NAS 5-21799
NAS9-13298

# UNIVERSITY OF WYOMING REMOTE SENSING LABORATORY

E7.4-10628
CR-138738



(E74-10628) SOME ILLUSTRATIONS OF THE ADVANTAGES OF IMPROVED RESOLUTION IN GEOLOGIC STUDIES (Wyoming Univ.) 83 p HC $7.25 CSCL 08G
N74-28864
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## SOME ILLUSTRATIONS OF THE ADVANTAGES OF IMPROVED RESOLUTION IN GEOLOGIC STUDIES

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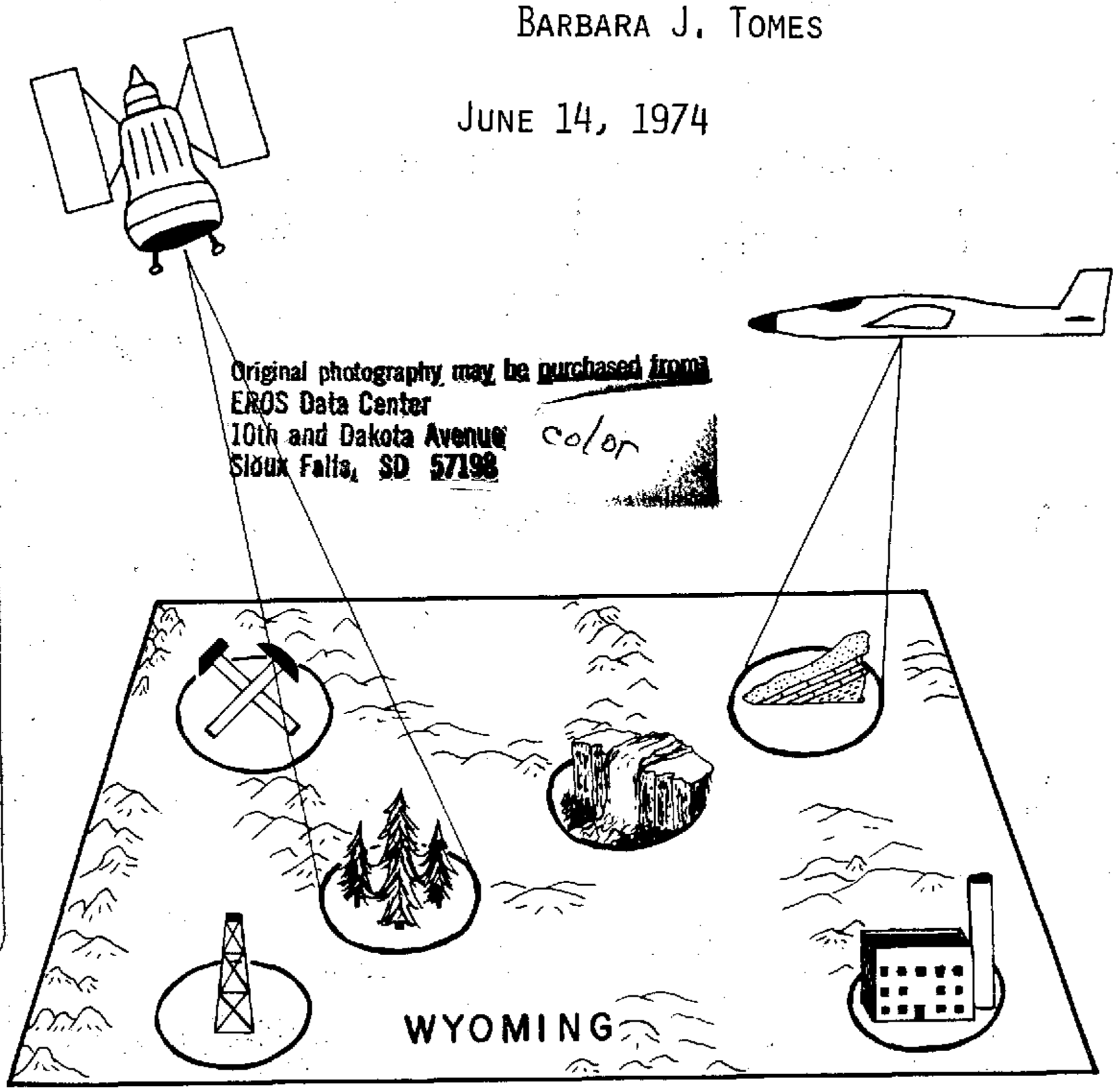
JUNE 14, 1974



# SOME ILLUSTRATIONS OF THE ADVANTAGES OF IMPROVED RESOLUTION IN GEOLOGIC STUDIES

by

Robert S. Houston

INTRODUCTION

Resolution is of critical importance to geologists who have for many years used black and white aerial photographs as a base for geologic mapping or black and white stereo-pairs of air photographs for photogeologic mapping. It has become so apparent that key information is lost in photogeologic study as a result of resolution limitations and other problems with standard black and white photographs that many geologists have abandoned photogeologic techniques entirely and use the air photograph simply as a base map to aid in determining location during field studies. Undoubtedly, this attitude has led some geologists to consider images acquired from space, with their obvious resolution limitations, as of little potential value in geologic studies or to quote an extreme view, "a boondoggle".

This attitude fails to take into consideration the fact that the NASA program is multilevel so that high resolution aircraft images are often available to support and supplement spacecraft images, and it also fails to consider the advantages of modern remote sensing methodology and resulting improved images over the typical black and white photographs in common use until the late 1960's. Nonetheless resolution is critical in geologic studies as the following reports will show.

The first report discusses geologic mapping emphasizing the advantage of a multilevel system in mapping, but shows that without high resolution aircraft photographs many areas cannot be mapped. This report also shows that ground studies must supplement photogeologic studies for satisfactory results. The second report illustrates certain advantages of the spacecraft image in outlining target areas for mineral exploration, but also shows that high resolution aircraft photographs, supplemented by field checks, are necessary to locate mineral deposits, per se. The third report shows the advantage of increasing resolution in lineation study.

The spacecraft image with its unparalleled synoptic view gives the geologist a perspective for regional study that he is just beginning to appreciate. Perhaps current state of the art, cost, or political consideration will not allow this spacecraft image to combine both the synoptic view and high resolution, but it is clear that an improvement in resolution such as that between Skylab S-190A and S-190B and ERTS is critical to many studies and that several orders of magnitude resolution improvement will greatly increase the value of the space image for geologic study.

# GEOLOGIC MAPPING USING SPACE IMAGES

by Robert S. Houston

## INTRODUCTION

State-of-the-art space imagery is not an optimum product for geologic mapping. Obviously the geologist needs the highest resolution image possible for accurate work, and in many areas most- or all of the mapping must be done by ground methods. Even in areas where vegetation is sparse and aircraft imagery excellent, ground surveys must supplement photogeologic mapping. Until recently, many geologists have abandoned photogeologic methods on the assumption that photogeologic methods are not quantitative enough for accurate mapping; or, if useful at all, the main use will be outside the United States because we are assumed to have essentially mapped the country. Studies by the United States Geological Survey (Kinney, 1970, p. 18) show that only about 25% of the country (post-1930 mapping) has been mapped at scales as large as 1:62,500. However, if we go to a scale of 1:250,000 or 1:500,000, a scale where space images might be most useful, we might assume that most of the United States is adequately mapped. Figure 1 shows the status of modern published and available unpublished mapping in the area covered by the Arminto AMS sheet of central Wyoming. This index has recently been brought up to date by J. D. Love for use in compiling the new state geologic map. Clearly we have some major gaps in the mapping and we have similar gaps elsewhere in the state, but the Arminto area is one of the worst so we selected it to see if spacecraft imagery could be helpful in geologic mapping.

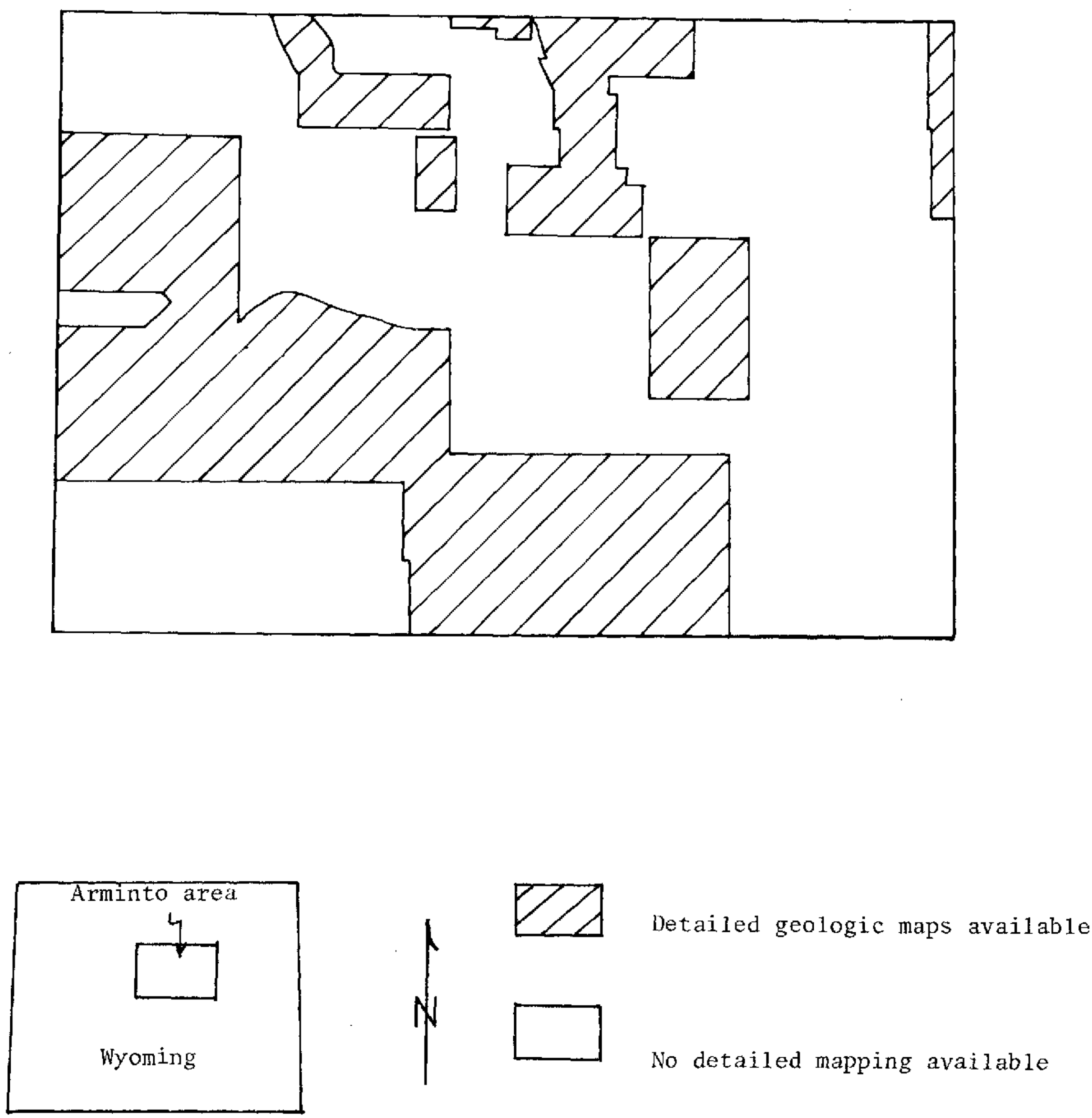



Figure 1. Index showing areas of available detailed coverage within the Arminto area.

LIMITATIONS OF TODAY'S METHODOLOGY

Photogeologic mapping using standard black and white products is basically an attempt to map contacts of photo units as expressed by tonal contrasts, texture, and geomorphic features, and to map faults and other structures by use of stereoscopic interpretation. Tonal contrasts expressed on black-and-white prints are useful in mapping lithology, but they can seldom be used to identify rock types. Laboratory determined reflectance spectra for common rocks show differences in the visible and near-infrared regions due primarily to electronic processes in the cation or impurity ions (iron the most common source) and to vibrational processes in hydroxyl groups or molecular water, and in the far infrared (9-12 um) due primarily to silica content (Hunt and Salisbury, 1971). The reflectance spectra also show variation in overall reflectances for rocks depending, in part, on electronic processes which can produce an extremely sharp cutoff in the visible or near-infrared spectrum, or continuous absorption throughout the entire range (Hunt, Salisbury, and Lenoff, 1971, p. 1-3). Thus rock spectra show two main characteristics: narrow absorption bands due mainly to the presence of iron, hydroxyl groups, water and silica, and broad reflectance differences or brightness differences. A granite, for example, has a relatively high spectral reflectance as compared with basalt, basalt may show absorption bands due to iron content not shown by granite, and silica absorption bands in granite are recorded at different wavelengths than those in basalt (Figure 2). These spectral differences appear to offer a possibility for remote identification of rocks and a number of studies have been undertaken, primarily using aircraft systems, to determine if rocks can indeed be identified by use of spectral differences. One of the

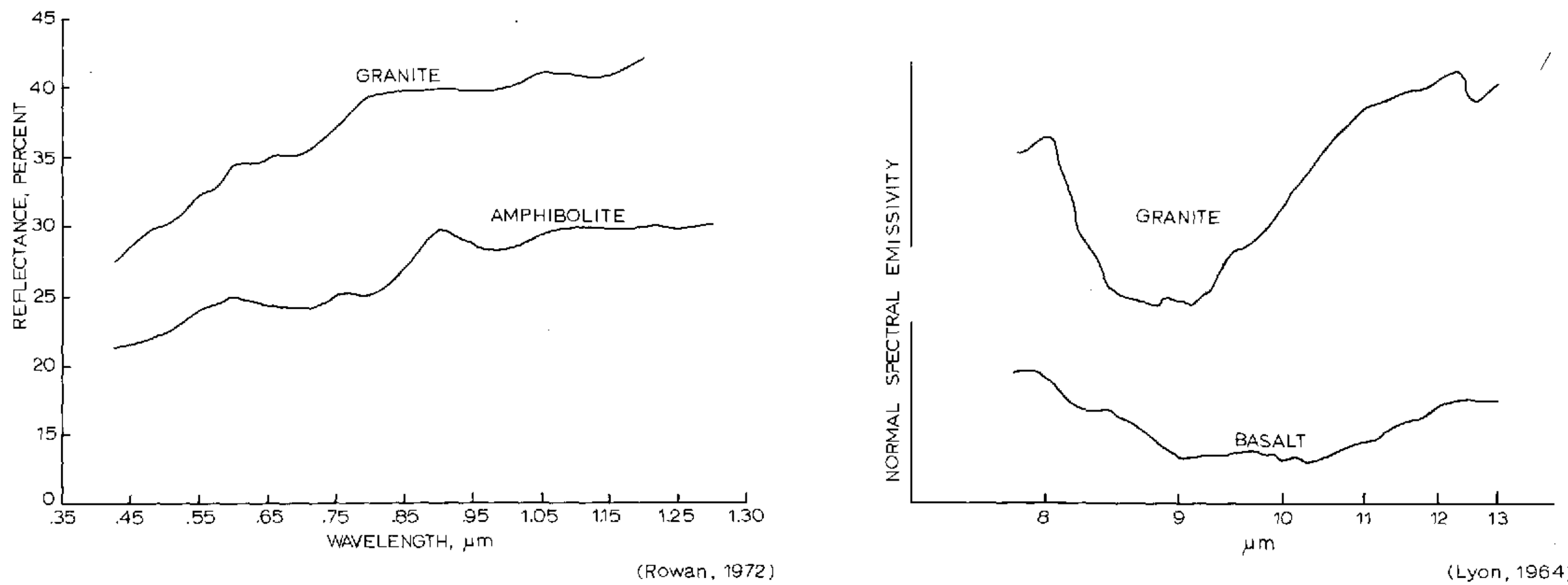



Figure 2. Comparisons of reflectance and emissivity spectra for acidic and mafic rocks. The reflectance curve for the mafic rock shows a reflectance low (absorption) at about 0.7 μm and 1.0 μm. The thermal emissivity curves show a decided shift in the emissivity low toward shorter wavelength due to the increased silica content of the granitic rock.

most comprehensive studies was that of Lyons (Lyons and Patterson, 1969, p. 527-552) at Stanford who has had some success in identifying rocks by taking advantage of the shift in silica absorption band with silica content in the far infrared. This study made use of an aircraft mounted spectrometer and radiometer. Characteristic spectra of common rocks were compared with those of the target or unknown as determined by the spectrometer, and under optimum conditions rock types and contacts could be mapped along the straight-line path of the spectrometer. The method is subject to a number of limitations that will be discussed, but for geologic mapping a major limitation is that information is confined to the single narrow path of the spectrometer and is difficult to extrapolate into other areas for mapping. An approach that uses the same silica shift principle in mapping rocks but makes use of a multispectral scanner instead of a spectrometer has been proposed and tested by Vincent (Vincent and Thompson, 1971, p. 247-252). Instead of using the complete rock spectra as was done by Lyons, selected bands of the spectra (i.e. 8.2-10.9 um/9.4-12.1 um) are ratioed and ratio images are produced that are useful in distinguishing silica-rich and silica-poor rocks. This method is less specific than that of Lyons, but multispectral scanners produce image data so that maps can be generated from the interpretations and identifications.

The ratio approach has been extended to make use of iron-absorption bands by a number of investigators (Vincent, 1972, p. 1239-1247; Rowan, 1972, p. 60-1-60-18), and because the MSS scanner of ERTS includes near infrared bands the technique has been used to map iron-rich rocks and alteration zones by use of ERTS data (Vincent, 1973; Rowan and others, 1973).

These various techniques plus others using related approaches (Watson, 1972; Pohn, Offield, and Watson, 1972; Watson, Rowan, and Offield, 1971) offer promise for eventual quantitization of geologic mapping, but, as is true for many geologic problems, the number of variables that must be considered to apply these techniques to actual field problems is very large. Factors that affect rock spectra include grain size, grain orientation, degree of weathering, vegetation cover, sun angle and azimuth, viewing geometry, slope angle, temperature, water saturation, atmospheric conditions and depth of the atmospheric column, shadowing, and such common factors as strike and dip of outcropping beds. No technique has been developed to take all of these factors into account although some are considered in most experiments. Statistical methods that essentially map significant reflectance differences in a given area or use training sets to map a certain tone or density that may characterize a rock in a given area (Anuta and others, 1971; Smedes and others, 1972; Watson and Rowan, 1971) are useful but, again, cannot be applied to general mapping because of variables cited above. The 1974 state-of-the-art suggests that enhancement techniques may be useful for mineral exploration under controlled conditions (i.e. where the method is tailored to a specific area) but general geologic mapping is still best done by the experienced photogeologist using standard photogeologic techniques.

NASA SYSTEM

The NASA system offers the photogeologist a number of products that were not previously available. Most systems include multiband images representing selected parts of the spectrum plus color and color infrared images.

The multiband images generally include green, red and near infrared bands that can be used by geologists for topical mapping. For example, near infrared images show bodies of water and water-saturated soils distinctly (dark colored to black) because the near infrared energy is strongly absorbed by water. In addition, the near infrared may show the best contrast between iron-rich and iron-poor rocks (basalt and granite) because of the presence of the iron absorption bands in this wave length. Red bands show vegetated areas as very dark objects because of chlorophyll absorption of light in this wavelength. Thus rocks marked by characteristic vegetation may be mapped much better by use of the red band image. Green band images are not especially useful for geologic mapping, but they are of great value to the sedimentologists who may be interested in mapping suspended sediment in water bodies because water does not strongly absorb this wave length and the sedimentologist can "see through" the water and pick up the reflectance of suspended particles.

Color and color infrared images may be generated by combining bands or may be available as photographic images. These products are better suited for geologic mapping because they add the additional dimension of color for mapping lithologies. No geologist will claim that color is diagnostic of rock type, but in a given region a particular rock unit often displays a characteristic color over a large outcrop area. Standard color-transparencies (preferred for mapping because of higher resolution) and prints are adopted by most geologists because they show rocks in a mode the geologist is accustomed to, but color infrared is just as useful and perhaps a better mapping tool because a good color infrared image is sharper due to better haze penetration, and, if rocks being mapped have a strong contrast in iron content, there is a greater tonal contrast in the infrared. Inasmuch as the color infrared image combines the red, which shows low reflectance for vegetation, with the infrared, which shows high reflectance for vegetation, vegetation is notably enhanced, and rock units with vegetation expression are readily mapped. In any event once the geologist is familiar with the color shift as shown in Figure 3, he can map as well or better with infrared.

APPLICATION

The best approach we have found for geologic mapping using space images is to try to recognize units with distinctive tone ($\pm$ texture) that can be used as marker beds in a given region, and to use these beds along with other standard recognition parameters for mapping decisions. Figure 4 shows laboratory reflectance spectra determined at Goddard Space Flight Center (Short, 1973, p. 9) for a typical suite of Wyoming sedimentary rocks. The spectra are not sufficiently distinctive to be diagnostic of rock type, and, as noted by Short and Lowman (1973, p. 18), several individual rocks displayed greater variation between spectra from fresh and weathered surfaces an inch apart than between quite different rock types. Yet it is apparent that one sedimentary rock group, the Cretaceous shales, has exceedingly low reflectance as compared with other units. These beds of the upper Thermopolis Shale and lower Mowry Shale contrast strongly with other units as the laboratory spectra predict and can be recognized through most of their outcrop area (Fig. 5). Furthermore, since we have the advantage of color images, color can also be used for mapping, and, throughout most of Wyoming, Permo-Triassic red beds make excellent marker units.

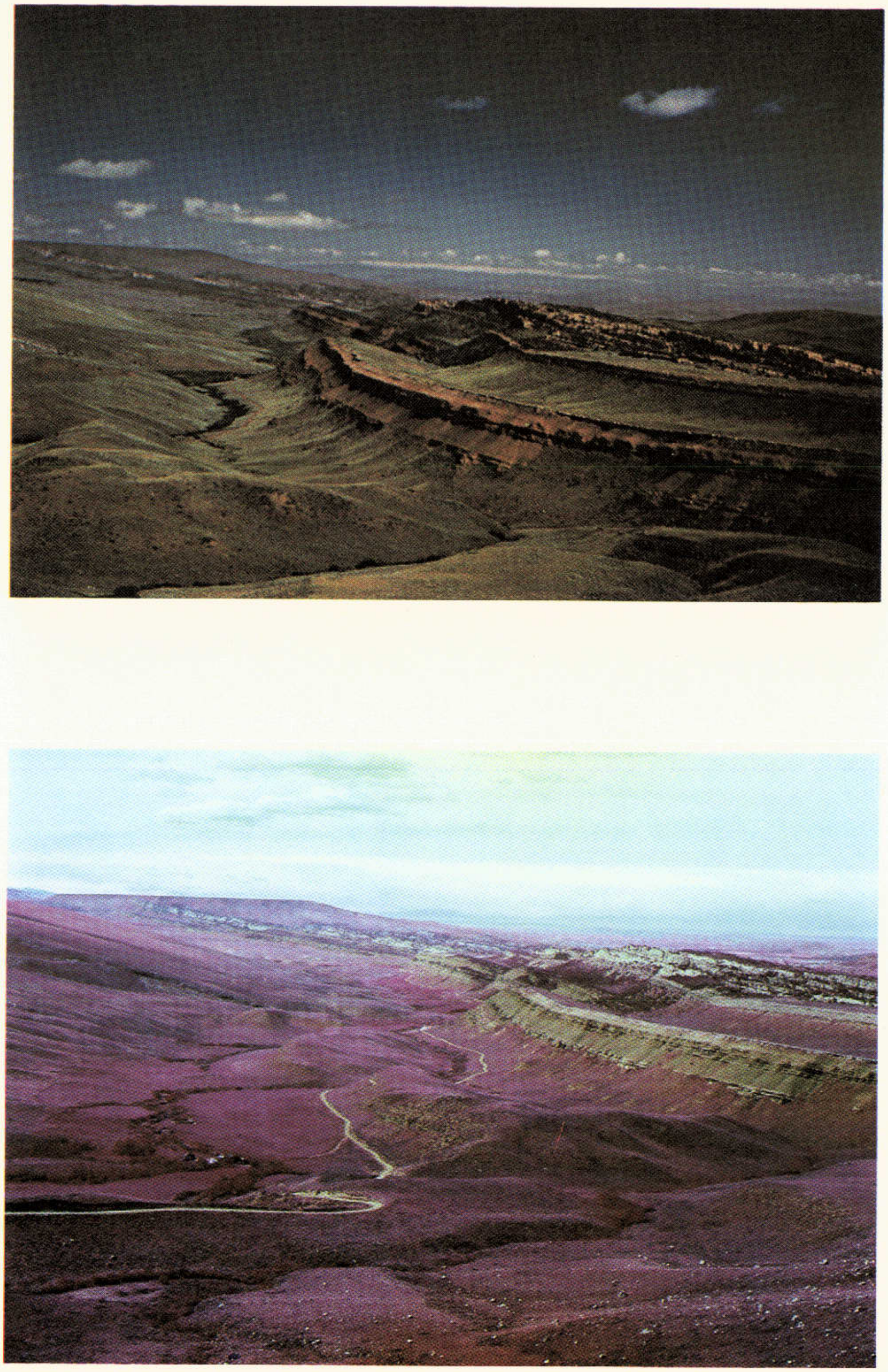


Figure 3. Comparison of color photograph (top) and color infrared photograph (bottom) of the Cedar Ridge red beds on the east flank of the Wind River Mountains.

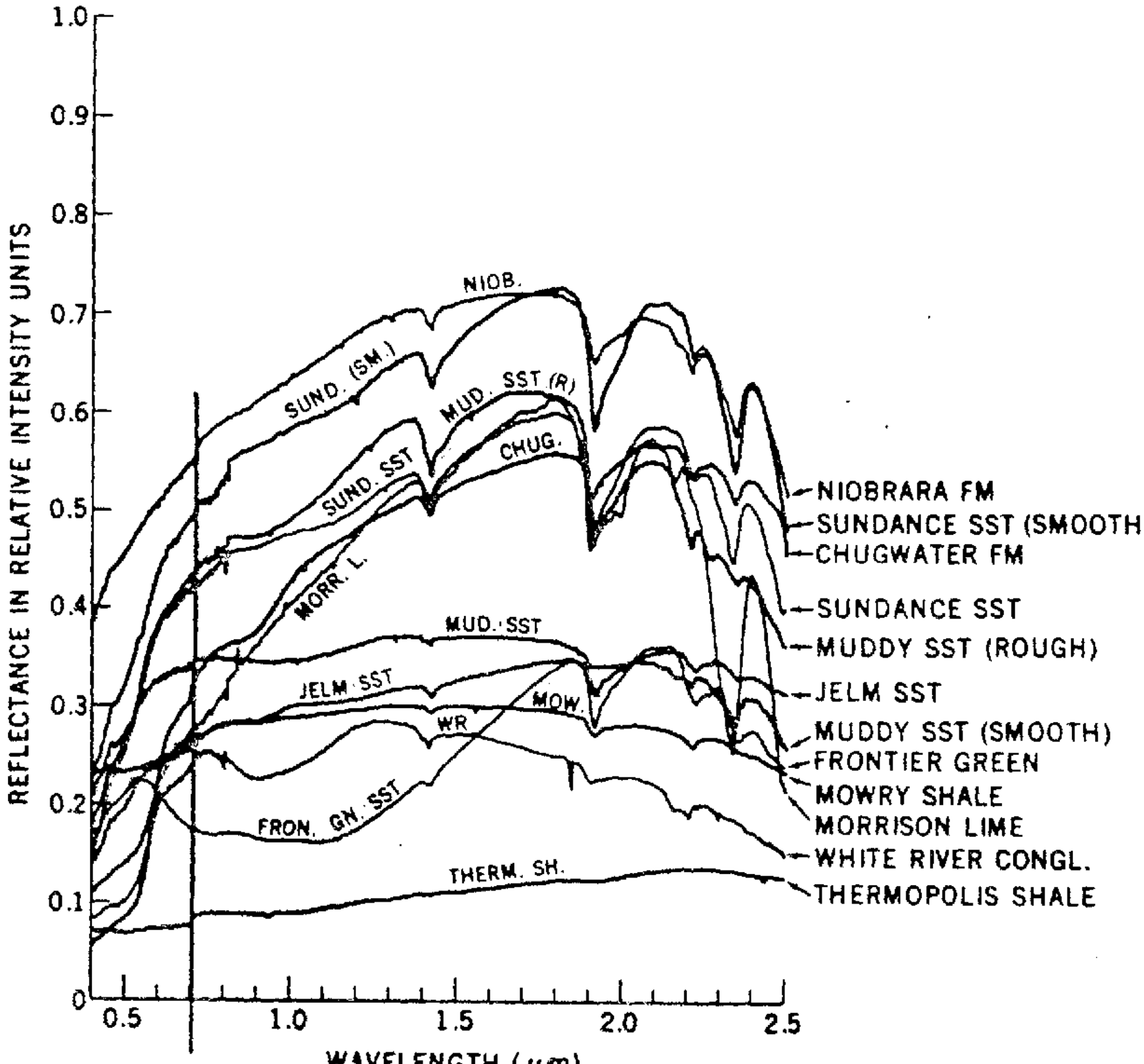



Figure 4. Spectral response curves for a group of rocks from Wyoming determined on a Carey 90 reflectance spectrometer (from Short and Lowman, 1973, Fig. 30, p. 91).

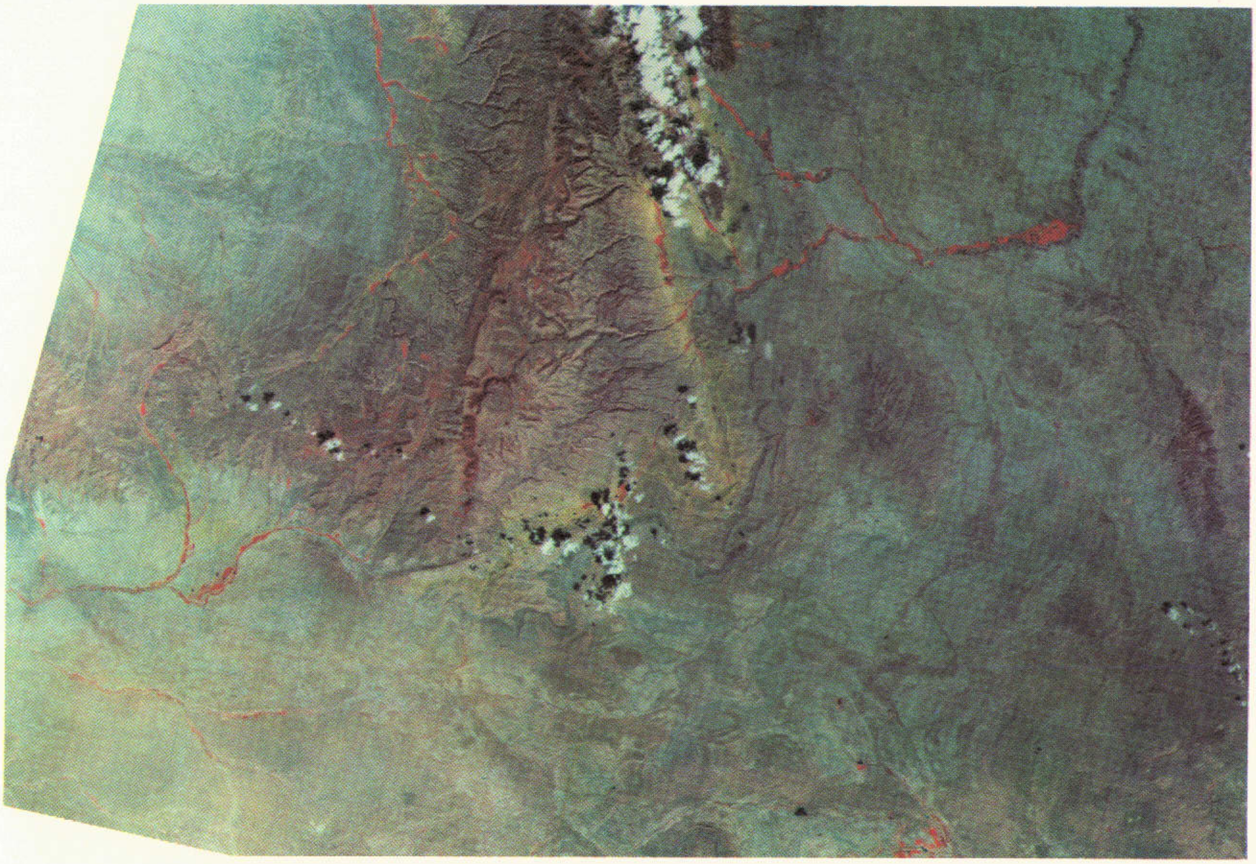


Figure 5. Color infrared ERTS image of the area covered by the Arminto AMS sheet of central Wyoming. ERTS-1 color composite 1030-17235. The dark blue units in the center of this image are Cretaceous shales with distinctive low reflectance. These are useful as marker beds in geologic mapping.

A geologic map (Fig. 6) of the Arminto area of central Wyoming was prepared from interpretation of an ERTS infrared color composite (Fig. 5) using a Bausch and Lomb zoom transfer microscope. When compared with the state geologic map, (Fig. 7) it is apparent that units mapped from tonal variations are surprisingly close to those chosen as formations by field geologists -- particularly since most of these major units are rock-vegetation units.

Figure 8 compares the southeastern quarter of the Arminto AMS map with same area on the 1955 geologic map of Wyoming. 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 whereas 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 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 Kstc 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 irregular vegetative cover. Finally, the lens shown as Kss may be the Sussex Sandstone member of the Cody Shale. The reason for the irregular vegetative cover on the upper Cody Shale bed has not been determined but it Kc(b) does coincide with the location of a major oil field. The odd-shaped area in T. 38 N., Rs. 81 and 82 W. is an area where the

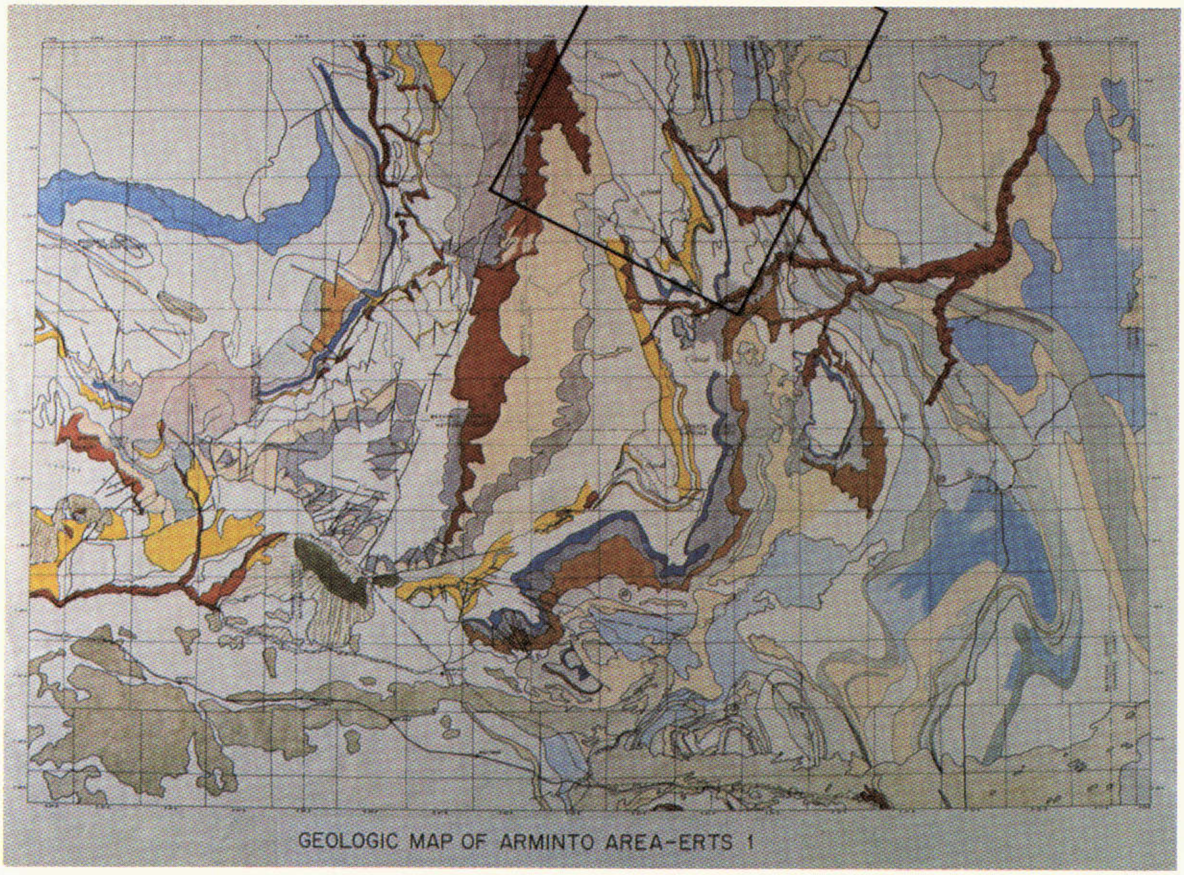



Figure 6. Reconnaissance geologic map of the Arminto area of central Wyoming prepared by use of an ERTS infrared color composite (Fig. 5). Radial line pattern in Tps 38 and 39 N., and Rs. 88, 89, 92, and 93 W. are probably a result of boulder and cobble trains on pediment surfaces. The coarse clastics are probably derived from Paleocene conglomerates. Map is color coded to approximate color of rock-vegetation units as seen on ERTS image -- bright red is Quaternary alluvium with active vegetation growth, blue is shale, dark blue is black shale, yellow is red beds, and flesh-colored units are sandstone or limestones of high reflectance and sparse vegetation. Area outlined in black is also mapped using Skylab 190B photographs (Fig. 10). Compare reconnaissance geologic map with state geologic map of same area (Fig. 7).

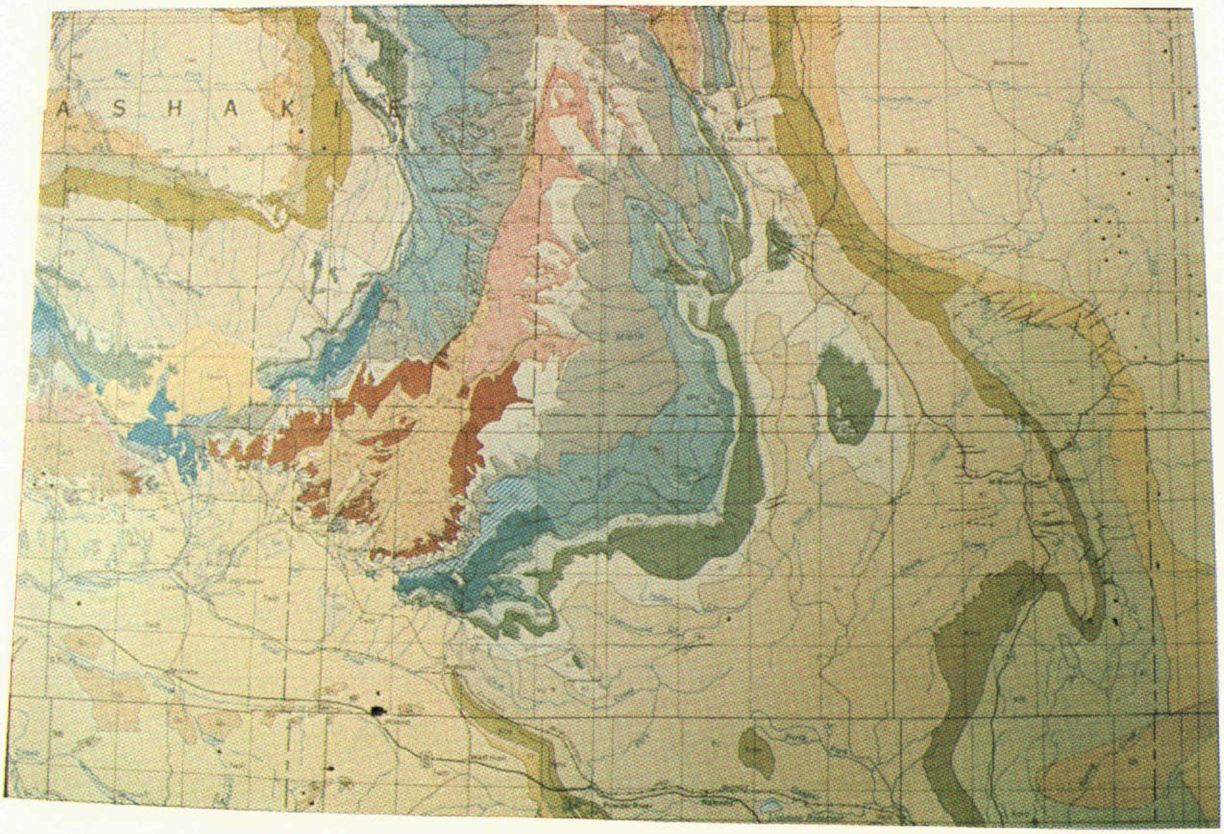


Figure 7. Geologic map of the Arminto area of central Wyoming after Love and others (1955). Compare with Figure 6.

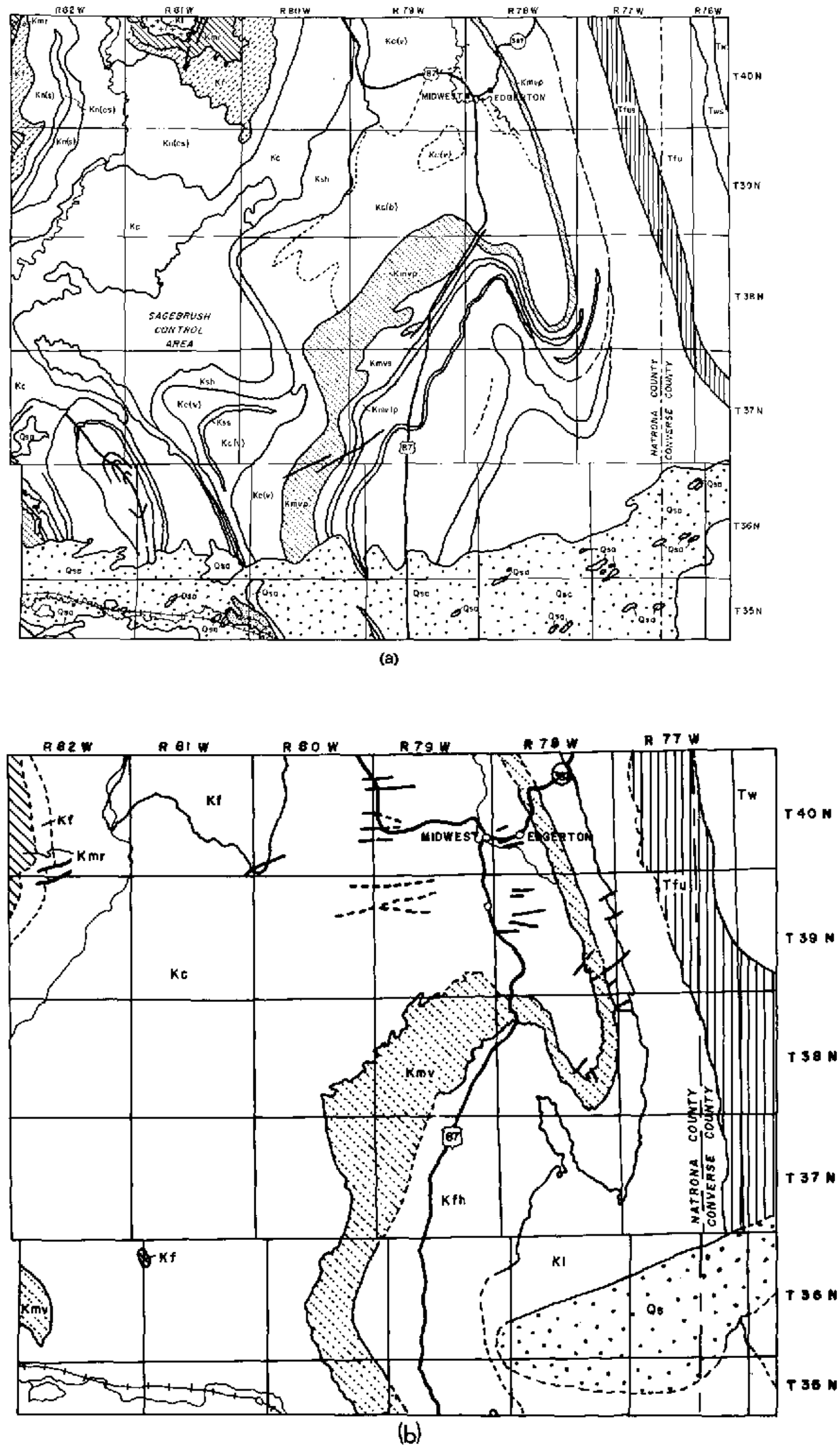



Figure 8. Details of the southeast 1/4 of the ERTS Arminto map (Fig. 6) compared with the same area on the state geologic map of Wyoming (b). See text for explanation of units. Geologic map of Wyoming after Love and others (1955).

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 that is probably the Teapot Sandstone member (Kmvtp). Distinctions were also made within the Fox Hills Sandstone (Kfh) and Lance Formation (Kl), but their significance is not known. A unit designated (Tfus) may be a lower, massive sandstone of the Fort Union Formation and a unit designated (Tuss) may be a sandstone of the Wasatch Formation. Finally, stabilized sand dunes (Qsc), active sand dunes (Qsa), and alluvium (Qal) are readily mapped.

The southeastern quarter of the Arminto AMS sheet is particularly well suited for regional geologic mapping with ERTS color infrared because the various formations display good vegetation control, have low dips, and exhibit a fairly broad outcrop area. Other areas are not so suitable for mapping because dips are steeper, structure more complicated, and vegetation tends to mask rock types rather than enhance them. A typical area of this type is outlined on the ERTS Arminto map in the north-central or Horn area (Fig. 6). Comparison of the ERTS Horn area map (Fig. 6) with the same area on the state geologic map (Fig. 7) shows the ERTS map to be inaccurate due to the above stated limitations combined with the 100-meter resolution of ERTS.

The Skylab photographs taken with S-190A multispectral camera facility and the S-190B earth terrain camera offer a solution to ERTS resolution problems. Figure 9 is an example of a Skylab high resolution panchromatic photograph taken with the S-190B earth terrain camera of the Horn area.

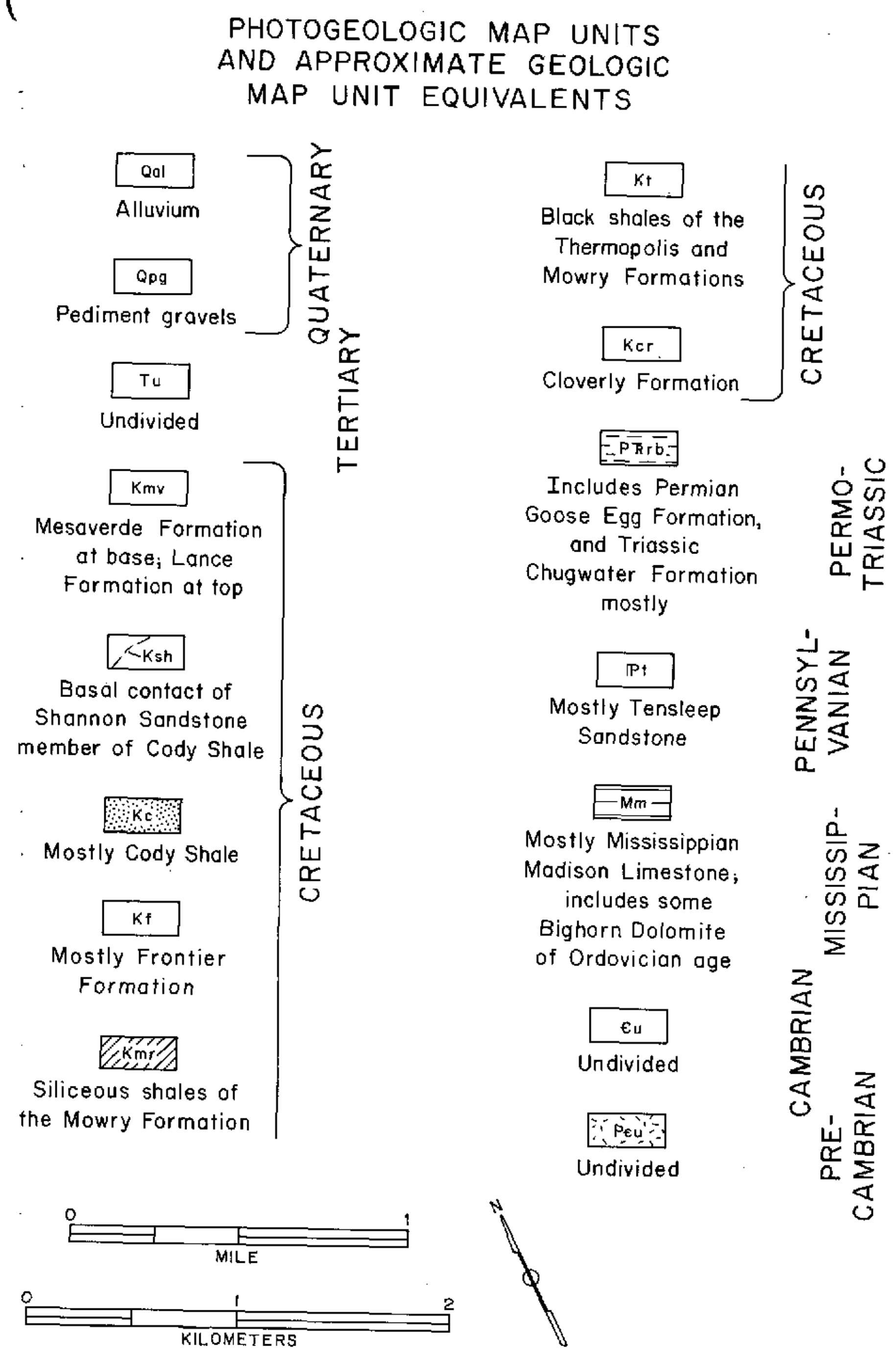
Figure 9. Skylab 190B photograph of the Horn area shown outlined in black on Figure 6 (Skylab mission 2, pass 10, June 13, 1973).

This photograph has a resolution approaching 10 meters compared with an ERTS resolution of about 100 meters. This Skylab photograph also has the advantage of stereo-coverage so structural studies are superior to those possible with ERTS where side lap is limited to 40 percent.

Geologic mapping with Skylab photographs can be done by enlarging the high-resolution S-190B photograph to 1:125,000 and mapping on mylar overlay. Structural and lithologic information can be added by using stereo-pairs of S-190A film positives, especially the color and color infrared photographs. If adequate control, such as roads, towns, and streams, is available, a base grid of Township and Range can be added to the geologic map by projection. There is generally so little distortion in the space photograph that a grid can be fitted with little or no adjustment.

The Skylab map of the Horn area (Fig. 10) can be compared with the same area on the 1955 state geologic map (Fig. 7). This map is not an improvement over the state geologic map partly because of too heavy vegetation in the northwest quarter and cloud cover in the northeast. It is a satisfactory reconnaissance map at 1:250,000, and in some areas, (southeast) it is actually more detailed than the state geologic map. It is unquestionably a marked improvement over the ERTS map of this area (Fig. 6).

Skylab photographs can also be utilized to select areas that require more detailed investigation (such as the area outlined in Figure 10). This area has been selected for photogeologic mapping using aircraft imagery. A geologic map was prepared by use of a B&L zoom transfer scope augmented by use of stereopairs of film positives on a Richards stereo-photointerpretation table. The photogeologic map (Fig. 11a) is quite comparable to field



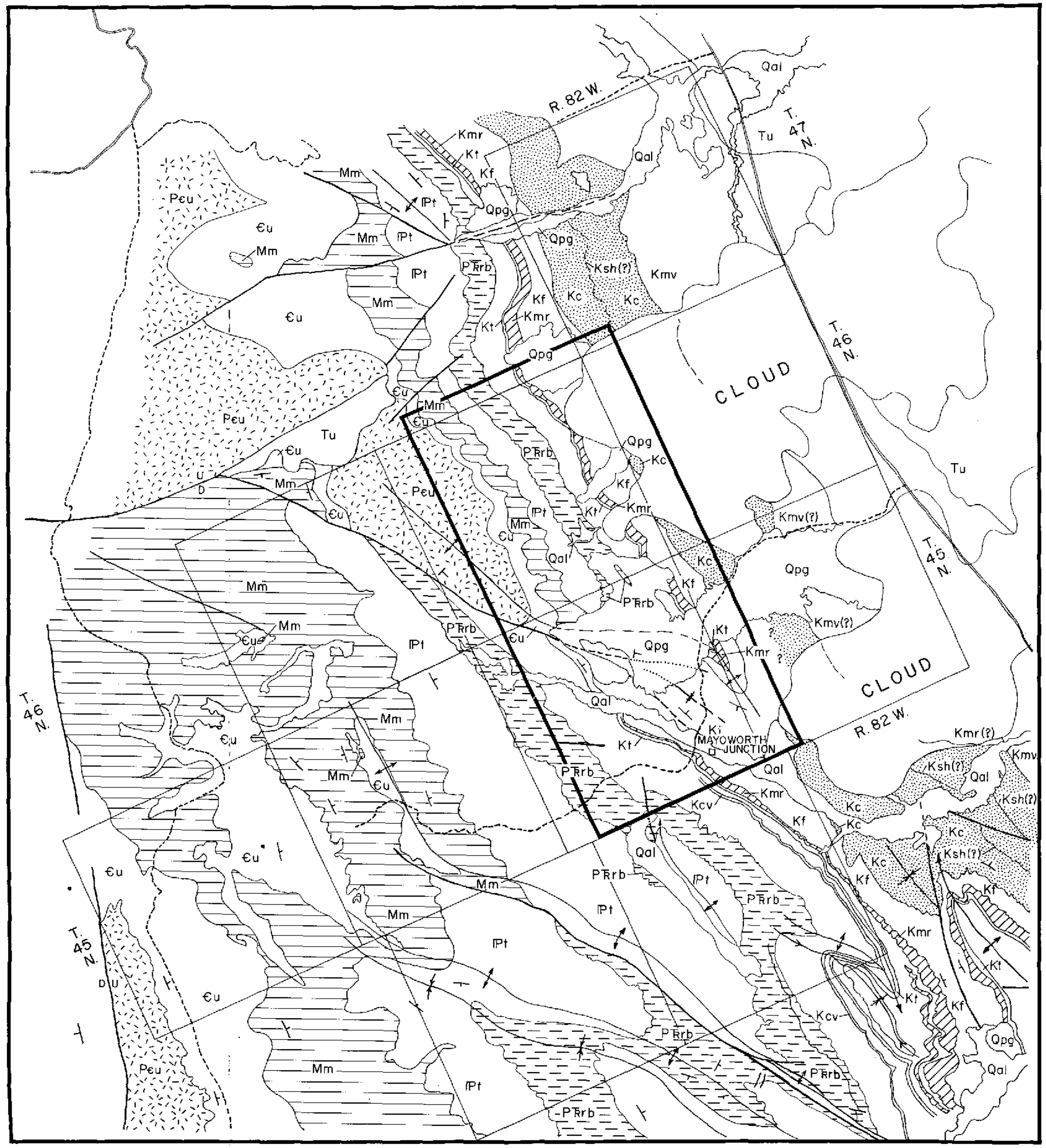




Figure 10. Reconnaissance geologic map of the Horn area from Skylab S-190B photograph and Skylab S-190A color and color infrared photographs. Area outlined in black was also mapped from aerial photography.

## PHOTOGEOLOGIC MAP UNITS AND APPROXIMATE GEOLOGIC MAP UNIT EQUIVALENTS

**QUATERNARY**

- Qal — Alluvium
- Qpg — Pediment gravels

**TERTIARY**

- Tu — Undivided

**CRETACEOUS**

- Kc1,c2,c3 — Subdivions of the Cody Shale
- Kf — Frontier Formation
- Kmrusi — Upper siliceous shale of Mowry Formation
- Kscubs — Upper black shale of Skull Creek Shale
- Kcvus — Upper beds of Cloverly Formation

**JURASSIC**

- Jsus — Upper shale of Sundance Formation

**PERMO-TRIASSIC**

- PTrb — Red beds

**PENNSYLVANIAN**

- IPt — Tensleep Formation
- IPMa — Amsden Formation

**MISSISSIPPIAN**

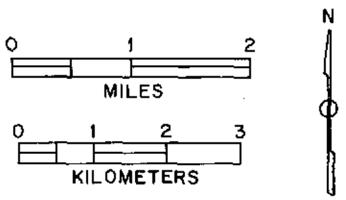
- Mm — Madison Limestone

**CAMBRIAN**

- €u — Undivided

**PRE-CAMBRIAN**

- P€u — Undivided



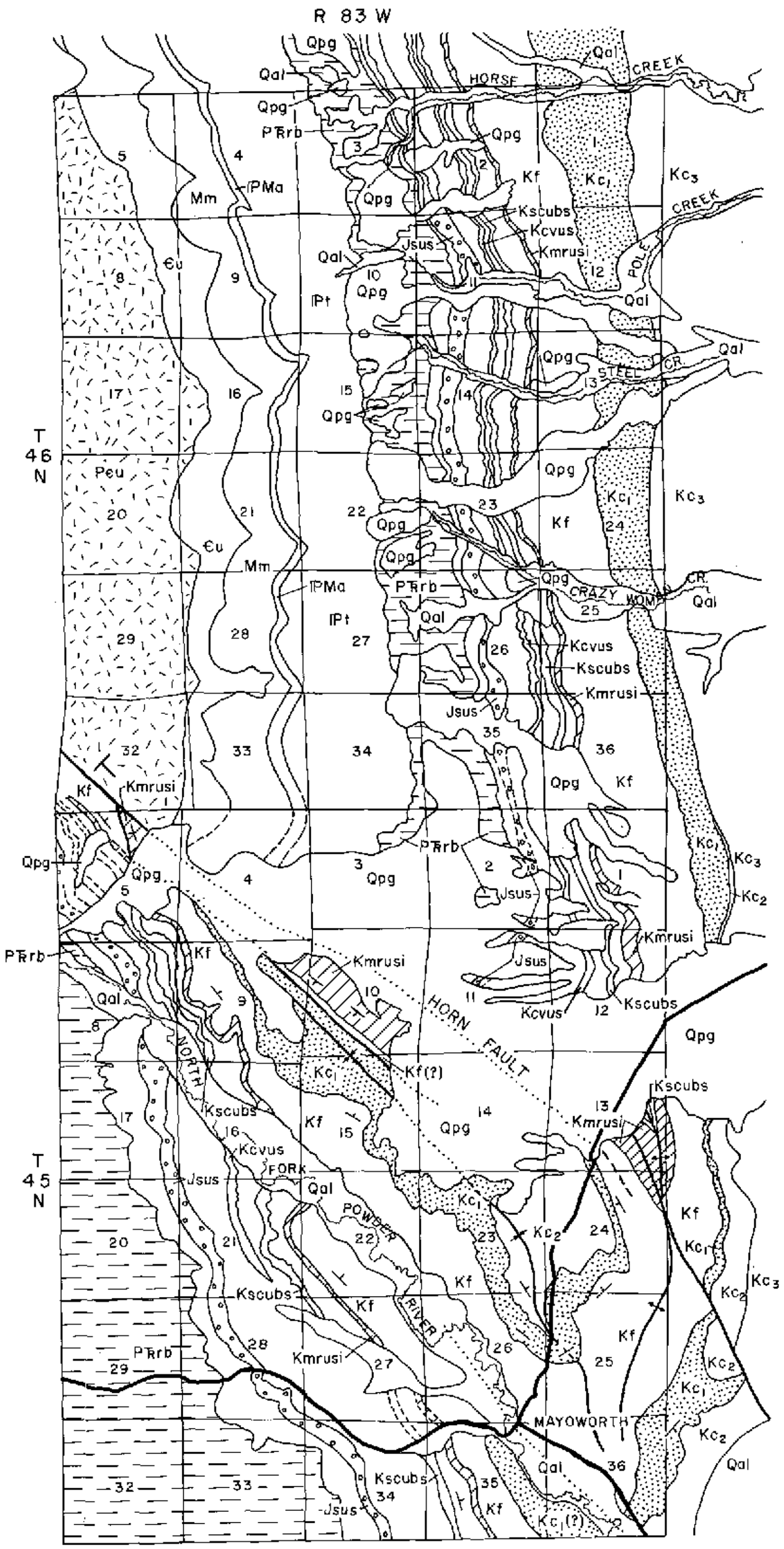




Figure 11a. Photogeologic map of the Horn Area prepared from color infrared aerial photography (NASA Mission 72-138, Sept. 10, 1972). Compare with Figures 10 and 11b.

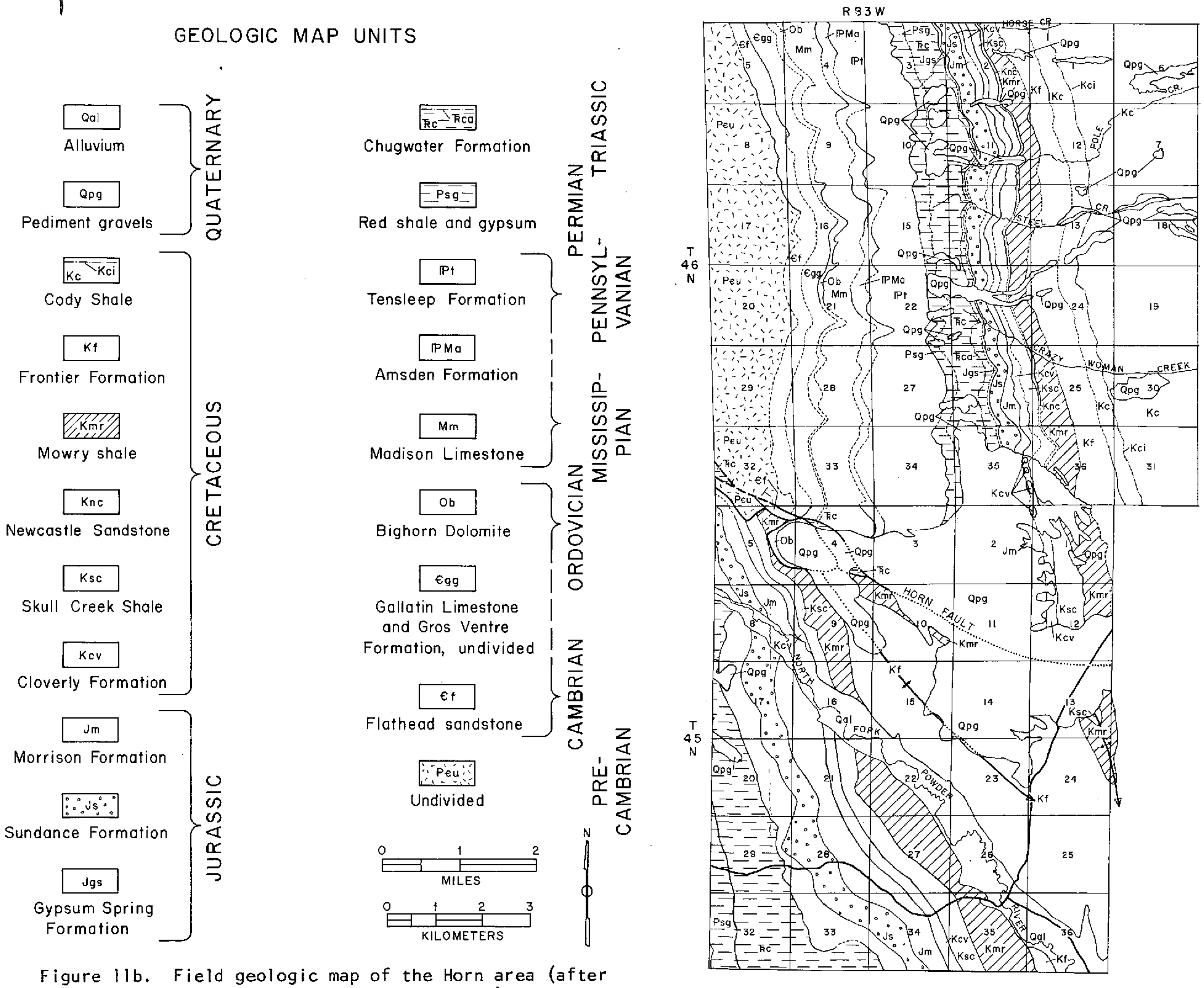



Figure 11b. Field geologic map of the Horn area (after Hose, 1955 and Richardson, 1950). Compare with Figures 10 and 11a.

geologic maps prepared at a scale of 1:24,000 except in areas of heavy vegetative cover. A major difference between the geologic and photogeologic map is the choice of map units. Photogeologic units were selected by choosing units that show distinctive and consistent tone on color infrared film positives. In this area shales are the best marker units -- 8 out of 11 units chosen on the basis of consistent tone were shales. As can be seen on Figure 12, photogeologic units may or may not correspond to units mapped as formations by field geologists. For example, the Skull Creek Shale (Ksc, Fig. 12) (Thermopolis Formation equivalent) of this area as defined by the field geologist (Hose, 1955) is a three-fold unit consisting of a lower subdivision of alternating gray siltstone and grayish-black shale, a middle, ridge-forming, siltstone bed and an upper unit of grayish-black, soft, flakey shale. The upper unit (Kscus, Fig. 12) exhibits a distinctive dark blue tone on the color infrared photograph and was chosen as a marker unit. The Cloverly Formaton (Kcv, Fig. 12) consists of a basal sandstone, overlain by grayish-black shale capped by a resistant brownish-gray siltstone the photogeologic unit (Kcrus, Fig. 12) that is most distinctive on color infrared is the grayish-black shale that has a dark brown tone on the photograph. Other photogeologic units include an upper, olive-gray, silty, calcareous shale (Jsus, Fig. 12) of the Sundance Formation that is distinctive and uniform on the infrared photograph, a lower, middle part of the Mowry Formation (Kmrusl, Fig. 12) that is highly reflective and appears bright blue on the photograph. Other units are mapped on the infrared photograph much as they are by field geologists -- for example Permo-Triassic red beds and red beds of the Amsden Formation.

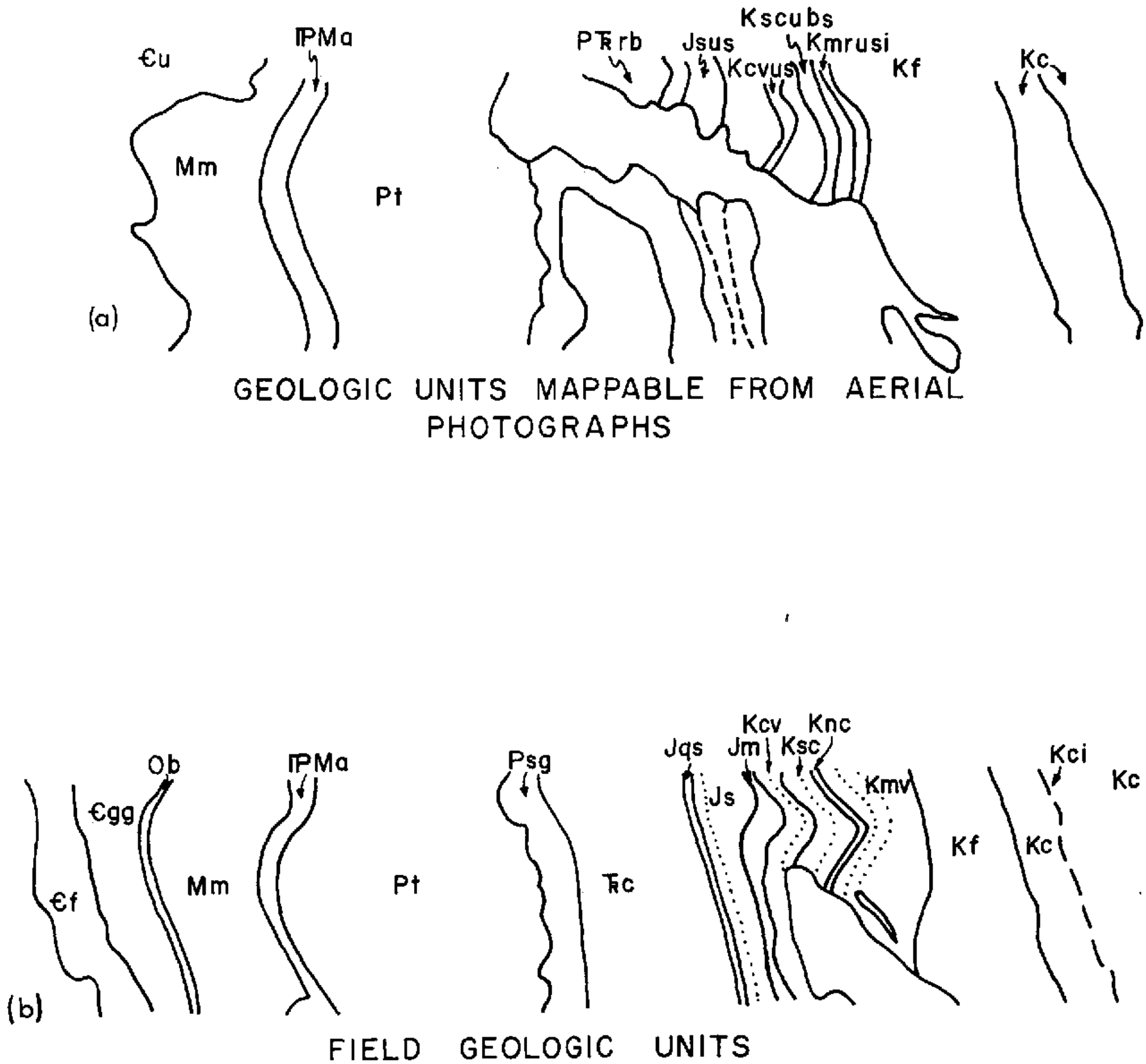



Figure 12. Comparison of photogeologic map units and units chosen by field geologists in part of the Horn area. See text for explanation of units.

The departure in selection of map units has the obvious disadvantage that the photogeologic mapping cannot be readily correlated with field maps. However, the aircraft photography is usually detailed enough so that units (or combinations of rock units) mapped as formations by field geologists can be selected and mapped using the photograph. This problem may require some rethinking of map units by geologists to see if the photo units are superior to formations as previously defined or visa versa. Perhaps the best choice lies in a compromise -- we may wish to use standard formations in most cases, but in some instances subdivisions may be made by photointerpretation even though they are simply not apparent on the ground.

Comparison of the geologic and aircraft map (Fig. 11) of the Horn area shows several major differences between the two. The geologic map is more accurate in Sec. 32, T. 46 N., R. 83 W., and in Secs. 4 and 5, T. 45 N., R. 83 W. where vegetation cover makes it impossible to map structural detail as accurately as in the field. On the other hand, the photogeologic map may be more accurate in the southeast (T. 45 N., R. 82 W.) where shales of the Frontier Formation and Cody Shale have been subdivided into four units based on tonal differences that can be seen on the photograph rather than the two units used by field geologists. If field checks show that these four subdivisions are indeed lithologic units, the structure in the hinge area of the Horn Fault is more complicated than suggested by earlier mapping.

In summary, the NASA, ERTS, Skylab, and aircraft products -- especially the color infrared and color film positives are the best tools publically available for photogeologic mapping today. They are not competitive with, nor are they a substitute for, careful field studies, but we believe that even in situations where money and time are available for detailed field studies, the geologist should utilize these images -- failure to do so might be analogous to studying a thin section with a 100X objective only.

# MULTILEVEL SENSING AS AN AID IN MINERAL EXPLORATION

## IRON FORMATION EXAMPLE

By Robert S. Houston

## INTRODUCTION

In Wyoming and in a number of other parts of the United States the NASA program offers the geologist an opportunity to select photographs or images taken at various elevations above the surface and thus having different perspectives and resolution. Short and Lowman (1973, p. 37) have suggested that this is like having two new low-power objectives (ERTS-Skylab) for a petrographic microscope that were never available before, in addition to a standard medium-power objective (aircraft) that has been in common use. The low-power objective enables the petrographer to see relationships between minerals as well as the individual minerals and the space photograph enables the geologist to see how a given feature fits a regional perspective, and perhaps more important, to recognize structures and other features of regional extent that may have been overlooked by mapping isolated areas. This space view has been appropriately referred to as the synoptic view and is, perhaps, the most valuable single feature of the space photograph or space image.

NASA coverage of Wyoming includes complete cloud free ERTS imagery (900 meters above the surface, Fig. 1) on a seasonal basis (18-day cycle about 1/3 to 1/2 cloud free); greater than 50 percent cloud-free Skylab (270 miles above the surface, Fig. 2), and greater than 70 percent aircraft coverage (15 to 60,000 feet above the surface, Fig. 3). Standard products include film positives and prints of multiband images generated

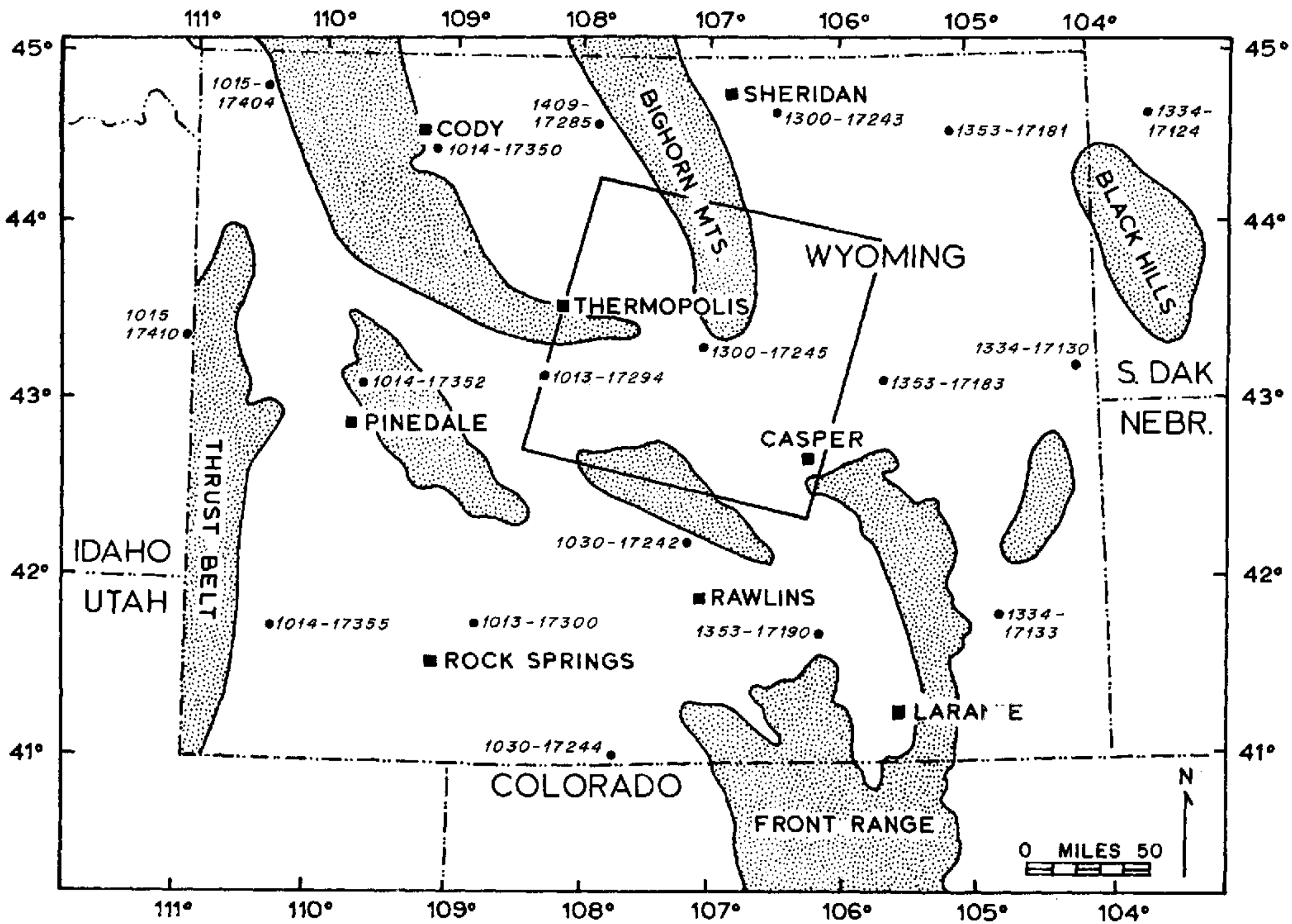



Figure 1. Map of Wyoming showing identification numbers of best ERTS-1 images generated between July, 1972 and October, 1973.

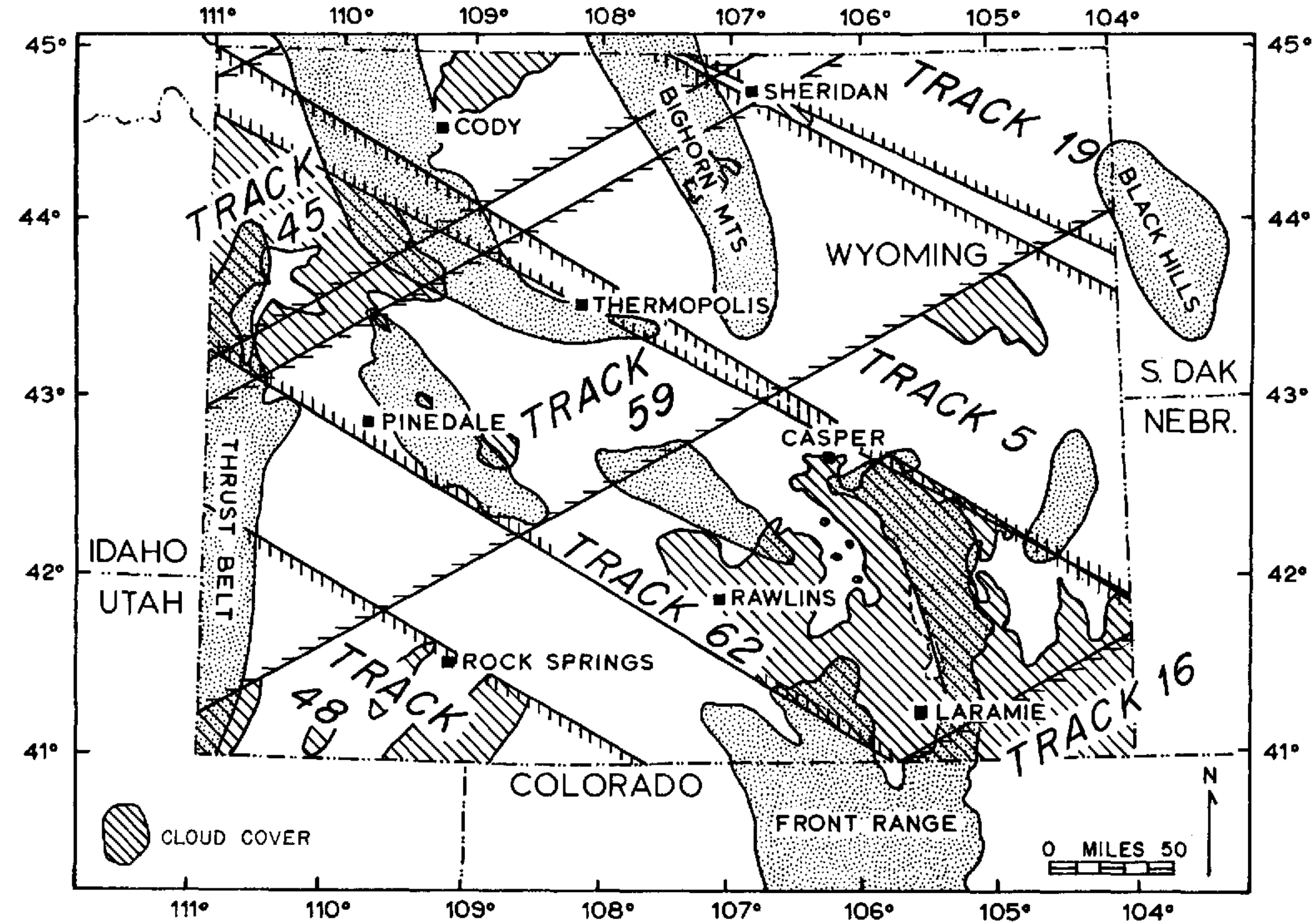



Figure 2. Index map showing Skylab S-190A coverage of Wyoming during Skylab missions 2 and 3. Cross-hatched area is cloud covered.

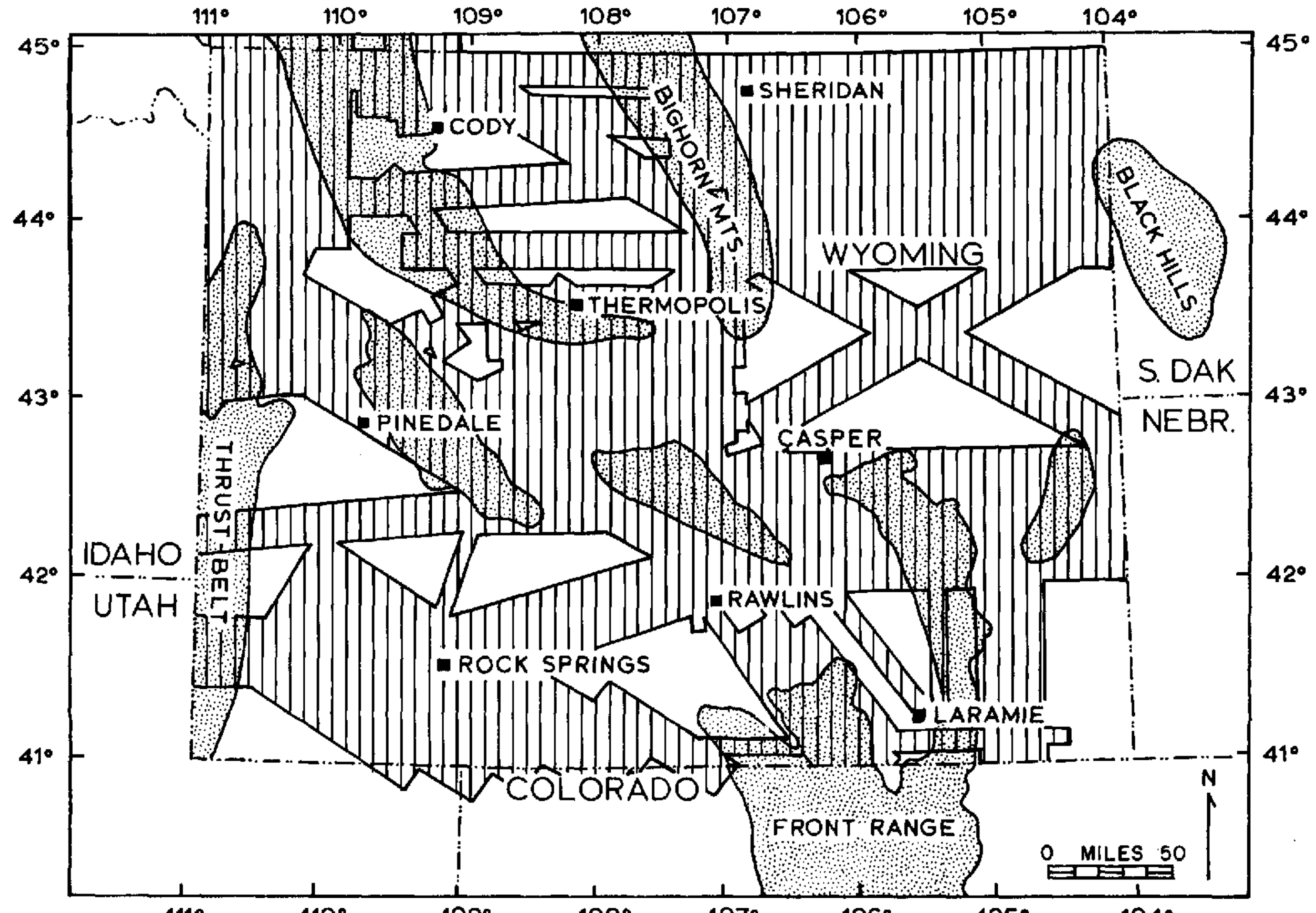



Figure 3. Index map showing NASA aircraft coverage of Wyoming as of October, 1973.

from the MSS ERTS multispectral scanner, film positives and prints of six bands from Skylab S190A cameras, color and color infrared film positives and prints from Skylab S190A, high resolution black and white and color positives and prints from the Skylab S190B camera and a variety of products from aircraft sensors including six or more bands from multispectral camera systems, high resolution color and color infrared prints and film positives from 10-in. aerial cameras and various products from multispectral scanners and spectrophotometers. This great wealth of information can be examined by geologists in various browse centers supported by NASA and other federal agencies (Denver Federal Center and Sioux Falls Centers are convenient to Wyoming users) and at research centers where data covering a specific area may be available (for Wyoming users the Remote Sensing facilities of the Department of Geology in Laramie).

MULTILEVEL SENSING

The multilevel sensing approach takes advantage of the availability this material to save time and money in geologic studies. Spacecraft images can be used to target areas of geologic and/or economic interest and images taken at lower (aircraft) elevations can be used to study key areas in greater detail. This approach saves time and money since the user will find the space image can be obtained and analyzed at less cost per unit area.

Examples of the use of this approach are 1) recognition of regional lineaments with spacecraft images and detailed study of these features with aircraft products and on the ground; 2) recognition of major color anomalies associated with mineralization by use of color and color infrared space images and verification or rejection of these by use of aircraft and ground studies; and 3) mapping of major lithologic units that may be host of mineral deposits by use of spacecraft images and study of these units in greater detail by use of aircraft and ground studies.

GREENSTONE BELT EXAMPLE

Rocks of Precambrian age in Wyoming are primarily Archean (2.5 b.y.) in age and consist of two major terrains -- greenstone belts and granite-granite gneiss. The granitic rocks are of economic interest because they may be directly or indirectly one of the sources of uranium now in the sandstone-type uranium deposits of the basins, but most of the mineral deposits in the Archean rocks are in the greenstone belts that make up a relatively small part of the total bulk of Archean rocks. The greenstone belts contain all known iron formations of economic significance and virtually all other metallic mineral deposits in the Wyoming Precambrian except deposits in post-Archean metasedimentary rocks located in southeastern Wyoming. For this reason, the greenstone belts are an economic target and mapping unknown belts or completing the mapping of partially known belts is a useful task.

PRECAMBRIAN TERRAIN DISTINCTION USING ERTS-MSS SENSOR

The results of a preliminary study using ERTS-MSS band-5, 9-inch positive transparencies for Precambrian terrain distinctions have been discussed by Houston and Short (1972, p. 11-13). At the time of this preliminary study (September, 1972) the only ERTS data available were the MSS-5 positive transparencies. Figure 4 shows the results of this preliminary study and as noted by Houston and Short (1972, p. 12) greenstone belts could be distinguished from granite-granite gneiss terrain quite well in the southeastern Wind River Mountains and to some degree in the Granite Mountains of Wyoming.

In the southeastern Wind River Mountains mapping by Bayley (1965a-d) and Bell (1955) gives adequate ground truth to enable us to evaluate the ERTS, MSS-5 interpretation. According to Bayley (1965a) the metasedimentary rock metavolcanic rock terrain(greenstone) consists chiefly of light-brown to black feldspathic and micaceous graywacke, conglomerate and mica schist, and dark-colored mafic lava flows and bodies of gabbro, black graphitic schist, dark brown meta-andesite flows, and lesser amounts of dark quartz-magnetite iron formation and white, gray, or pale green quartzite and pale green mica (fuchsite) schist. The terrain underlain by these rocks is dark colored and distinctly layered. The granitic terrain (Bayley, 1965c) may be gray quartz diorite and grandodiorite or white to pink coarse-grained granite (Bell, 1955, p. 13). The granitic terrain, for the most part is light colored and texturally more massive than the metasedimentary metavolcanic rock terrain. This tonal contrast shows quite well on ERTS MSS-5 imagery with the metasedimentary metavolcanic terrain indicated as areas of low reflectance and the granitic terrain as areas of higher reflectance.

Although similar distinctions can be made in the Granite Mountains the interpretation from the ERTS image is not as accurate as that of the southeastern Wind River Mountains. The accuracy of the interpretation may be judged by comparing Figure 4 (the ERTS interpretation) with Figure 5 which is a geologic compilation from the best available geologic and photogeologic mapping of this area. The major area of metasedimentary metavolcanic rock in the northeast Granite Mountains can be

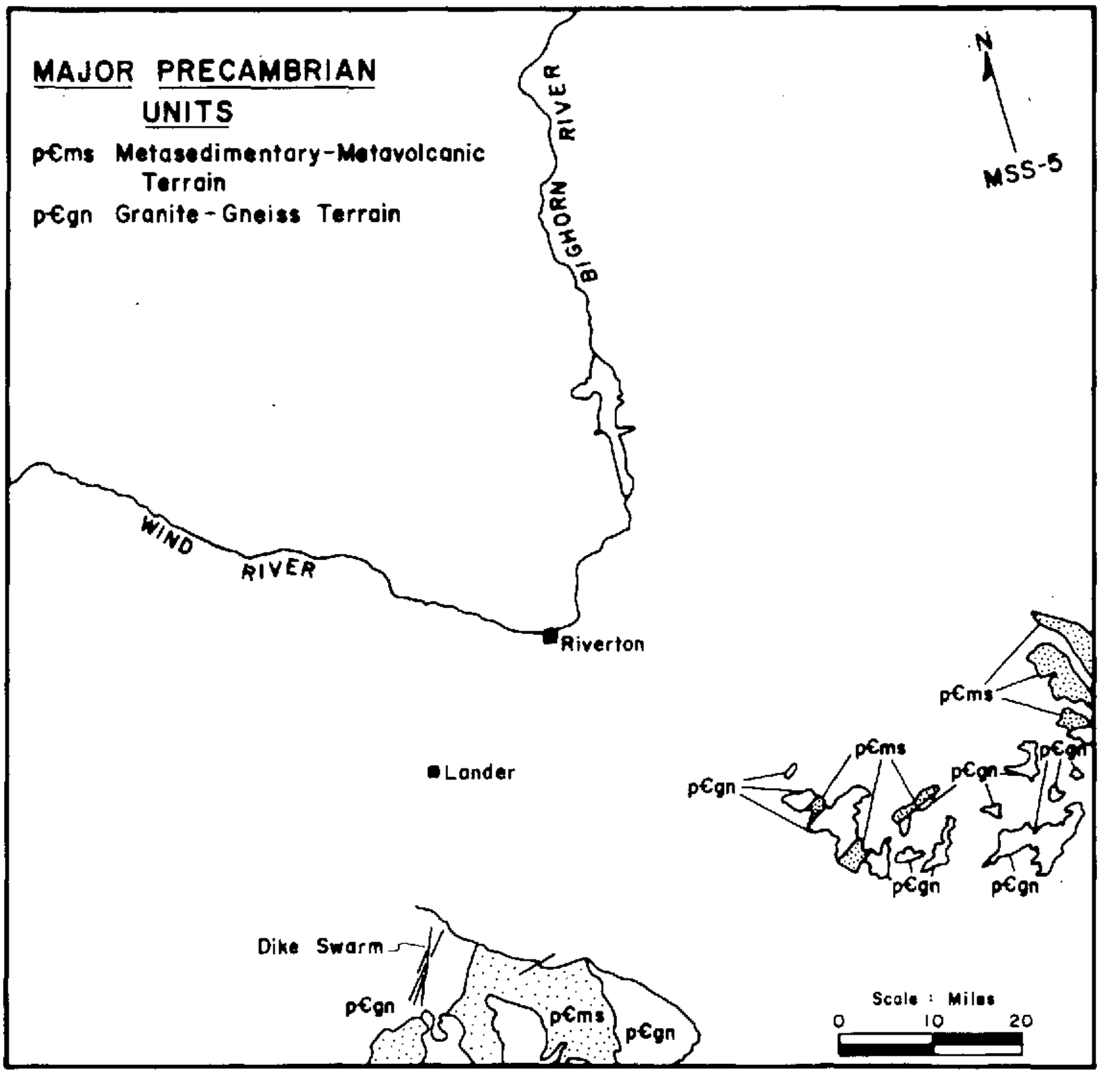



Figure 4. Map of Precambrian terrane of the southern Wind River Mountains (bottom center) and Granite Mountains (lower right) showing greenstone belts pCms mappable from ERTS imagery.

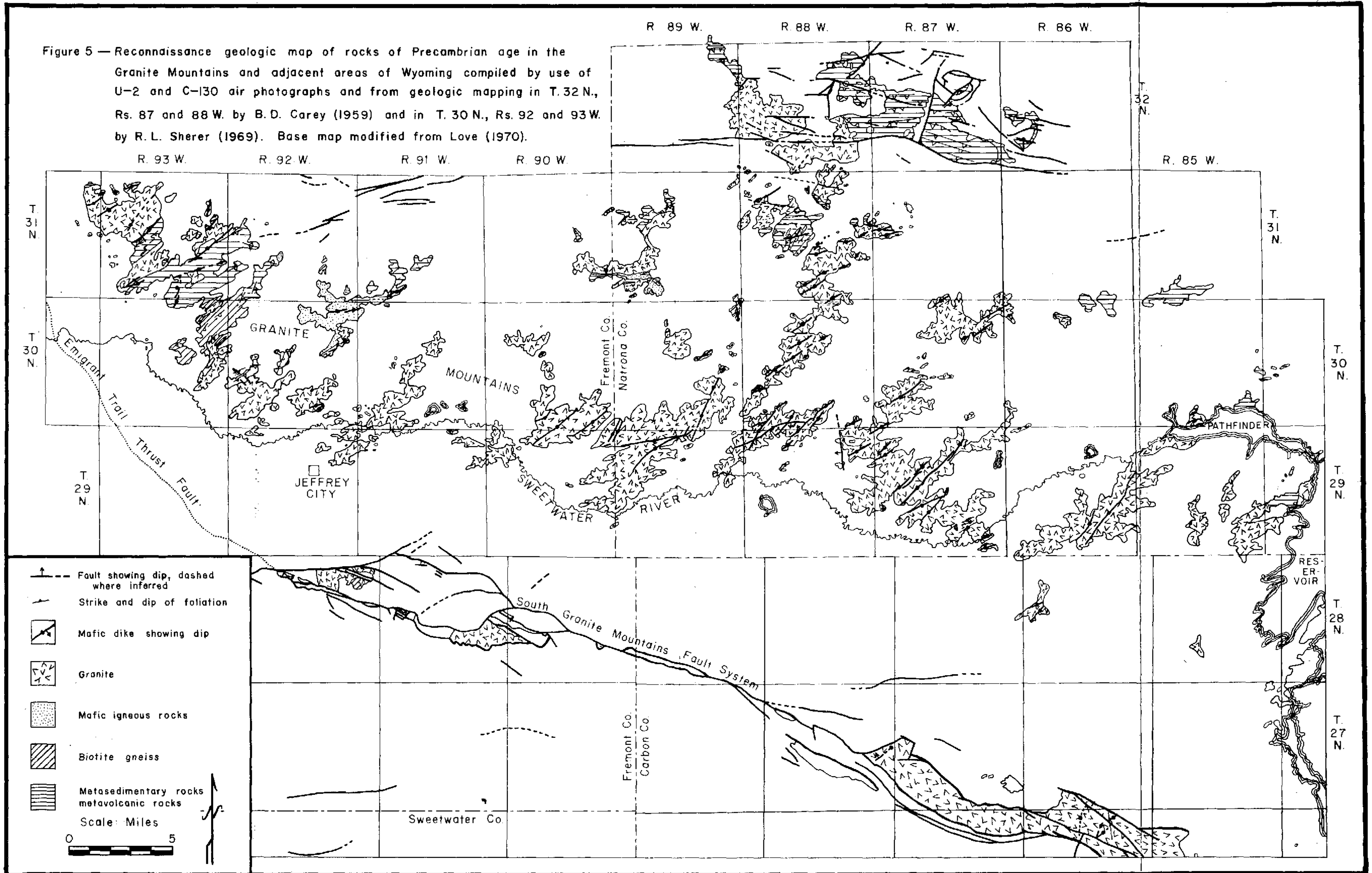



Figure 5 — Reconnaissance geologic map of rocks of Precambrian age in the Granite Mountains and adjacent areas of Wyoming compiled by use of U–2 and C–130 air photographs and from geologic mapping in T. 32 N., Rs. 87 and 88 W. by B. D. Carey (1959) and in T. 30 N., Rs. 92 and 93 W. by R. L. Sherer (1969). Base map modified from Love (1970).

distinguished but minor granite bodies within this area cannot. In the southwest the general area where metasedimentary metavolcanic rocks are present can be recognized from the ERTS MSS-5 imagery but an area of metasedimentary rock approximately two miles wide and six miles long was misinterpreted as granite.

The difficulty in making distinctions between rock types in the Granite Mountains is probably the result of several factors. The Granite Mountains are interpreted (Love, 1970) as a once great mountain area like the Wind River Mountains that collapsed to form a graben. The mountains were partially exhumed so that today we see isolated masses of rocks of Precambrian age surrounded by flat-lying sedimentary and volcanic sedimentary rocks of late Tertiary age. Some masses stand well above the Tertiary floor and others are barely exhumed. In general, the granitic rock terrain has higher relief, less soil, and, as stated above, is light colored as compared to the metasedimentary metavolcanic terrain. The higher reflectance in the red band of granitic terrain is probably a combination of all of these factors rather than a simple expression of rock color alone. In addition, some metasedimentary rock units in the Granite Mountains are more felsic in composition and lighter in color than those of the Wind River Mountains; and are difficult to distinguish from granite even with high-resolution color and color infrared photography. The various factors undoubtedly hinder lithologic distinctions in this area. This conclusion is supported by limited field checks and available ground truth.

## PRECAMBRIAN TERRAIN DISTINCTIONS USING SKYLAB-190B PHOTOGRAPHS

Unfortunately a direct comparison of greenstone belt mapping using

ERTS and Skylab sensors was not possible in the Granite Mountains of Wyoming because all Skylab images of this area had too much cloud cover. However, continued study of the Wyoming Archean using ERTS images showed that in some areas (Owl Creek Mountains) where greenstone belts were known to be present they could not be mapped using standard ERTS imagery. This appeared to be the result of a combined resolution vegetation cover limitation.

Figure 6 shows a geologic map of the extent of a greenstone belt in the Owl Creek Mountains of Wyoming as known from published geologic maps, and Figure 7 shows this belt as it appears on a high resolution Skylab photograph (190B color) and Figure 8 is a map of this greenstone belt as prepared from the Skylab photograph. Comparison of the geologic map (Fig. 6) and the Skylab photogeologic map (Fig. 8) shows that the known western part of the belt was mapped with reasonable accuracy at 1/500,000 using the Skylab photograph. It was also possible to extend the belt to the east where no published maps were available. It is rarely possible for a photogeologist to be certain he is mapping in an unprejudicial manner when published maps are available and when the geologist has some familiarity with an area as was the case for the western part of this greenstone belt, but at the time the Skylab photogeologic map was prepared there was no information on the eastern extension of the greenstone belt so this can be considered unbiased photogeologic mapping. After mapping this belt it was determined that H. Barnes of the United States Geological Survey had prepared a reconnaissance map of the eastern part of the greenstone belt so it was possible to check the accuracy of the unbiased photogeologic mapping. Comparison of Barnes Map (Fig. 9) and the Skylab map (Fig. 8) shows that the "unknown" part of the belt was

WESTERN OWL CREEK GREENSTONE BELT
FIELD GEOLOGIC MAP

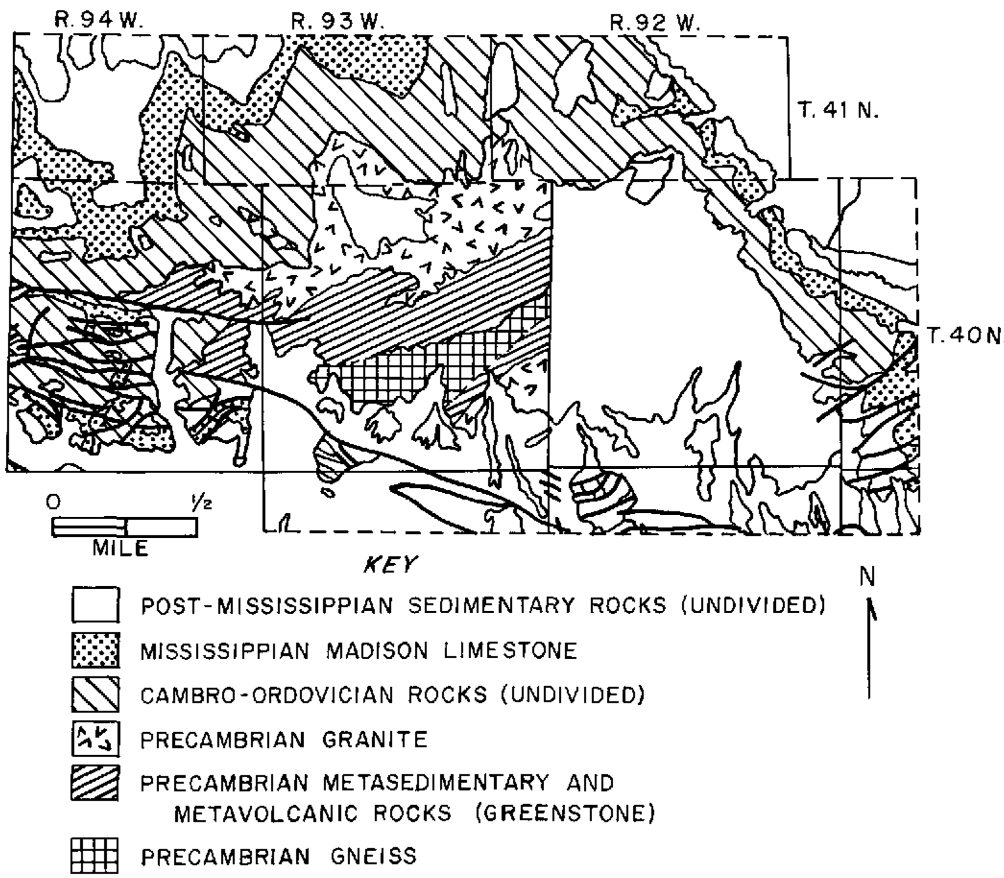



Figure 6. Geologic map of Precambrian units in the Owl Creek Mountains of Wyoming (Precambrian units after Duhling, 1969; other units after Love and others, 1955).

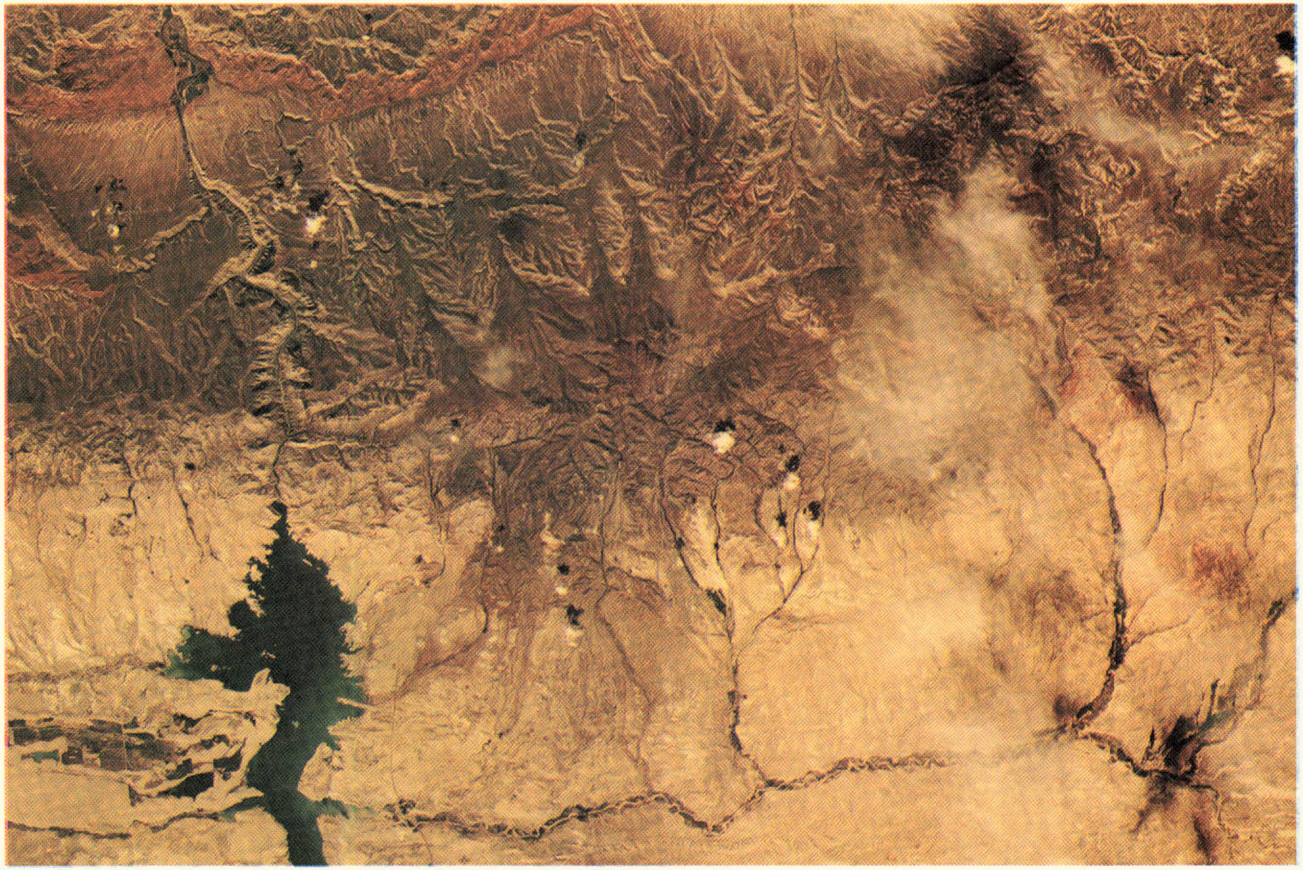


Figure 7. Skylab S-190B color photograph of the Owl Creek Mountains of central Wyoming (pass 28, roll 88, frame 18, Sept. 13, 1973).

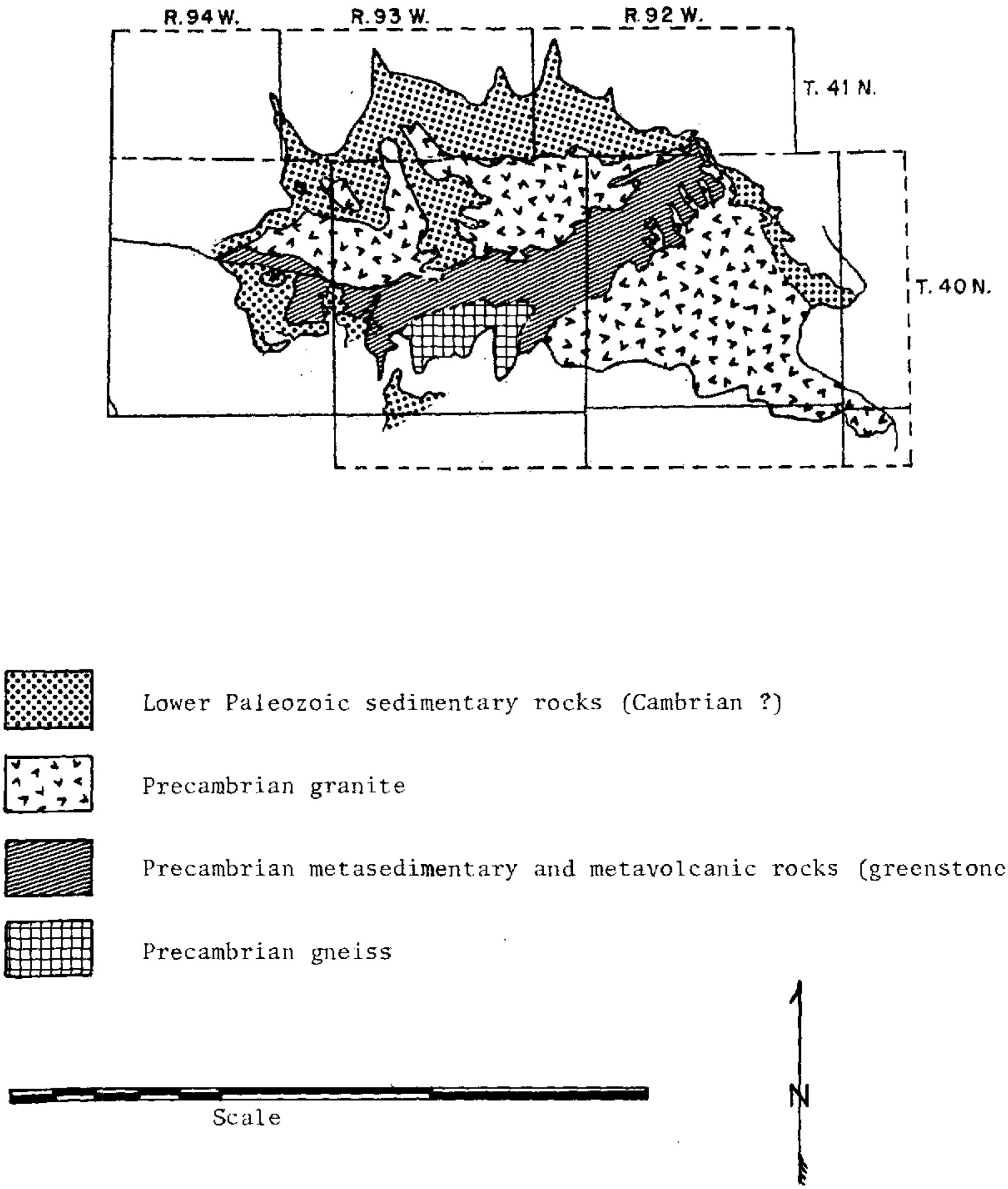



Figure 8. Photogeologic map of the Owl Creek greenstone belt as interpreted from Skylab S-190 photography (after Houston, 1974).

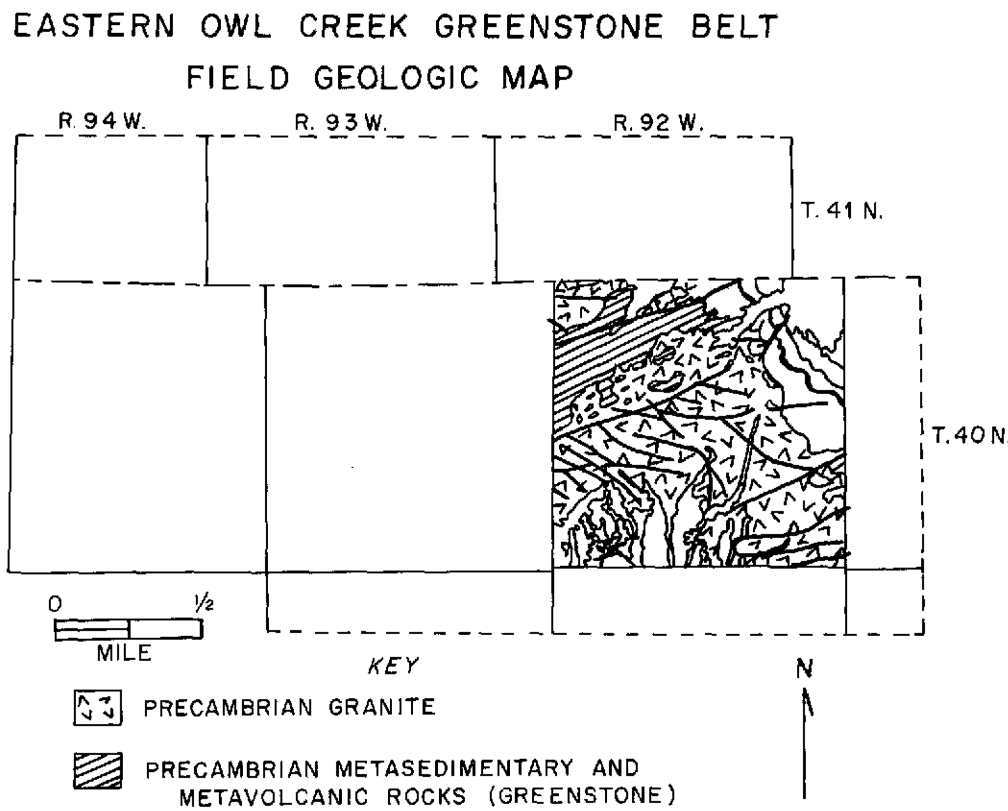



Figure 9. Reconnaissance geologic map of the eastern Owl Creek Greenstone Belt (after H. Barnes, U. S. Geological Survey, personal communication, April, 1974).

certainly mapped as accurately as the known.

PRECAMBRIAN TERRAIN DISTINCTIONS USING U-2 AIRCRAFT FILM POSITIVES

Figure 10 is a geologic map prepared from interpretation of U-2 red band and color infrared 70 mm negative transparencies. Resolution of the U-2 photographs was adequate to distinguish many of the large diabase dikes that cut the granitic rocks of this area so three Precambrian lithologies were mapped; granite-granite gneiss terrain, greenstone belt terrain, and diabase dikes. The distinctions made using U-2 images are good as indicated by a comparison with Figure 5. In fact, in one area, T. 30 N., R. 92 W., the terrain contrast from the U-2 photography appears to be greater than that available from low-altitude aircraft (C-130) images of much higher resolution (Fig. 11).

Direct comparison of the U-2 photography (Fig. 11a) with the Mission 184 (C-130) photography (Fig. 11b) shows that only half as many dikes can be resolved on the U-2 photography as on the higher resolution C-130 photography. This is apparently a line resolution limitation rather than a reflectance difference because the wider dikes are clearly distinguished on the U-2 images.

Figure 12a and 12b compare U-2 and ERTS images of a granite-metasedimentary rock contact in the southeastern Wind River Mountains. In this area the U-2 has no advantage over the ERTS images inasmuch as the contact can be readily mapped with either image.

PRECAMBRIAN TERRAIN DISTINCTIONS USING C-130 AIRCRAFT PHOTOGRAPHY

Five aircraft passes were made over portions of the Granite Mountains and the quality of the resulting color and color infrared photographs was excellent on all lines. These high resolution transparencies

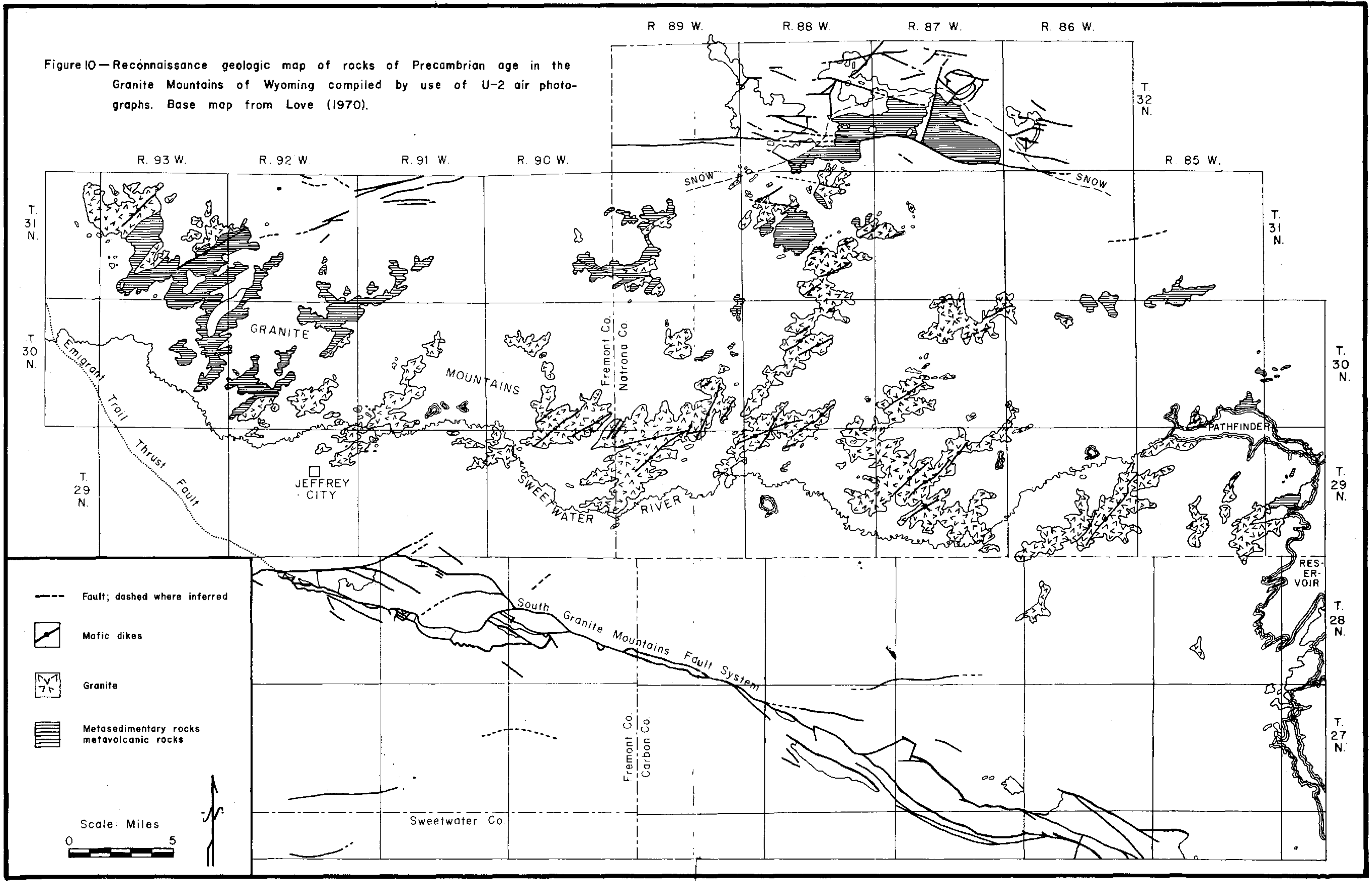


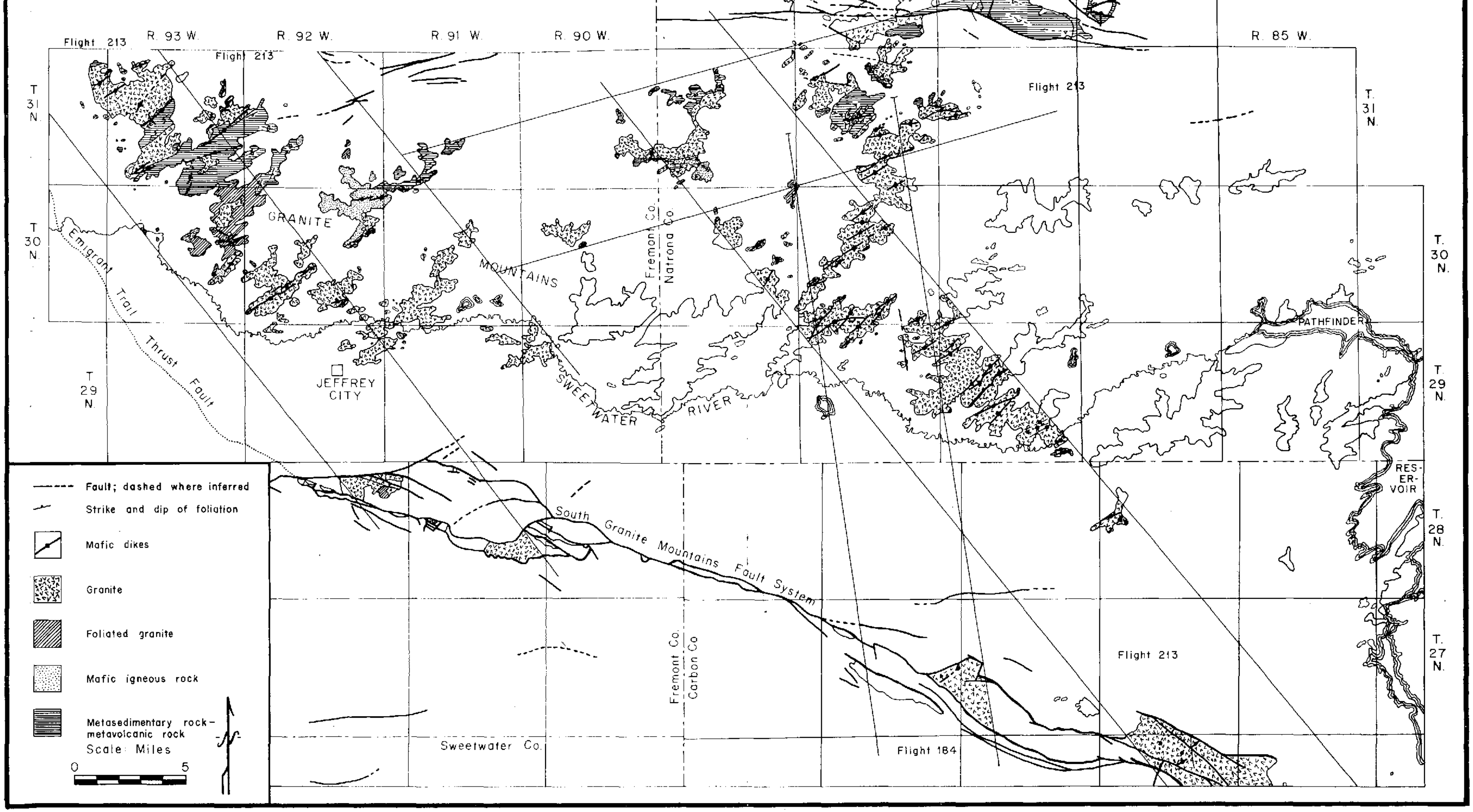

Figure 10—Reconnaissance geologic map of rocks of Precambrian age in the Granite Mountains of Wyoming compiled by use of U-2 air photographs. Base map from Love (1970).

FOLDOUT FRAME 1

FOLDOUT FRAME 2



Figure 11 — Reconnaissance geologic map of rocks of Precambrian age in the Granite Mountains and adjacent areas of Wyoming compiled by use of C-130 air photographs. Base map from Love (1970).



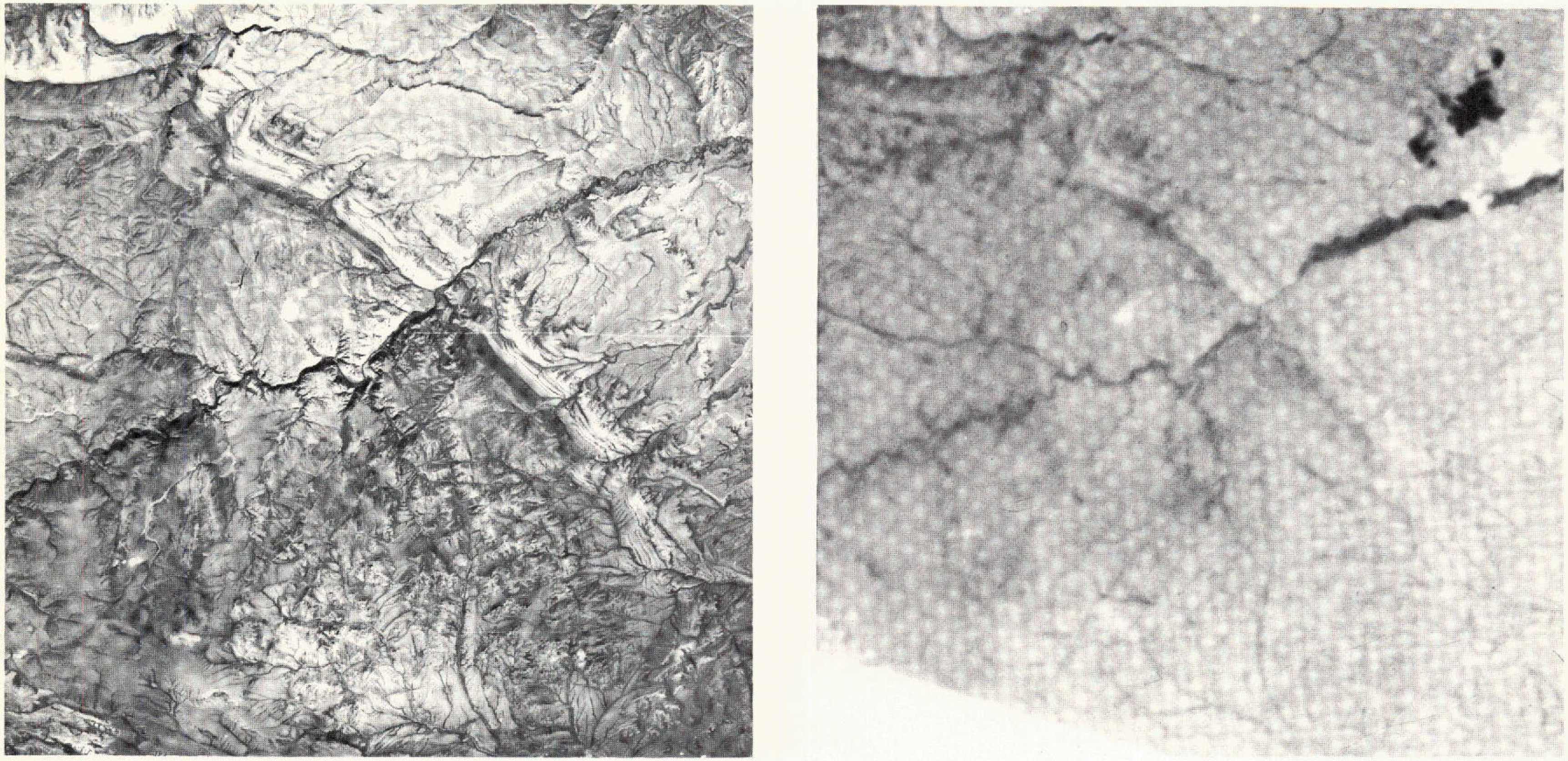


Figure 12. Images of the southeastern Wind River Mountains of Wyoming showing contact between Precambrian metasedimentary rock - metavolcanic rock (dark mass on left) and granite-granite-gneiss; red band U-2 (A) and MSS-5 (B). The contact strikes approximately north and can be clearly seen in the left center of the images near the fork in the Sweetwater River. A contact between northeast dipping Paleozoic rocks and the Precambrian is in the northeast portion of each image.

allow the interpreter to distinguish a great number of lithologic units. Within the greenstone belt succession, hornblende gneiss and amphibolite could be distinguished and individual layers of amphibolite could be distinguished from hornblende gneiss in some hornblende gneiss areas using either color or color infrared film positives. More felsic metasedimentary units, (in part quartzite, mica [fuchsite] schist, and feldspathic quartzite) could be distinguished from the hornblende-rich units in some areas. In the central and western Granite Mountains units were mapped that appeared to be foliated igneous rocks of intermediate and mafic composition. Dikes of andesitic composition were distinguished from diabase dikes, and pegmatite dikes and sills were readily resolved. Granite and granite gneiss terrain is clearly distinguishable on the low altitude aircraft imagery and the initial field checks suggest that it is possible to distinguish strongly foliated or gneissic granite from more massive varieties.

These lithologic distinctions were made without benefit of available ground truth and prior to an August, 1972 field check. Figure 13 is a detailed map of the Barlow Gap area in the Granite Mountains made from interpretations of color and color infrared film positives from C-130 Mission 184. This area has not been mapped nor was the writer familiar with geology of the immediate area, but a brief one-day field check confirmed that the original photogeologic mapping was an essentially correct reconnaissance map of the area. Accurate distinction was made between granite-granite gneiss terrain and metasedimentary rock-metavolcanic terrain and, in addition, hornblende gneiss, amphibolite, felsic metasedimentary rocks, pegmatite, and mafic dikes were mapped. An important

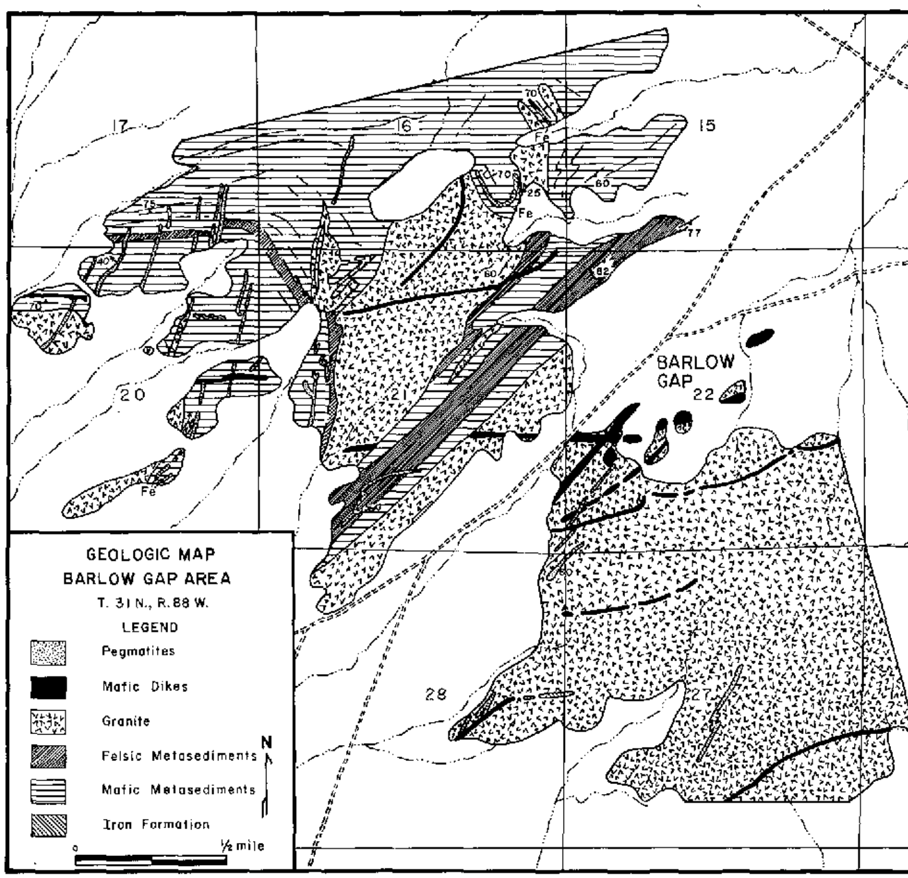



Figure 13. Reconnaissance photogeologic map of the Barlow Gap area, Natrona County, Wyoming. Compiled from interpretations of C-130 aerial photography.

error in the original mapping was failure to distinguish between iron formation layers and amphibolite layers in the hornblende schist. The iron formation was identified in the field and was mapped as amphibolite in the photointerpretation; it is shown on Figure 13 because of its economic importance and amphibolite layers that cannot be distinguished from iron formation are omitted since it was not possible to check each amphibolite layer in the field.

Figure 11 is a geologic map made from interpretation of the C-130 aircraft color and color infrared photography. If this map is compared with Figure 5, the reader may note that the photogeologic mapping compares favorably with the geologic maps, but several exceptions are apparent. In T. 30 N., Rs. 92 and 93 W. a series of outcrops of gneissic granite, biotite gneiss, and granite gneiss are exposed in secs. 16, 17, 18, 19, 20, 21, 30, and 31, T. 30 N., R. 92 W., and secs. 1, 2, 11, 12, 13, 14 and 24, T. 30 N., R. 93 W. (Fig. 7). According to Sherer (1969, p. 7-22) the biotite gneiss is a layered rock with alternating biotite-rich and quartz-feldspar-rich layers and it forms brownish-black to dark-gray outcrops whereas the gneissic granite and granite gneiss (both shown as granite in Figure 5) have less well developed layering are generally lighter in color than the biotite gneiss. These rocks are mineralogically similar, containing chiefly feldspar, quartz, and biotite with the primary difference being a greater abundance of biotite and better developed layering in the biotite gneiss. They are not easily distinguished in the field because all units have gradational contrasts and are inhomogeneous in mineral percentages. Thus, it is not surprising that these units are not readily distinguished by photogeologic techniques. The biotite gneiss which is probably sedimentary in origin was interpreted as either granite or foliated granite by photogeologic techniques and contacts between the various units are not correct.

## IRON FORMATION OF THE BARLOW GAP AREA

The area in the general vicinity of Barlow Gap is perhaps the best for photogeologic mapping in the Granite Mountains. The major rock types show strong color contrasts and lithologies show greater tonal and textural contrast on the film positives than in the field. As noted above iron formation was discovered in the area during a field check of the photogeologic map in August of 1972. This is the first report of iron formation in the Barlow Gap area, but a small body of iron formation was discovered in an area several miles northeast of Barlow Gap in 1971 by Alfred Pekarek (personal communication, 1971), graduate student at the University of Wyoming.

Three bodies of iron formation (Fig. 13) were noted at Barlow Gap in the one day reconnaissance survey of the area. The largest occurrence is in a small anticline (as indicated by primary structures in sedimentary rock noted in the field) located in SE 1/2, sec. 16, T. 31 N., R. 88 W. (Fig. 13). Oxide and silicate facies (James, 1954, p. 249) iron-formation were recognized. The oxide facies iron formation consists of layers of magnetite alternating with layers of green silicate and brown chert. The silicate facies is a laminated greenish black rock probably composed of minnesotaite and/or iron-rich amphiboles. Thin layers of iron-rich carbonate are also present, but the most abundant iron-bearing rocks are the oxide-facies type with alternating magnetite and green silicate layers. Chemical analyses of these various rock types are in Table 1. The magnetite layered iron formation ranges from 21 to 29.5

Table I. Iron, manganese, titanium and chromium content of samples of iron formation from Barlow Gap, Wyoming. (Analyst -- J. W. Murphy, Univ. Wyo. Rock Analysis Lab).

| Rock Type | Sample No. | % Fe(± 0.2) | % Mn(± 0.003) | % Ti(± 0.1) | % Cr (± 0.02) |
|---|---|---|---|---|---|
| Silicate | RS72-2A | 11.2 | 0.178 | 0.5 | 0.05 |
| Silicate | RS72-2B | 31.1 | 0.198 | 0.9 | 0.10 |
| Carbonate | RS72-3A | 6.1 | 0.162 | 0.9 | 0.19 |
| Magnitite-Silicate layered | RS72-3B | 21.0 | 0.213 | 0.9 | 0.06 |
| Magnetite-Silicate layered | RS72-3C | 29.5 | 0.268 | 0.9 | 0.10 |
| Magnetite-Silicate layered | RS72-3D | 21.0 | 0.164 | 0.9 | 0.06 |

percent iron which is about 5 percent less iron than is typical for this facies as suggested by James (1954, p. 249).

## ECONOMIC SIGNIFICANCE OF IRON FORMATION

The iron formation at Barlow Gap and that discovered by Alfred Pekarek northeast of Barlow Gap represents a series of small isolated outcrops; none large enough to be of economic value at present and many factors; in addition to tonnage (Ohle, 1972), must be considered before any firm conclusions about the economic value of the iron formation can be made. However, the geologic study of this area is only reconnaissance and the total areas of metasedimentary rocks where iron-formation outcrops are known covers at least 36 square miles. In addition to these outcrops Love (1970, C140) reports results of drilling which brought up numerous fragments of iron formation from the Tertiary Wagon Bed Formation at a depth of 140-160 feet. These fragments of iron formation in the Tertiary beds were probably derived from iron formation in the Precambrian. The well in which they are found is in NW 1/2 sec. 14, T. 32 N., R. 86 W., 16 miles from the Barlow Gap area. These observations show that iron formation is present in Precambrian metasedimentary rocks in, at least, three townships and Figure 5 shows that similar metasedimentary rocks are present throughout much of the northern Granite Mountains. It is the writer's opinion as was Love's (1970, p. C140) that this area should be studied to determine the extent of these iron-bearing units.

Perhaps the most useful and least expensive tool for initial exploration would be an airborne magnetometer survey. Such a survey might locate iron formation both in surface outcrops and in Precambrian metasedimentary rocks that are buried beneath the relatively thin cover of Tertiary sedimentary rocks.

## CONCLUSIONS

Photogeologic techniques allow the geologist to subdivide rocks of Precambrian age into two broad categories -- greenstone belt terrain vs. granite-granite gneiss terrain, in parts of central Wyoming. The spectral signatures are not unique in that they do not allow a specific rock type to be identified but tonal contrasts plus other features of the rocks such as structure, may be used by the experienced photogeologist, who must also have some first order experience with the lithologies, to make useful reconnaissance geologic maps. These major Precambrian rock units can be distinguished by interpretation of MSS imagery from ERTS, Skylab high altitude aircraft, and low-level aircraft with the expected increase in detail with higher resolution aircraft imagery.

Successful mapping with the MSS-ERTS sensor was dependent on atmospheric conditions and terrain. Atmospheric conditions were best on the ERTS pass of August 5th, 1972 and better lithologic distinctions could be made in the southeastern Wind River Mountains where greater areas are underlain by each of the two terrain types and where relief is relatively low within the area of Precambrian rocks. Lithologic distinctions could be made but with less accuracy in the Granite Mountains where relief is greater and the terrain is one of isolated bodies of Precambrian rocks surrounded by sedimentary rocks of Tertiary age. Skylab S-190B photographs could be used to map greenstone belts where ERTS resolution was too limited.

The U-2 aircraft images gave results similar to those of ERTS with better lithologic distinctions possible in the Granite Mountains than with ERTS. The most useful U-2 sensors were the red band and color infrared. The greater resolution of the U-2 images made it possible to map many of the large diabase dikes that cut grantitic rocks in the Granite Mountains.

Low level C-130 aircraft images gave the best results because of the higher resolution and better spectral coverage. Both color and black and white infrared images were especially useful in distinguishing these rock types at low altitude. Mafic lithologies such as hornblende gneiss and amphibolite, have minimum spectral reflectances in the infrared or a characteristic vegetative cover that makes them easy to distinguish with this band. The resolution of the low-altitude color and color infrared photography was such that fairly detailed reconnaissance geologic maps could be made and it was possible to distinguish such units as amphibolite from hornblende gneiss. A brief field check of the photogeologic map of the Barlow Gap area in the Granite Mountains demonstrated that most of the lithologic distinctions were accurate, but some layers mapped as amphibolite proved to be iron formation of possible economic value.

The iron formation discovered through field checks of low-altitude aircraft imagery interpretations added to isolated bodies of iron formation reported in adjacent areas suggests that this part of the Wyoming Precambrian should be mapped in detail using geophysical and geologic techniques because economic deposits of iron formation may be present in outcrop or beneath the relatively thin cover of Tertiary sedimentary rocks.

This photogeologic study illustrates the value of multilevel sensing in mineral exploration. The ERTS and Skylab sensors can be used to delineate areas of favorable terrain to be imaged in greater detail by aircraft. Despite the fact that individual mineral deposits of economic interest are not distinguished by aircraft images, the choice is narrowed further and field checks may be used to search for rock types of possible economic interest.

# COMPARISON OF ERTS, SKYLAB 190A and 190B SENSORS, AND AIRCRAFT PHOTOGRAPHS FOR LINEATION MAPPING

by B. J Tomes, R. W. Marrs, and R. S. Houston

## INTRODUCTION

Photogeologic lineations are lines seen on images chosen on the assumption that they originate through geologic processes. If the lineation originates through geologic processes, it is usually a fracture (fault or joint) or a linear expression of a fracture system or shear zone. When the geologist can prove (normally by field checks) that these lineations are indeed fractures, such identifications are of geologic and economic interest. Faults recognized by this method are of potential economic value in prospecting for fault-controlled ground water (Goetz and others, 1973), metallic mineral deposits (Rowan, 1973), petroleum (Collins et al (1973), and in studies of problems in engineering geology and environmental geology.

The spacecraft image has a major advantage and a major disadvantage in lineation study. The synoptic view allows the geologist to see lineations of regional extent that cannot be recognized by any other technique, but the relatively low resolution of the spacecraft image makes it difficult or impossible for the geologist to recognize linear features that are of non-geologic origin. For example, study of lineations seen on ERTS images of Wyoming shows that a significant but variable percentage of lineations are of non-geologic origin. In parts of some mountain uplifts approximately 80% of the lineations are fractures or joints (Parker, 1972), but in parts of some basin areas (Blackstone, 1973) virtually no lineations can be proven to be geologic in origin.

The low resolution of ERTS results in the following types of features being mapped as potential geologic lineations; graded roads, ungraded roads, fence lines, tornado swaths, contrails, railways, fire lines, and such non-fracture geologic features as linear blowouts and long transverse stabilized dunes. Most of these features can be recognized as non-geologic simply by use of higher resolution aircraft images or, in many cases, Skylab 190B or 190A photographs. Further documentation of problems with non-geologic lineation mapping using ERTS images is in Short and Lowman (1973, p. 12-14).

Example

A portion of the Wind River Mountains of Wyoming has been studied by use of ERTS images, Skylab 190A and 190B photographs, aircraft photographs, and on the ground. The Wind River Mountains are a northwest striking, Precambrian cored, major uplift located in west central Wyoming (Fig. 1). The uplift is approximately 100 miles long and over 30 miles wide at its greatest width. The uplift has the form of an assymetric anticline with steep overturned and faulted limb on the southwest and great gently dipping northwest striking hogbacks of Paleozoic and Mesozoic sedimentary rocks on the northeast (Berg, 1962). The Precambrian rocks of the core of the structure are primarily Early Precambrian felsic gneisses and schists and various types of foliated granite cut by basalt dikes of different Precambrian ages. In the extreme southeast part of the uplift (Bayley, 1965a) a major greenstone belt cuts through the range.

The Precambrian core of the Wind River Mountains is cut by numerous fractures ranging from major faults and shear zones to minor faults and

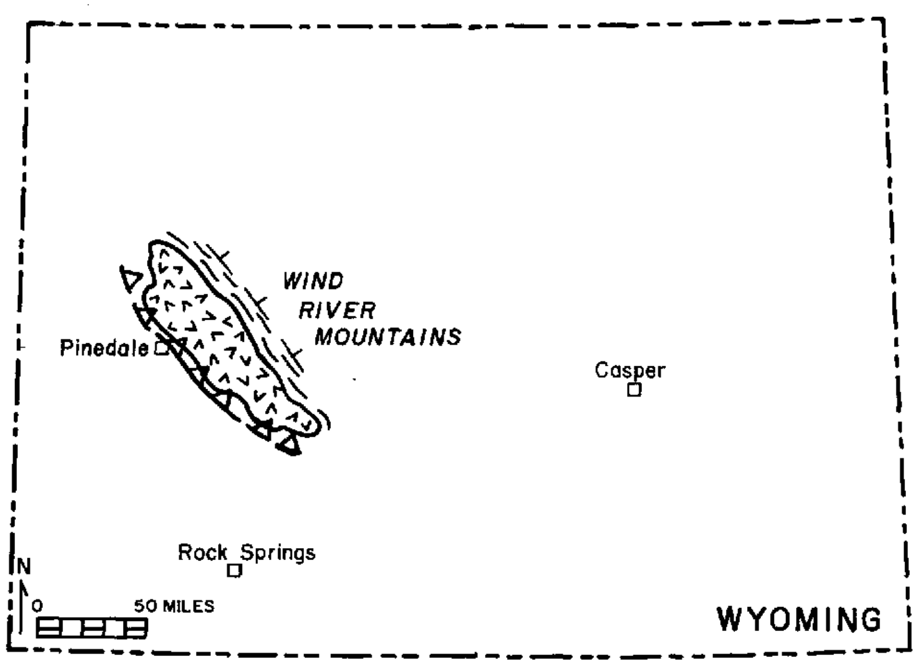



Figure 1. Index map of Wyoming showing the Wind River Mountains study area.

joints. These fractures have been mapped in a small part of the uplift (Barrus, 1968; Granger and others, 1971; Parker, 1972; Pearson and others, 1971; and Richmond, 1945) and they range from shear zones with extensive catalysis and mylonization that probably developed during Precambrian episodes of high rank metamorphism to discrete fractures of Tertiary age. Many of the Precambrian fractures were filled with basaltic magma and are now expressed as basalt and diabase dikes that cut the gneisses and granitic terrain.

The most striking aspect of ERTS and Skylab images of the Wind River Mountains is the multitude of lineations, that are primarily expressions of the fractures and dikes, that show on the images (Fig. 2). The initial study of the Wind River lineations was made by Parker (1972) who mapped the major fractures of the mountain using ERTS MSS-5 and 7 images and compared these with lineations seen on aircraft images, and faults and fractures recognized on the ground by a field survey of part of the area covered by aircraft and also made comparisons with faults and fractures mapped by previous workers (Figs. 3 and 4). Parker (1972, p. 2) points out that the major lineations seen on aircraft photographs (color infra-red preferred) were zones of dislocation, cataclasis, metasomatism or alteration which were for the most part 10-50 meters wide. These structures which were field-checked in August and September of 1972 are probably major faults, but as Parker notes obvious displacement of rock units has not been detected. Fractures mapped by previous workers (Fig. 3) were, for the most part, recognizable on the ERTS imagery, but some fractures and dikes mapped by Granger and others (1971) could not be found on the ERTS

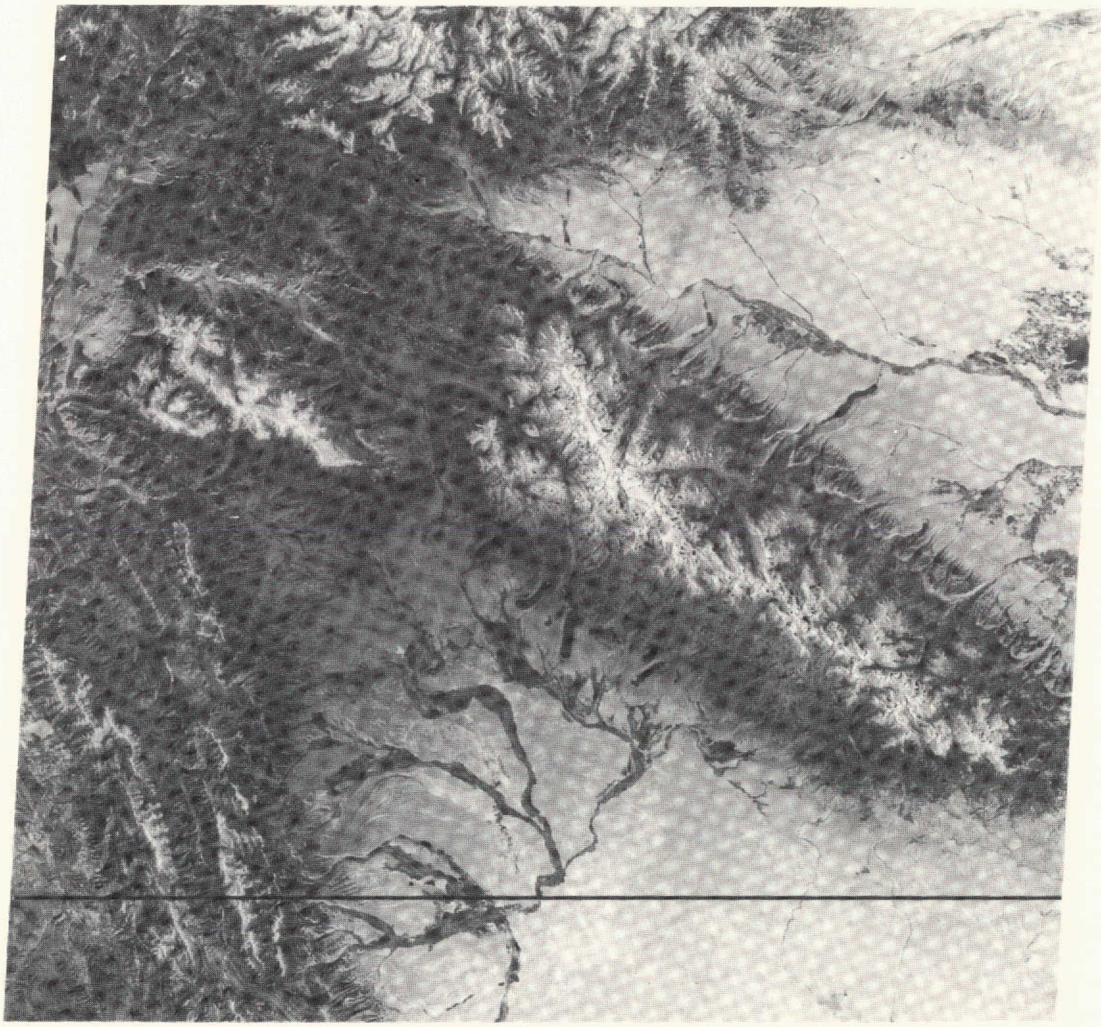


Figure 2. ERTS-1 image 1014-17352-5 of the Wind River Mountains. Linear features were interpreted from this and other ERTS images of the same area.

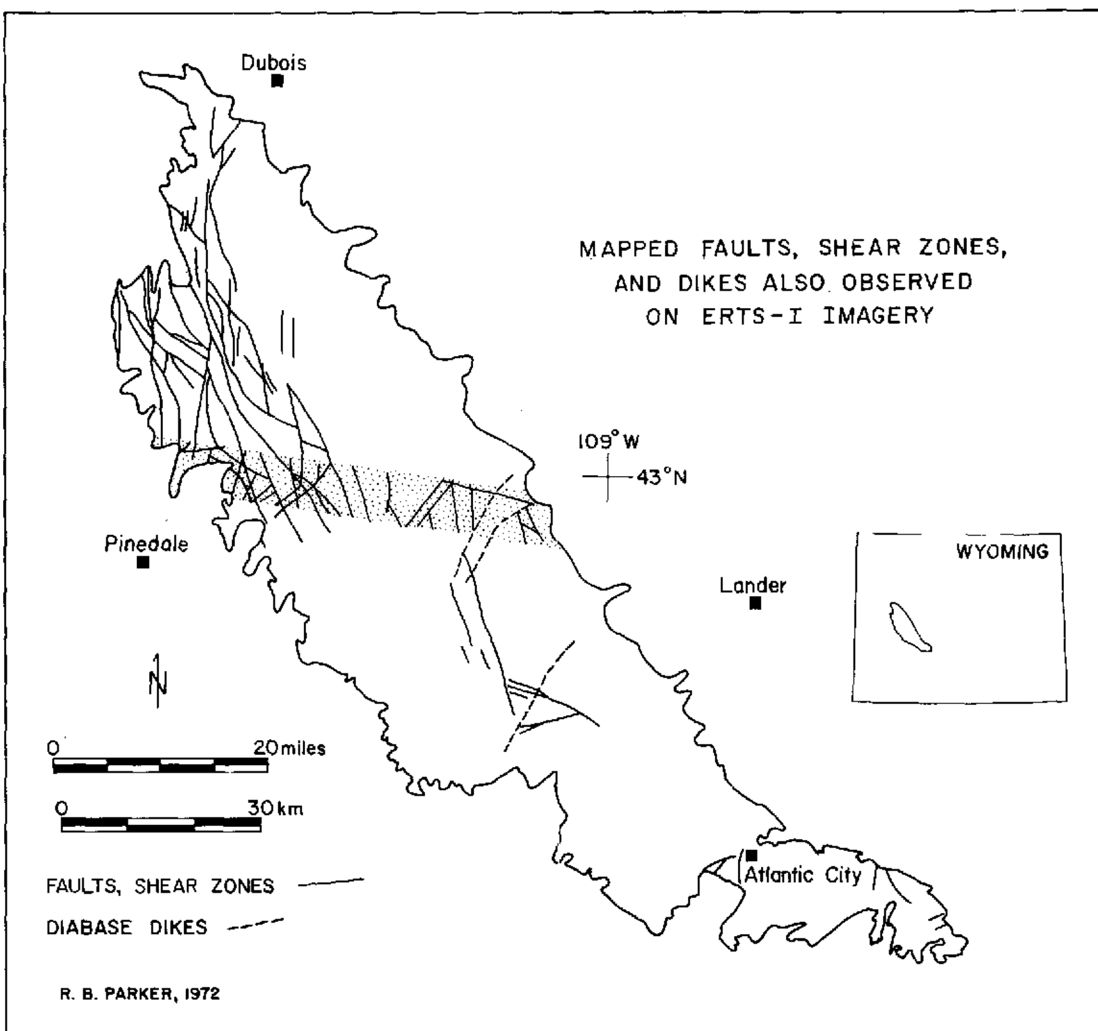



Figure 3. Principal mapped faults, shear zones, and dikes also observed on ERTS-1 imagery (from Parker, 1972, Figure 1).

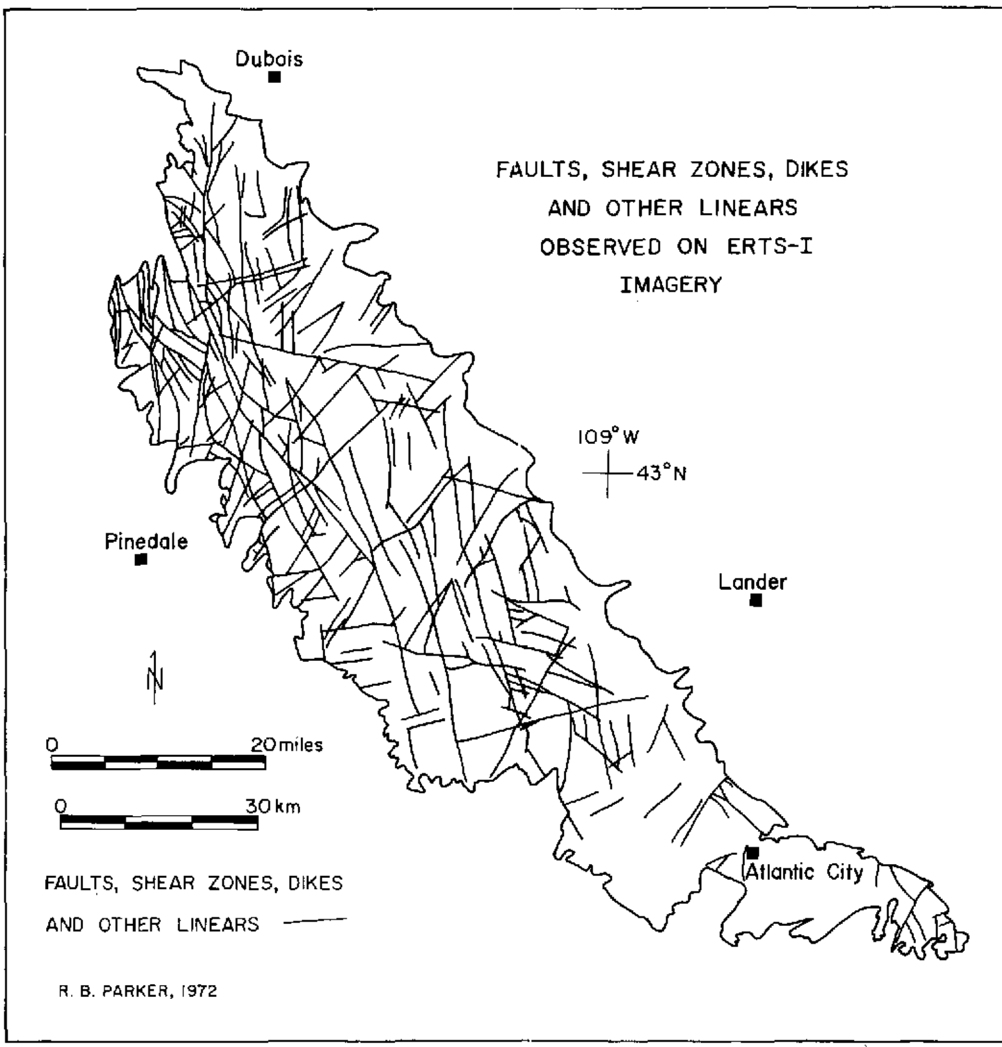



Figure 4. Principal faults, shear zones, and other linear features observed on ERTS-1 imagery from (Parker, 1972, Figure 2).

imagery (Parker, 1972, p. 3) and some prominent lineations observed on ERTS were not mapped by Granger and others (1971). Figure 3 is Parker's map of major lineations mapped from ERTS imagery that could be confirmed from field studies and Figure 4 is a map showing all major lineations recognized in this first study. It is clear that most of these lineations have not been recognized before, but that there is a close correlation between mapped fractures and lineations as mapped with ERTS images. A key point is that with ERTS resolution all mapped fractures cannot be recognized.

Figures 5 and 6 show lineations mapped from ERTS images and Skylab 190A photographs of the western part of the Wind River Mountains. In this study all lineations were mapped that could be recognized, rather than simply the major lineations that were mapped by Parker. Three factors affected the mapping -- resolution, sun angle and sun azimuth. ERTS is sun synchronous so that images are ordinarily generated in the morning with a sun azimuth that establishes a bias towards northeast-striking linear features whereas Skylab passes give different perspectives and may result in the emphasis of a completely different set of lineations as shown in Figure 7. Rose diagrams in Figure 7 show that there are not only more lineations recognized on the Skylab 190A photograph but that the major set strikes north-northwest rather than northeast as is the case for ERTS. This is a sun azimuth effect because the major linear features are approximately perpendicular to the sun azimuth in both examples. This sun azimuth effect is primarily due to the fact that many lineations are expressed topographically and sun shadowing due to topography is more pronounced at right angles to the direction of illumination. Sun elevation will also play a role in lineation mapping because low sun elevations cause more

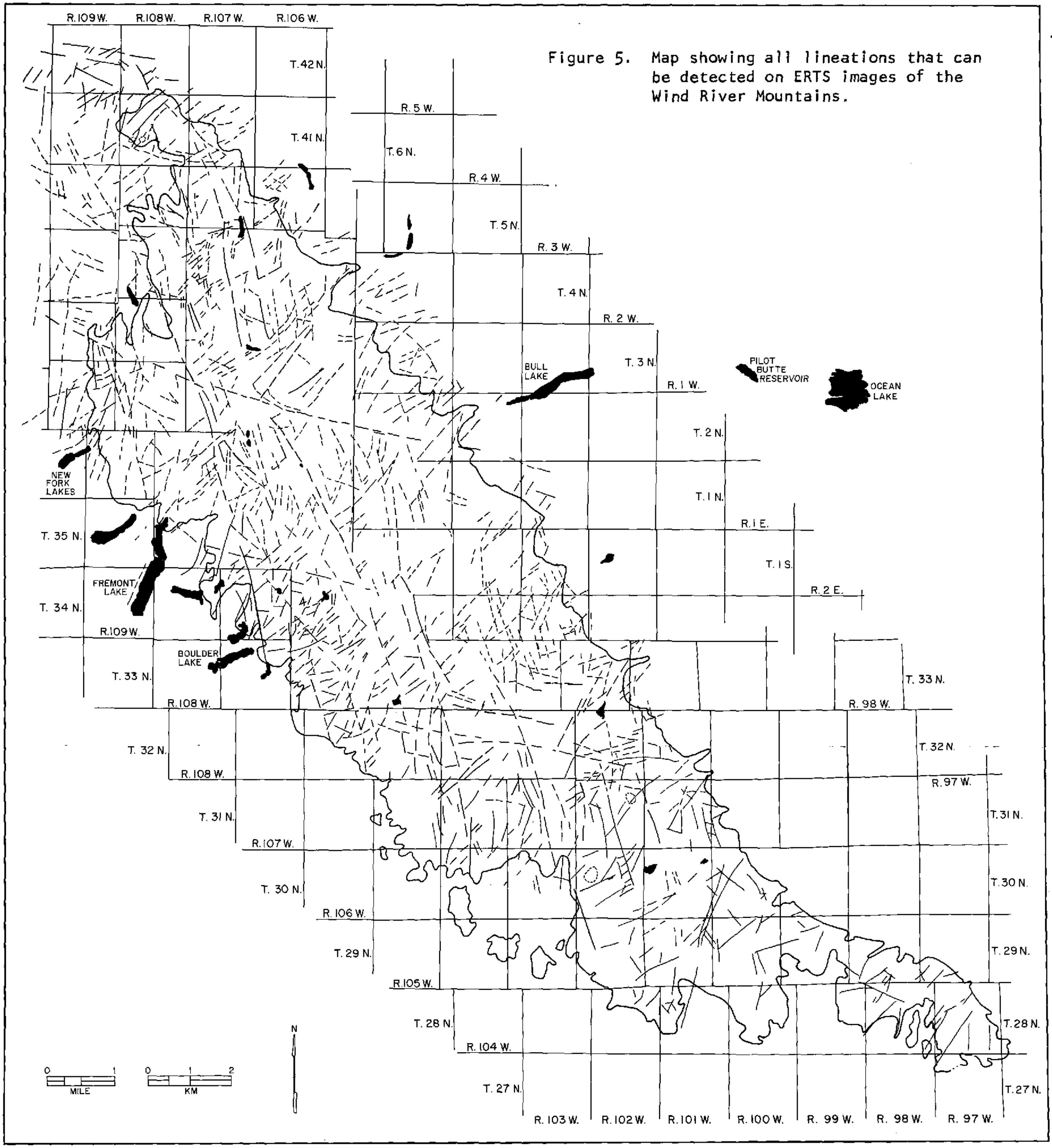



Figure 5. Map showing all lineations that can be detected on ERTS images of the Wind River Mountains.

FOLDOUT FRAME 1

FOLDOUT FRAME 2

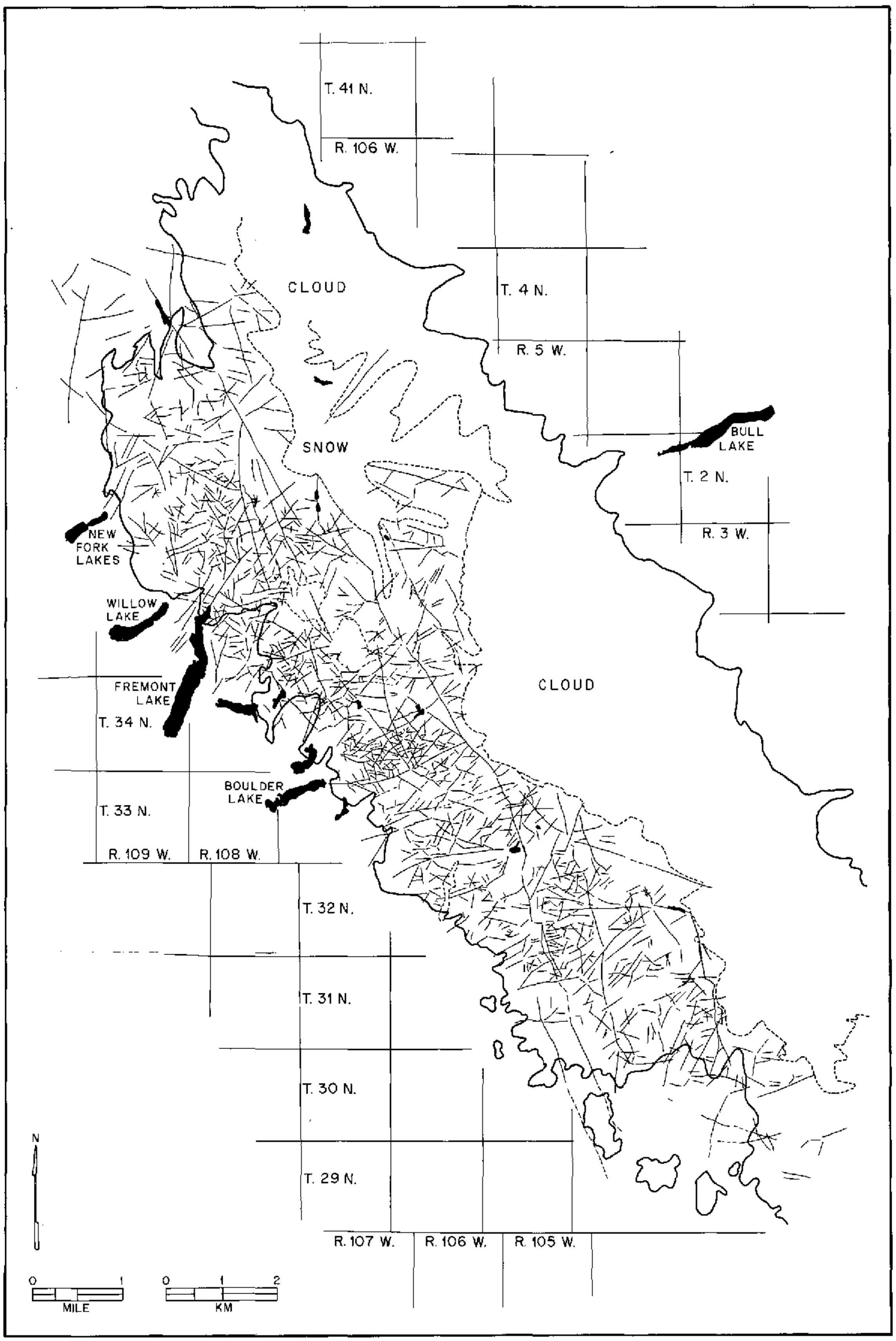



Figure 6. Map showing all lineations that can be detected on Skylab S-190A photography of the Wind River Mountains.

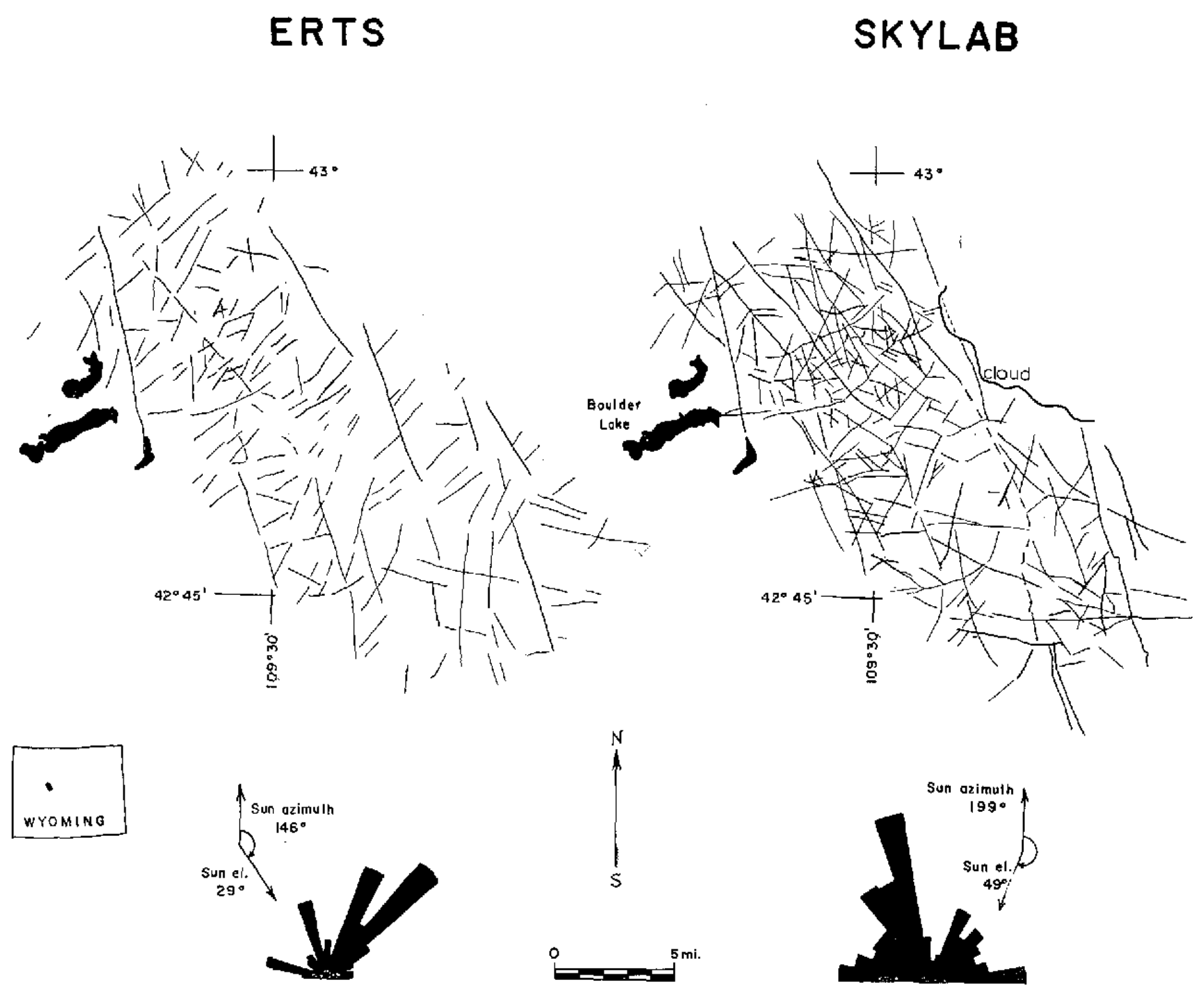



Figure 7. Comparison of linear features mapped using ERTS images and Skylab S-190 B photographs of a part of the Wind River Mountains showing sun-azimuth bias.

distinct shadowing where lineations are topographically expressed so that a few more lineations might have been mapped at the 29° sun elevation of ERTS than at the 49° sun elevation of Skylab, but this cannot be quantitized because of the variation in azimuth.

A judgment of the affect of resolution cannot be made directly because of the role played by sun azimuth. For example, Parker's map of major mapped fractures in the Wind River Mountains (Fig. 3) suggests that more fractures strike northwest than northeast. If this is true throughout the range the sun azimuth of Skylab would tend to bring out lineations that result from these fractures better than that of ERTS so that more lineations should show on Skylab photographs regardless of resolution. However, if we select a lineation direction such as east-west that should not be biased by sun azimuth the number of lineations mapped on a Skylab photograph is about three times that of ERTS for the area shown in Figure 7. This cannot be taken as a quantitative measure of the exact resolution difference for lineation measurements because the total number of lineations measured by use of Skylab photographs is only an order of magnitude greater than ERTS for this area (Fig. 7), but it is clear nonetheless that more lineations can be recognized on the higher resolution Skylab 190B photograph.

If we compare known faults (as mapped by field geologists) with linears mapped using Skylab and ERTS, we find a similar correspondence. In the northwestern part of the Wind River Mountains Richmond (1945) mapped a series of faults and shear zones and this mapped area is covered by both Skylab and ERTS. Results of study of linears from this area are shown below:

| | Skylab (190A) | ERTS |
|---|---|---|
| Total number of linears | 202 | 104 |
| Total length of linears | 600 meters | 520 meters |
| Total number of linears that correspond to mapped faults and shear zones | 17 | 13 |
| Total length of corresponding linears | 95 meters | 95 meters |
| Total number of corresponding linears unbiased by sun azimuth | 7 | 4 |

A portion of the Wind River Mountains east of Fremont Lake (Fig. 8) has been mapped using aircraft images (C-130 infrared photographs). Figure 8 shows clearly the great advantage of high resolution aircraft photographs in lineation mapping. The number of lineations mapped is many orders of magnitude greater than ERTS or Skylab. Nonetheless it was noted that a "woods for the trees" relationship did exist because some major lineations noted on Skylab were overlooked on the aircraft photograph until the photograph was re-echecked using the Skylab photograph, and the regional lineations did indeed exist.

FOLDOUT FRAME

FOLDOUT FRAME

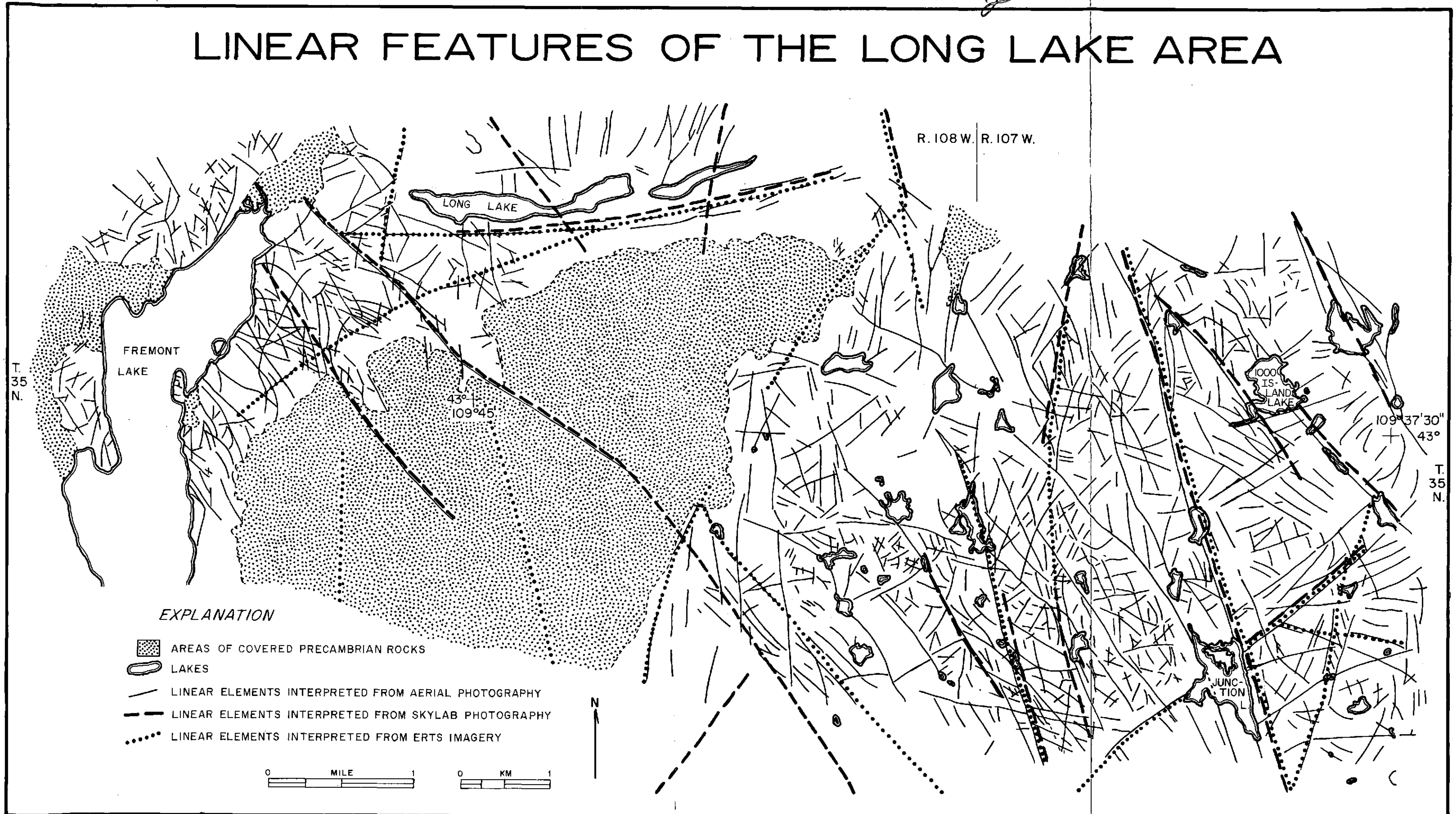



Figure 8. Linear features of the Long Lake area as mapped from 1:30,000-scale aerial photography (NASA Mission 184, roll 11).

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