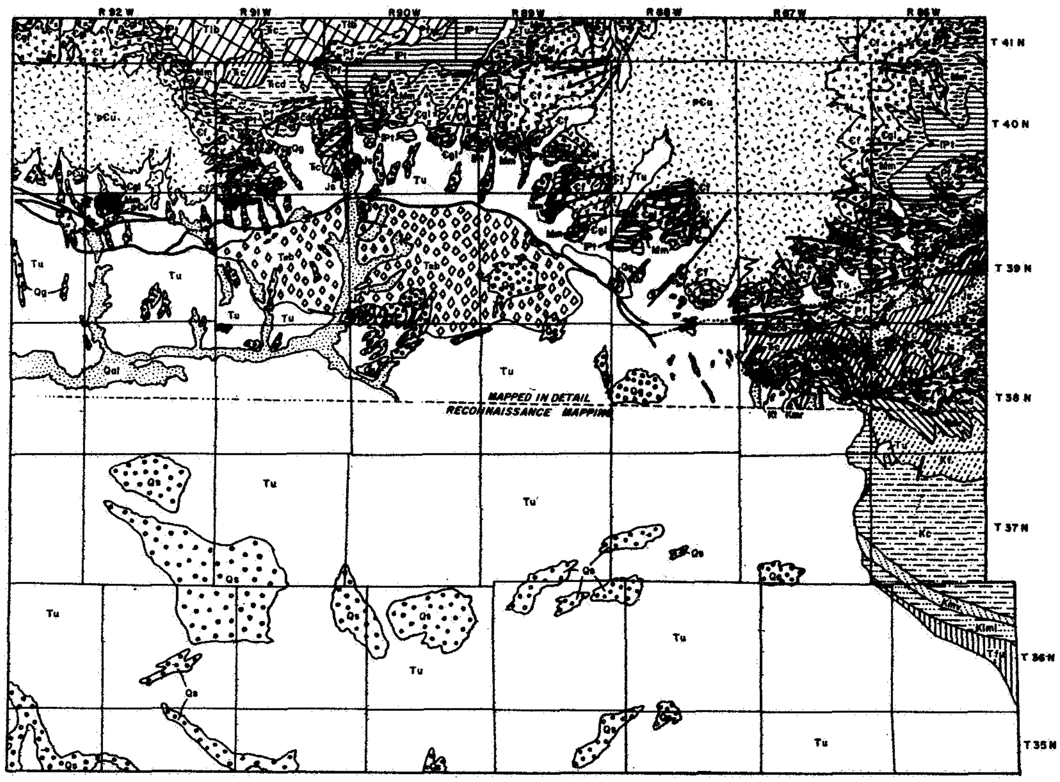


Figure 3. Geologic map of same area as in figure 2, modified from Tourtelot (1953), Woodward (1957), Rich (1962), and Keefer (1970). See text for explanation of units.

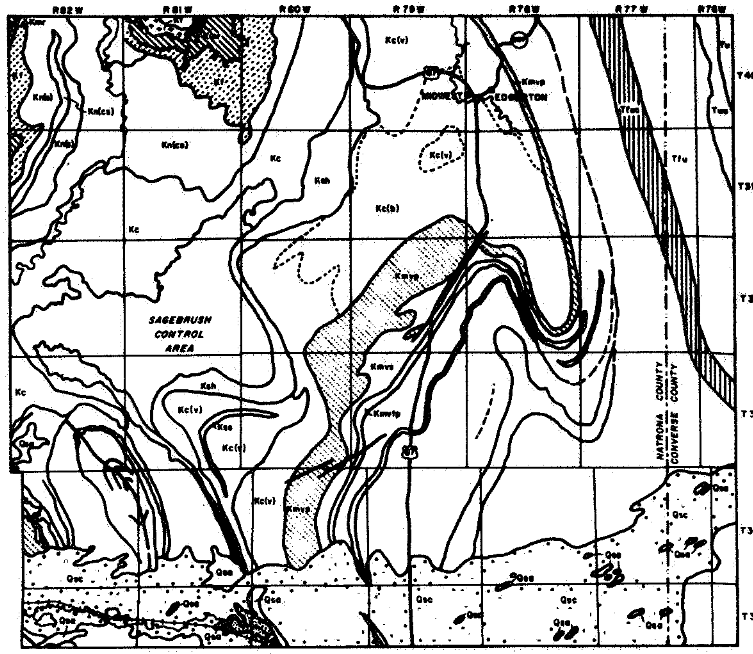


Figure 4a. Photogeologic map prepared from ERTS color composite (image 1030-17235) of area north of Casper, Wyoming.

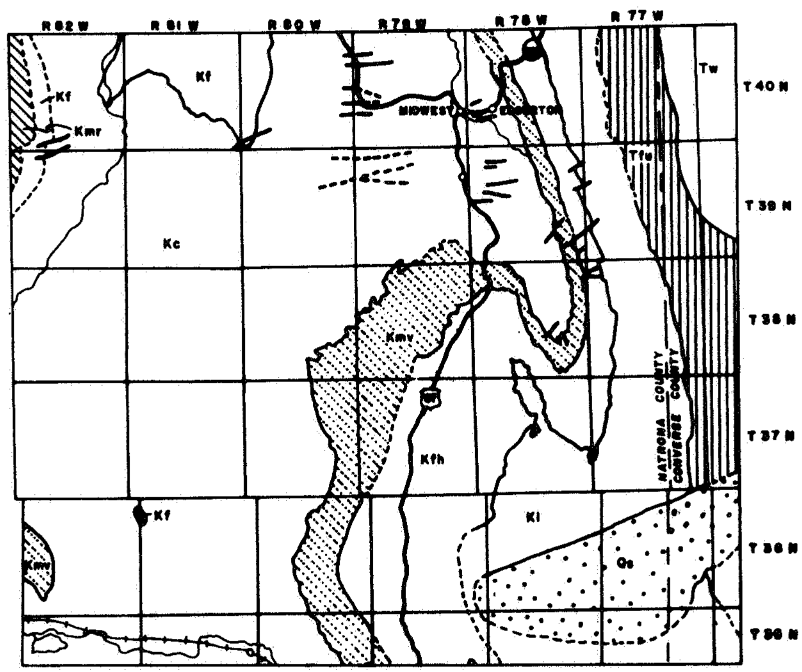


Figure 4b. Geologic map of above area modified from state geologic map of Wyoming (Love, Weitz, and Hose, 1955). See text for explanation of units.

several units; the areas shown as Kn(cs) and Kn(s) probably correspond to calcareous shales and shales of the Niobrara Formation. The area shown as Kc is typical Cody Shale. The area shown as Ksh is the Shannon Sandstone member of the Cody Shale. The area shown as Kc(b) is Cody Shale with very little vegetative cover and that shown as Kc(v) is Cody Shale with varying vegetative cover. Finally, the lens shown as Kss is probably the Sussex Sandstone member of the Cody Shale. The reason for the varying vegetative cover on the upper Cody Shale bed is not determined but it (Kob) does coincide with the location of a major oil field. The curious area in T. 38 N., Rs. 81 and 82 W. is an area where the natural vegetation has been disrupted by extensive spraying to kill sagebrush so its significance is probably not lithologic.

The Mesaverde Formation can also be subdivided into the Parkman Sandstone Member (Kmvp), a shale unit (Kmvs), and an upper unit called the Teapot Sandstone member (Kmvtp). Distinctions can also be made within the Fox Hills Sandstone (Kfh) and Lance Formation (Kl), but their significance is not known. The lower massive sandstone of the Fort Union (Tfus) and a similar sandstone in the Wasatch Formation (Tuss) can also be distinguished. Finally, stabilized sand dune areas (Qsc), active sand dunes (Qsa), and alluvium (Qal) are readily mapped to complete the more accurate ERTS map of this area.

This second mapping illustration clearly shows the advantage of an ERTS color composite in regional mapping (up to 1:250,000) in areas where detailed surface mapping has not been done. Many areas of this type still exist in the United States and a great many more exist outside of this country. Naturally, where good aerial mosaics are available, accurate mapping can be done by use of the mosaic but at higher cost to the user and without the major advantage of the color infrared mode and other multispectral enhancement procedures.

Color photographs or film positives are considered by most geologists (Wilson, 1970) the best tool for photogeologic mapping. Color is not a specific guide to rock type, but in a given region certain lithologies have characteristic colors that persist over broad areas so that color is extremely valuable in formation identification. Where characteristic colors of rocks or rock-vegetation units have been established for a geologic section, under these circumstances the geologist can map units with some assurance that he is identifying the rocks correctly. Color infrared offers the same possibilities once the interpreter is familiar with the color shift. We have attempted to define the "typical" color shift and have derived several false-color infrared rock guides (Fig. 5) which relate certain key beds to their typical color on a false-color image. With the color guide and/or experience, the interpreter can use the false-color imagery more efficiently.

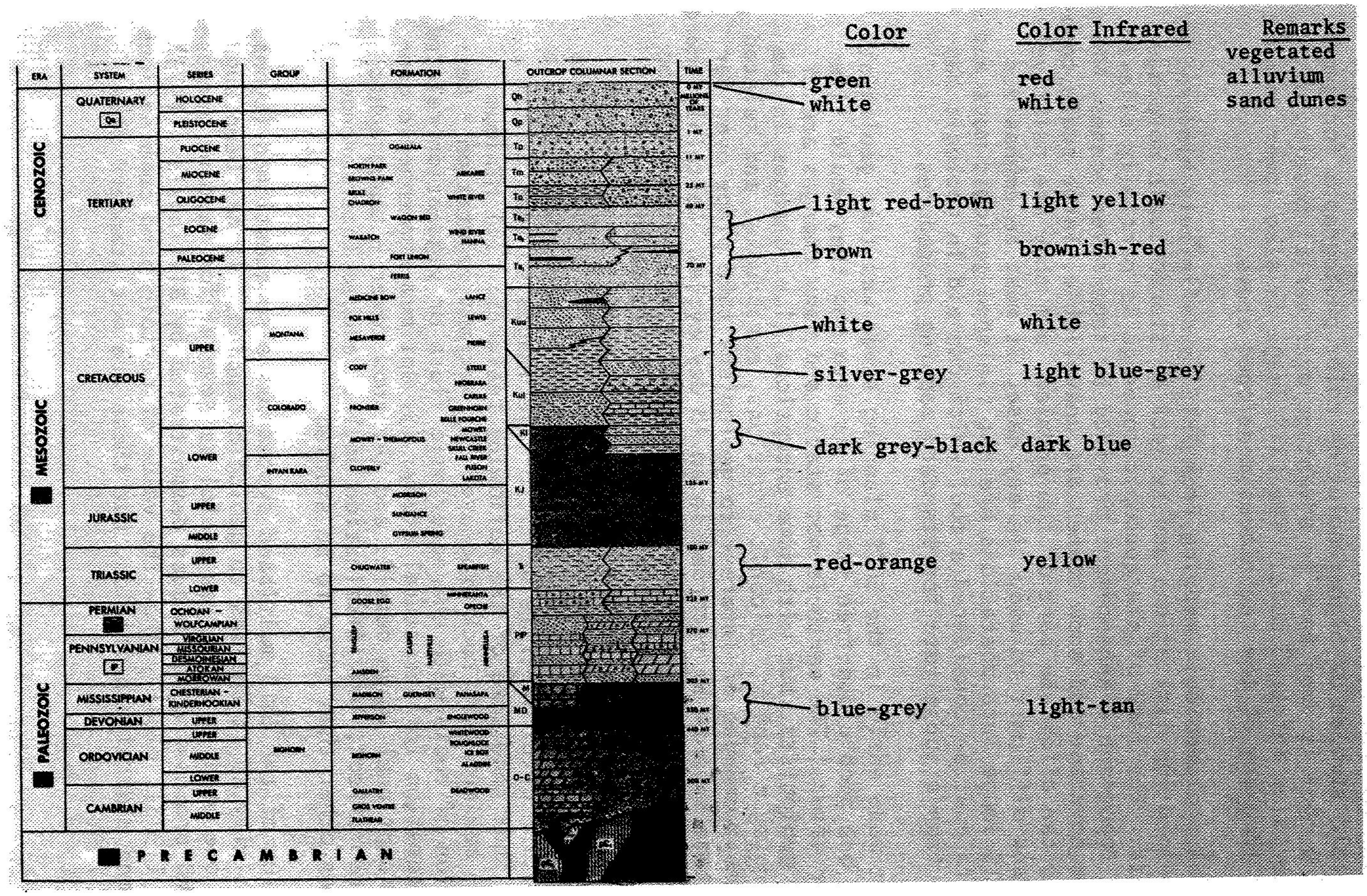


Figure 5 Color guide relating key units in the stratigraphic section of eastern Wyoming to their typical color representation on color and color infrared imagery.

The ERTS color composite is thus an extremely useful tool for geologic mapping in arid regions such as Wyoming, especially where detailed mapping has not been done. Obviously the image is not competitive with field studies or high-resolution color photographs for geologic mapping, but it does have an advantage over aerial mosaics because of the color infrared mode. The ERTS image is also lower in cost to the user than any of the techniques mentioned above.

Regional photogeologic mapping from ERTS is definitely hindered by the image-resolution limitations and by lack of stereoscopic coverage in many areas. The lack of stereoscopic coverage is partially alleviated by the topographic enhancement provided by snow-cover scenes. When stereoscopic coverage and snow scenes are unavailable, large scale topographic maps can alleviate part of the problem, but they are relatively cumbersome and difficult to use. In any case, it must be emphasized that the ERTS image interpretations are not finished geologic maps and the ERTS data must be considered a tool which can aid in geologic mapping rather than a substitute for standard mapping procedures.

A point made early in the ERTS planning stage was that geologists needed only one good cloud-free image of an area and they would live happily ever after. The earth is not static and many changes are of interest to geologists, but with some exceptions (i.e. changes in the surface hydrologic regime, volcanic eruptions, earthquakes and related phenomena) most changes of interest to geologists take place over far too long a time span to be recorded in an 18 day cycle. Certainly there was no compelling reason to suggest that a repetitive system would be useful to the individual interested only in geologic mapping.

An 18 day cycle may not be required but study of seasonal images does facilitate geologic mapping. A user of ERTS images will benefit from examination of browse-file or micro-file images so that he can pick images that show some of the following features: (1) Minimum vegetation - maximum bare rock exposure; (2) Maximum vegetation - better definition of rocks with characteristic flora or vegetation related to water saturation for structural study; (3) Optimum atmospheric conditions - exceptional image detail; and (4) snow cover - topographic effect, stereo-effect, low illumination angle, reduced interference from features other than those to be studied.

The value of the ERTS multiband system was also questioned (Lyons, 1970); especially as it applies to geologic mapping. It has been suggested that one band is almost as useful as several for mapping purposes. The multiband processing techniques demonstrated by Billingsley (1973) and Vincent (1973), clearly show the value of certain band combinations in mapping and mineral exploration, but these are not standard data products from ERTS. The infrared color composite which is a standard data product requires three of the four bands for its construction and is demonstrably superior to a black and white product for geologic mapping. In addition, the individual ERTS bands tend to enhance contrasts between certain rock types. For example, bands four and five often show a strong contrast between rock types that are marked by characteristic vegetation, and band seven generally enhances contrast between iron rich and iron poor rocks such as granite-basalt contacts (Rowan, 1973; Houston and others, 1973).

TOPICAL MAPPING

The ERTS data is better suited to certain topical studies than to general mapping programs. Several such studies have been completed as a part of the Wyoming investigation. They include determination of extent of Pleistocene glaciation and related geomorphic features (Breckenridge, 1973), mapping of sand dunes (Kolm, 1973), playa lakes, pediments, regional facies changes, average slopes, major strip mines, large areas of surface instability, linear features, and large-scale tectonic elements.

The study of lineations has become a major facet of the ERTS-1 geologic applications and has attracted more than a fair share of attention and criticism. Lineations have always been somewhat of a special problem to the geologist because, as an aspect of megatectonics, the study of lineations and their implications is a field under constant criticism. The chief problem is the difficulty in compiling data on a group of lineations, faults, or shear zones without including a few, and sometimes many, features of questionable validity. This allows a critic to discredit an entire concept by disproving a small part of the supportive evidence.

The synoptic view of ERTS lends itself so well to mapping of lineations that even an experienced interpreter can become somewhat over-zealous, and map lineations that are unrelated to geology. Linear features that must be dealt with in compiling a "tectonic" interpretation include roads and highways, railways, fire lines, fence lines, tornado swaths, condensate trails, aeolian features, dikes, faults, shear zones, joints, topographic breaks, snow-lines, moisture and cloud patterns, and vegetation changes. The resolution limitations of ERTS and the extremely high-altitude overview often make distinction between these features difficult. Consequently, even the experienced photogeologist can be embarrassed by finding that he has erred in his interpretation. Ordinarily one would resolve such problems by a simple field check. However, subtle linear features have been located on ERTS which appear on several image cycles and yet defy identification in the field (Blackstone, 1973c). These we hope to identify from very low-level aerial photography.

Despite the confusion with non-geologic linear features and the difficulty in field checking, we are convinced that most of the linear features identified on ERTS have geologic significance. As yet, no particular economic significance has been attached to the newly discovered linear elements, but we anticipate that some of these will prove economically important.

The ERTS imagery quite frequently suggests extensions of fault systems beyond their mapped limits, with some systems showing expression into younger rocks than were previously known to be involved. From these relationships we can establish better dates for some episodes of crustal movement.

Another aspect of tectonics being pursued with the aid of ERTS imagery is the interrelationship between structures in the Wyoming mountain ranges and those in the basins. The ERTS imagery allows rapid compilation of orientations for major faults and joints in the exposed cores of mountains and similarly rapid assessment of the axial trends of adjacent basin folds. These can then be compared to determine possible interrelationships. Figure 6 is a generalized map of the major faults, folds, and linear elements of the Bighorn-Pryor Mountains area. These features were mapped by photogeologic interpretation of ERTS images. Figures 7a and 7b are rose diagrams comparing the orientations of linear features in the mountains to fold axes. In this case, no strong correlation was seen (Blackstone, 1973b). A similar study for the Laramie Range and Laramie Basin showed a strong similarity in the orientations (Figs. 8 and 9), suggesting a common genesis (Blackstone, 1973a). The economic significance of such information, if any, will come with continued study of the tectonic systems and their local implications.

MINERAL EXPLORATION

The utility of standard ERTS data products in direct mineral exploration is still somewhat in doubt. Tests in which the standard imagery was used to locate exposed alteration zones give variable results.

In the Absaroka Mountains of Wyoming (Fig. 10d) attempts were made to map zones of reddish alteration that might be related to intrusive activity and mineralization. To eliminate some of the subjectivity, two separate maps were made. One (Fig. 10b) was compiled by a geologist who has extensive experience in the area and the other (Fig. 10a) by a geologist with no experience in the area. Both were asked to look for anomalously red (yellow on the false-color composite) areas. The obvious similarities between the two interpretations and their mutual correlation with a map of known mineralization (Fig. 10c) indicates that some areas of alteration, although subtly expressed, can be identified from ERTS. Areas identified on the image interpretations and not corresponding to known mineralization have yet to be checked.

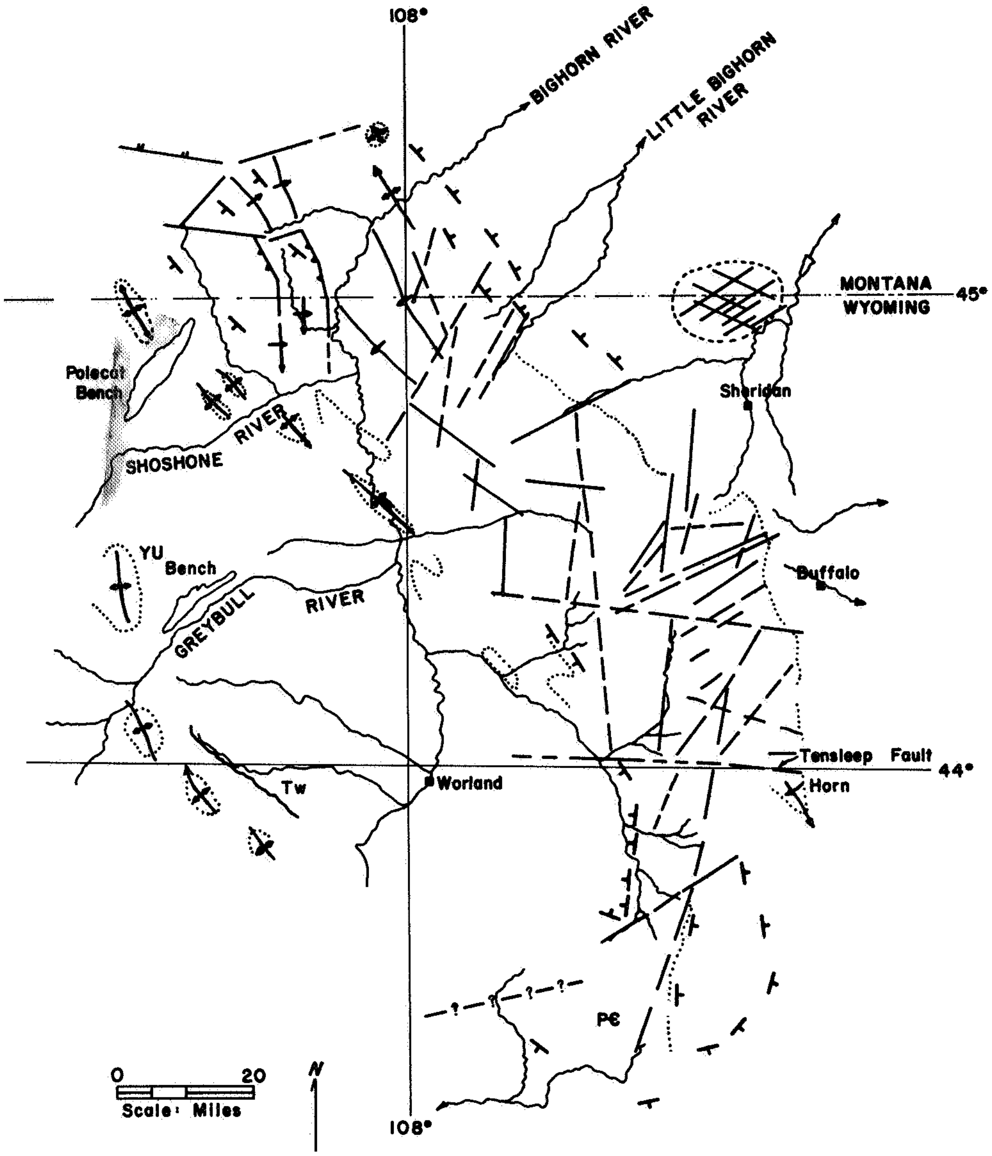


Figure 6. Major linear elements of the Pryor and Bighorn Mountains.

(after Blackstone, 1973c)

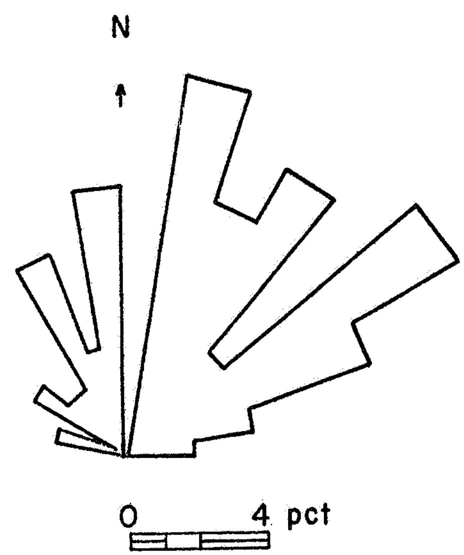


Figure 7a Rose diagram showing trends and orientations of observed linear elements.

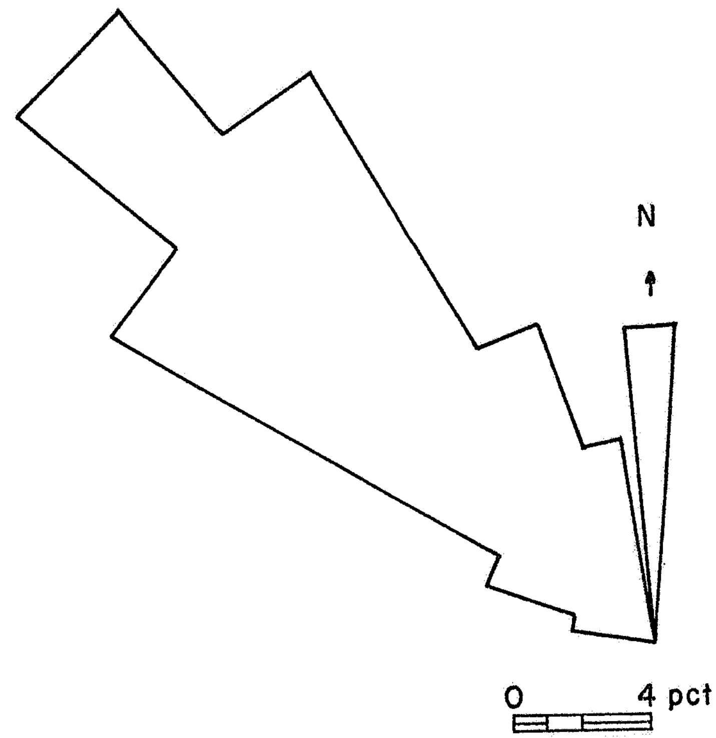


Figure 7b. Rose diagram showing the orientations of fold axis in the Bighorn Basin.

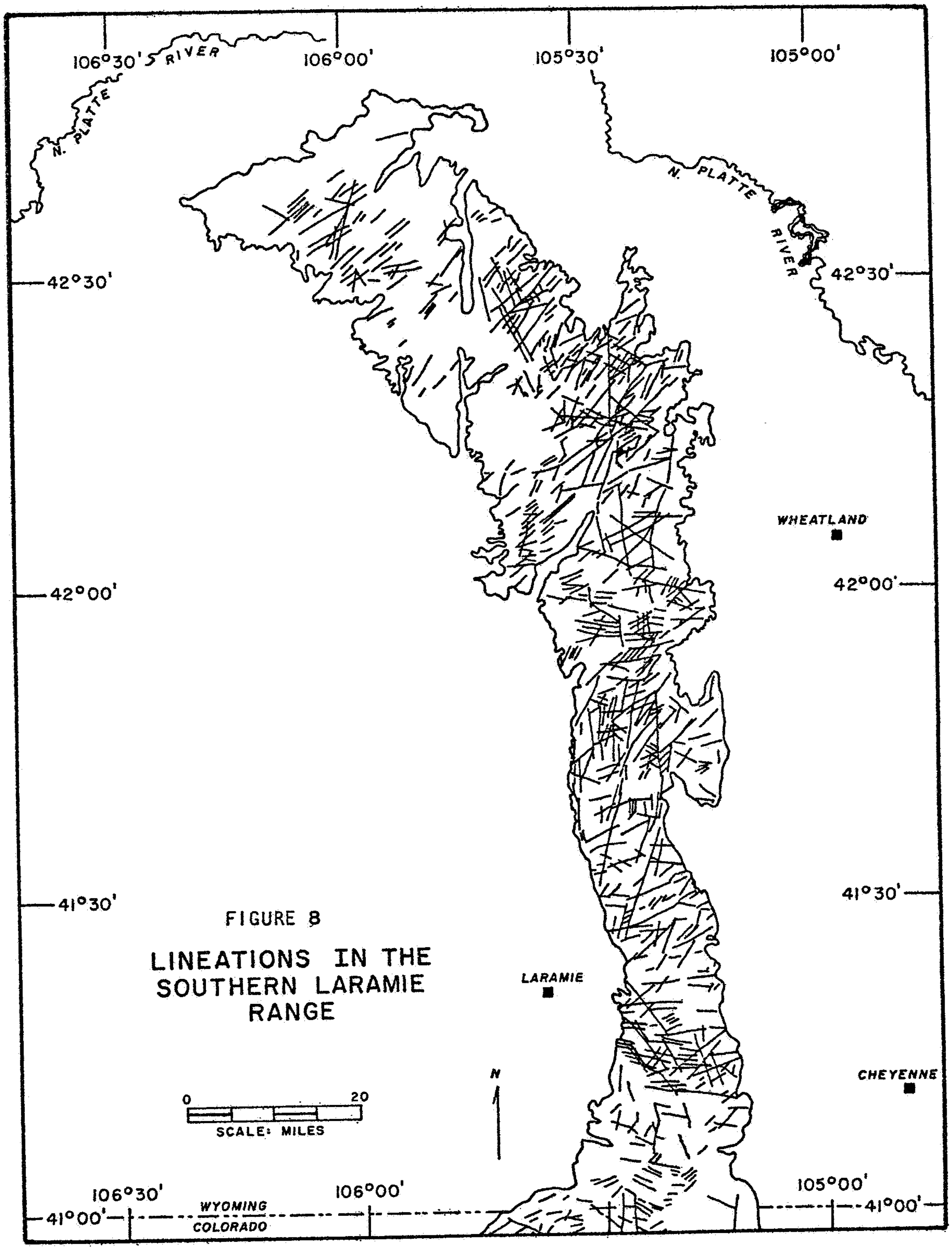


FIGURE 8

LINEATIONS IN THE SOUTHERN LARAMIE RANGE

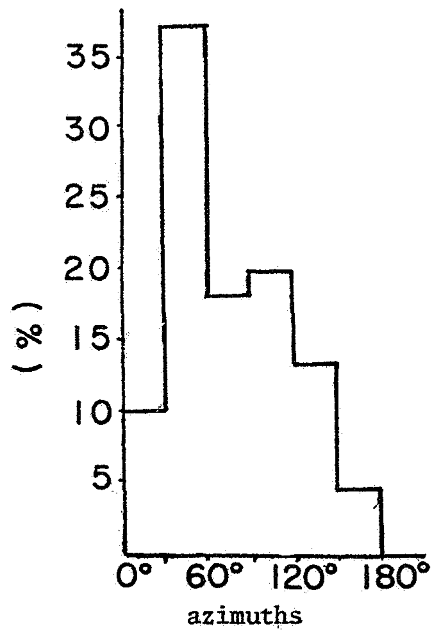


Figure 9a. Orientation of axial surfaces of the folds, surface and subsurface.

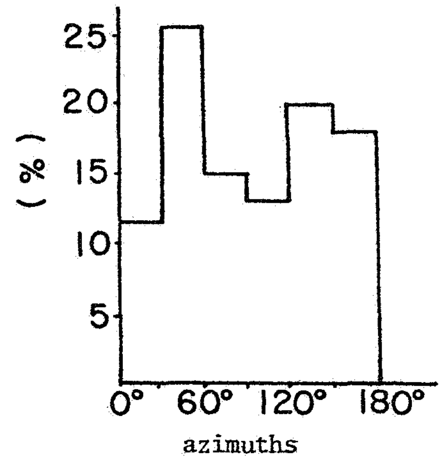
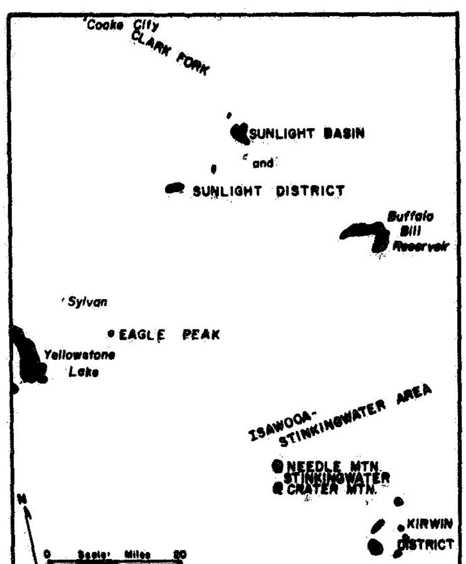


Figure 9b. Orientation of Precambrian linear features in the Laramie Mountains, such as faults, folds, fractures and foliations.

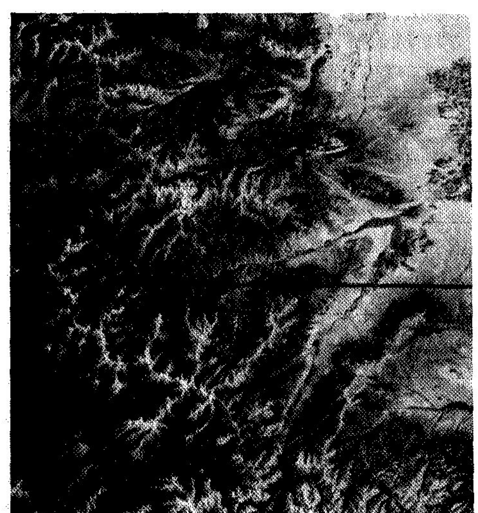
Figure 9. Comparison of orientation histograms for Laramie Basin folds and structures in the Laramie Mountains. Note the twin peaks of the Laramie Basin histogram relation fold axis that are both parallel and orthogonal to the dominant structural trend of the Laramie Mountains. (after Bekkar, 1973)

10-a. Alteration zones mapped by an interpreter unfamiliar with the study area.

10-b Alteration zones mapped by an interpreter with extensive experience in the study area.



10-c Map of previously known areas of alteration.



10-d Portion of ERTS-1 image 1014-17350 showing the Absaroka study area.

Figure 10 Maps of alteration zones in the Absaroka Mountains of northwest Wyoming. Interpreted from ERTS-1 color composite image 1014-17350.

A similar attempt was made to identify oxidized arkosic sandstone associated with uranium mineralization. In all major uranium producing areas of Wyoming the uranium occurs at the interface between oxidized and unoxidized sands (Fig. 11). The interface is generally marked by a distinct color change, with the oxidized sandstone being red or yellowish red and the unoxidized sandstone being tan or grey. We had hoped that the contrasting sandstones could be detected from ERTS, but our test study in a known uranium area of the Powder River Basin was unsuccessful (Fig. 12). A subtle contrast was noted in the test area, but when it was mapped and compared to the known color changes in the sands, the correspondence was slight. The lack of correspondence is greatest toward the southern end of the test area where the sandstone exposures are poorest. Coincidence of the mapped and known zones is considerably better in the northern part of the area, and there is some hope that such zones may yet be mapped in areas of good exposure. At the present time, however, we consider this an unsuccessful application of the ERTS data.

One of the earliest indications of the economic potential of ERTS resulted from a program in which the ERTS imagery was used to map greenstone belts in an area of granite-gneiss terrane of central Wyoming (Houston, 1973). Two greenstone belts were recognized on the ERTS image interpretation; a known greenstone belt in the southern Wind River Mountains and an unmapped belt in the northern Granite Mountains (Fig. 13). Detailed inspection of the Granite Mountains greenstone belt from high-altitude aerial photographs revealed several very distinct, dark colored outcrops. These proved to be outcrops of iron formation (Fig. 14).

The iron formation outcrops could not be detected on the ERTS-1 imagery, but they are confined to the greenstone areas that can be recognized on ERTS imagery. This, then, is a situation in which ERTS provides a means of "narrowing down" the area of interest so that the real exploration target (the iron formation) can be sought more efficiently by more detailed surveys.

ENVIRONMENTAL STUDIES

Wyoming, Montana, and North Dakota share enormous reserves of low-sulphur, sub-bituminous coal and lignite that will undoubtedly be developed by strip-mining techniques as soon as it becomes politically possible. Many of the necessary environmental surface resource studies to be done in conjunction with this development can be aided by remote sensing. The NASA programs in earth resources remote sensing come at a very opportune time in that the ERTS and aircraft data acquired in 1972-73 will not only serve as base line for detection of change, but also provide a great deal of the data necessary for planning and resource studies.

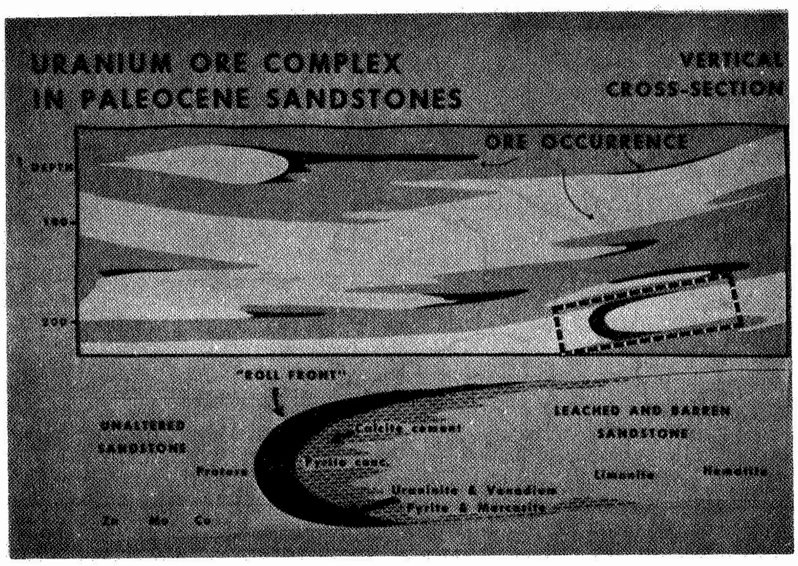


Figure 11. Diagram showing typical pattern of uranium deposition in Wyoming sandstones.

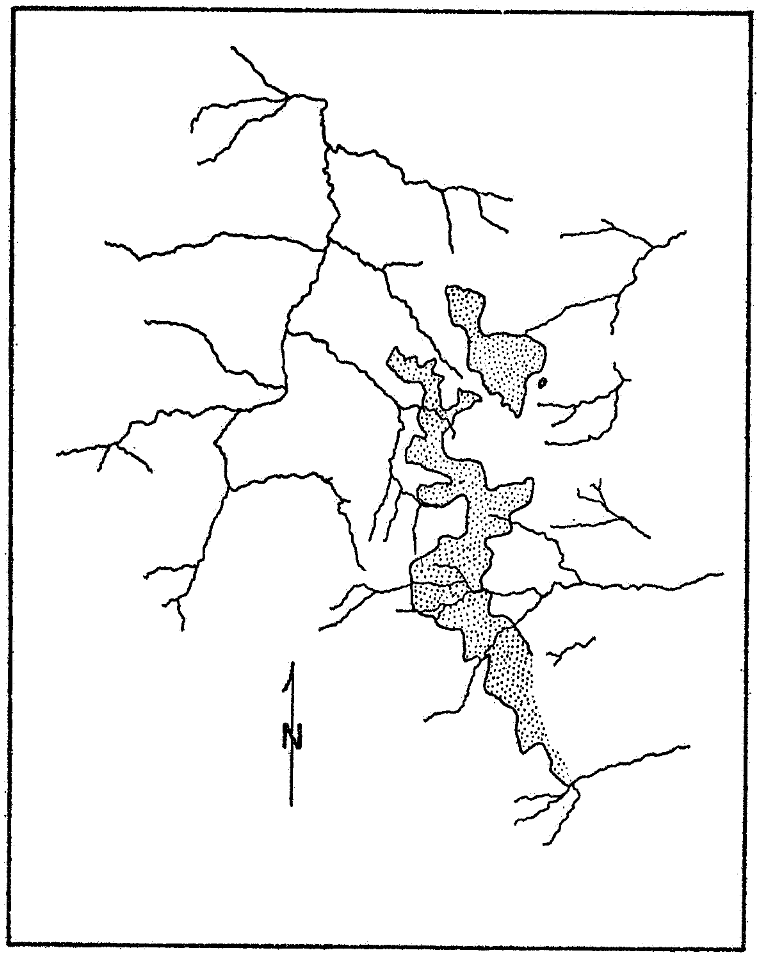


Figure 12a Surface color-change map of Pumpkin Buttes area, southern Powder River Basin, Wyoming. Anomalous zone interpreted from color composite ERTS image 1047-17182.

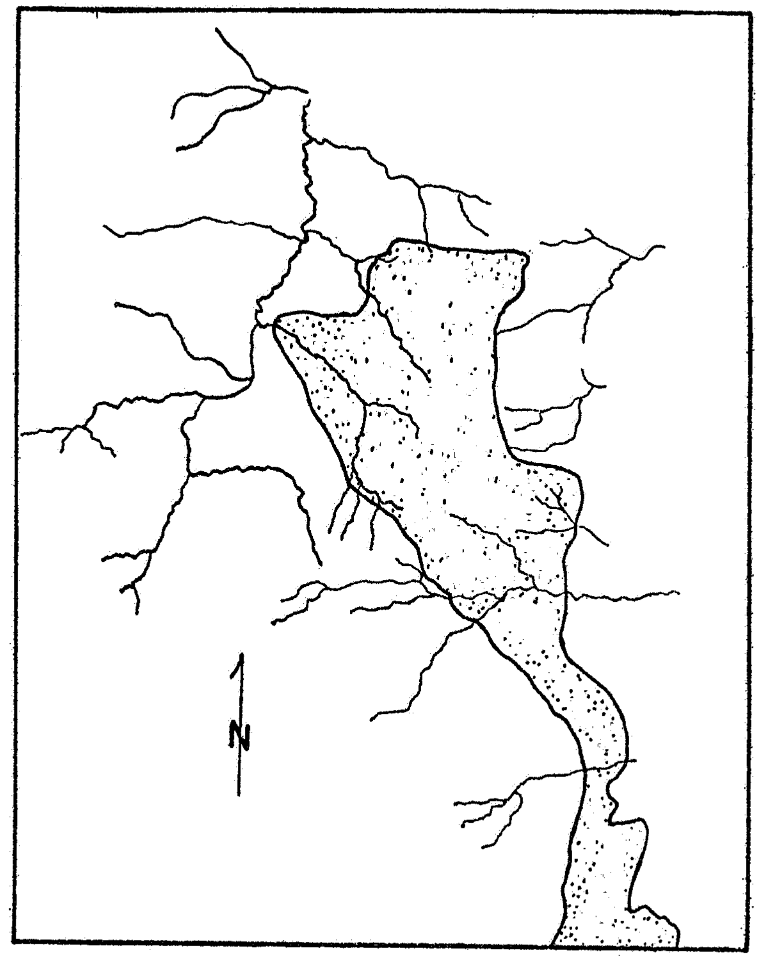


Figure 12b. Map of Southern Powder River Basin uranium area. Stippled area represents area of altered coarse-grained to conglomeratic sandstone. (after Sharp and Gibbons, 1964, plate III)

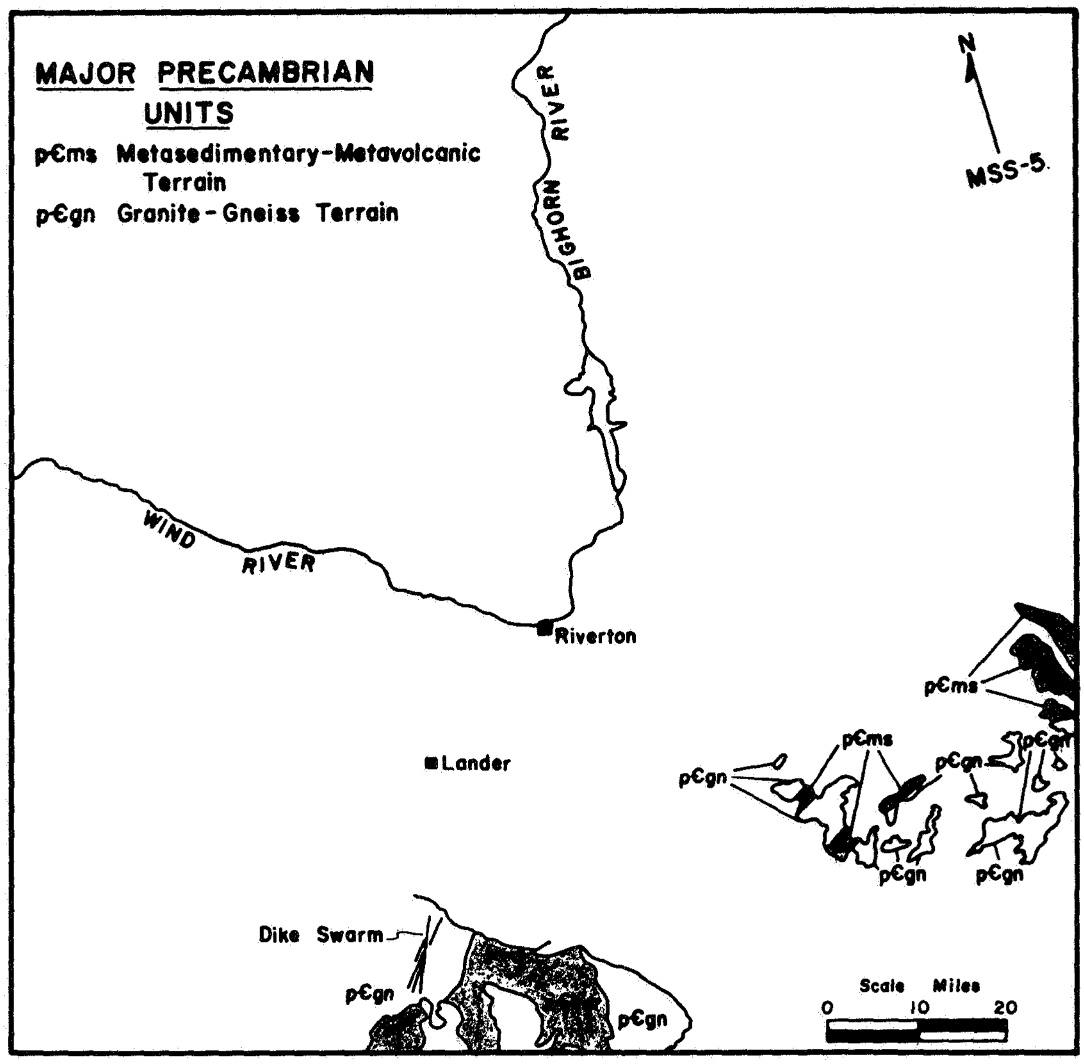


Figure 13 Map of Precambrian terrane of the southern Wind River Mountains and Granite Mountains showing greenstone belts p€ms mappable from ERTS imagery.

Figure 14. Horseshoe-shaped bed of iron formation, Barlow Gap, Wyoming.

In January, 1973, a pilot program designed to test the applications of ERTS-1 data to land-use and resource management in Wyoming was completed for the Wyoming Department of Economic Planning and Development (Breckenridge and others, 1973). This pilot study demonstrated successful applications of ERTS image interpretation in ten land-use related studies. In the Powder River Basin test area, the study resulted in a 14-class land-use map, a regional soils map, a 6-class subdivision of range land, a water-impoundments map, a map of present open-cut mining operations, a map of coniferous and deciduous forests in the Bighorn Mountains, maps of several small urban areas, an average-slope map and several other topical maps related to geology. Density analysis and color-additive image enhancement proved of considerable value in several of these analyses.

SPECIALIZED INTERPRETIVE TECHNIQUES

Computer enhancement techniques employed in the various earth resources studies at the University of Wyoming include density analysis, clustering, and image ratioing. Such techniques are of demonstrated value in some applications, but, for the geologist, it appears that standard photointerpretation and image enhancement are still the chief means of using the ERTS and other remote sensor data. When special enhancement procedures appear to be necessary, the geologist (or other earth scientist) should have access to processed data. The processed data in such cases should be displayed in image form so that the interpreter can compare it to standard images and interpret it efficiently. Because the equipment necessary to process and re-display the data is prohibitively expensive, it seems that the processed data should be made available as an optional product along with the data original.

CONCLUSION

As the above studies illustrate, the present ERTS system has many applications in geology and related surface resource studies. Improved resolution and a narrower band selection will make future systems even more useful. There are probably very few geologists, regardless of their interests who cannot gain a new prospective and new information from ERTS. A major goal of the ERTS investigator should be to persuade these geologists to look at the images.

SELECTED REFERENCES

Bekkar, Hamed, 1973, Laramide structural elements and relationship to Precambrian basement, southeastern Wyoming; unpublished M.S. Thesis, University of Wyoming, Laramie, 70p.

Billingsley, F. C., 1973, Some digital techniques for enhancing ERTS imagery; in Symposium on Management and Utilization of Remote Sensing Data, Sioux Falls, South Dakota, Nov. 1, 1973, p. 285-293.

Blackstone, D. L., 1972, Tectonic analysis of southwestern Wyoming from ERTS-1 imagery; NASA Technical Report CR-129651, 8p.

_____, June 1, 1973a, Analysis of photo linear elements, Laramie Mountains, Wyoming; NASA Technical Report CR-132172, 16p.

_____, June 10, 1973b, Analysis of photo linear elements, Bighorn-Pryor Mountains, Montana and Wyoming; NASA Technical Report CR-133017, 15p.

_____, August 15, 1973c, Geology of photo linear elements, Great Divide Basin, Wyoming; NASA Technical Report NASA-CR-133634, 14p.

Breckenridge, R. M., 1973, Glaciation in northwestern Wyoming; in Symposium on significant results obtained from the ERTS-1 Satellite, March 5-9, 1973, p. 363-370.

Breckenridge, R. M., Marrs, R. W., and Murphy, D. J., 1973, Remote sensing applied to land-use studies in Wyoming; Symposium on significant results obtained from ERTS-1, March 5-9, 1973, p. 981-990.

Houston, R. S., 1973, Distinguishing major lithologic types in rocks of Precambrian age in central Wyoming using multilevel sensing with a chapter on possible economic significance of iron formation discovered by use of aircraft images in the Granite Mountains of Wyoming; NASA Technical Report CR-130557, 34 p.

Houston, R. S., Zochol, F. W., and Smithson, Scott B., 1973, Reconnaissance geologic mapping in the Dry Valleys of Antarctica using the Earth Resources Technology Satellite; NASA Technical Report CR-135665, 33p.

Keefer, W. R., 1970, Structural geology of the Wind River Basin, Wyoming; U.S. Geol. Survey Prof. Paper 495-D, 35p.

Kolm, K. E., 1973, ERTS multispectral scanner imagery applied to mapping of sand dunes in Wyoming; Univ. of Wyoming Department of Geology, Special Report under Contract NAS5-21799.

Love, J. D., Weitz, J. L., and Hose, R. K., 1955, Geologic map of Wyoming; U.S. Geological Survey Map.

Lyons, R. J. P., 1970, The multiband approach to geological mapping from orbiting satellites: Is it redundant or vital?; Remote Sensing of Env., Vol. 1, No. 4, p. 237-244.

Nature, 1973, ERTS-technological success, scientific failure?; Nature, volume 245, no. 10, p. 345.

Rich, E. I., 1962, Reconnaissance geology of Hiland-Clarksen Hill area, Natrona County, Wyoming; U.S. Geol. Surv. Bull. 1107-G, p. 540.

Rowan, L. C., 1973, Iron-absorption band analysis for the discrimination of iron-rich zones; NASA Technical Report CR-129286, 4p.

Sharp, W. N., and Gibbons, A. B., 1964, Geology and uranium deposits of the southern part of the Powder River Basin, Wyoming; U.S. Geol. Survey Bull. 1147-D, 60p.

Tourtelot, H. A., 1967, Geology of the Badwater area, central Wyoming; U.S. Geol. Survey Oil and Gas Map OM-124.

Vincent, R. K., 1973, Ratio maps of iron ore deposits of Atlantic City District, Wyoming; in Symposium on Significant Results Obtained from the ERTS-1 Satellite, March 5-9, 1973, p. 397-386.

Wilson, J. E., 1970, Sensor detection capabilities study; U.S. Geol. Survey Circ. 616, 26p.

Woodward, T. C., Geology of Deadman Butte Area, Natrona County, Wyoming; American Assoc. Petroleum Geologists Bull., v. 41, no. 2, p. 212-262.