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Utilizing ERTS-1 Imagery for Tectonic Analysis Through Study of the Bighorn
Mountains Region. MMC #256
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The first half of the period was spent in a study of scenes of the various seasons. We now have good coverage of the fall, winter, and spring seasons. Although we do not have complete cloud-free coverage for each season, there is no part of the project area that is not cloud-free at at least one time. The best season of the year for all-purpose geologic study is the fall. In this part of the country the grass has thinned out and that which remains has a much higher reflectivity. As a result soil and lithologic effects are stronger than in the spring. Spring imagery tends to have much less tonal contrast because the green grass has a reflectivity more like that of the trees. Also, this is a time when the snow cover can be very deep in the uplifts. As reported previously, scenes taken in early December when the ground was uniformly covered by not too heavy snow provide a remarkable enhancement of topographic detail; exceptional clarity of the atmosphere also aided in providing higher resolution.

We are still awaiting some color composites^s ordered in February. An appeal was sent to get these as soon as possible. Without question, high quality color composites are the most valuable single image that we have used. The 70mm diazos made by our photo service are quite good but not as good as the 9X9's from NASA.

The low altitude photography by The Colorado State Flight facility was finally taken in the second week of September. The film is to be delivered in early October.

We are currently compiling our data from individual overlays on to a composite map of the whole area. Our work ahead will be essentially involved in completion of analysis and preparation of the final report.

The bulk of the period was spent in field checking. Fig. 1 shows the areas that were covered in the Bighorn region. The following summary represents the preliminary results as expressed by the individuals involved. The numbers are those on Fig. 1.

I. Nels Voldseth, graduate student

I was able to make use of NASA ERTS E-1085-17294 image in my work this summer, which centered around Cottonwood Canyon, Big Horn County, Wyoming (about 108° to 108°07'30" west longitude and 44°47'30" to 44°55' north latitude). I found band 7 imagery to be quite satisfactory. Much of my work was on a scale too large for the ERTS imagery to be useful, for example measuring fractures, but the ERTS imagery provided a very nice regional view, especially of structure. Features of interest in my area of research which stand out particularly well on the ERTS imagery include:

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FIGURE 1

1. Cottonwood Canyon Monocline. This large north trending structure stands out clearly along its entire length, from south of Cottonwood Canyon to its intersection with Big Bull Elk Ridge in Montana, a distance of about 25 miles. There is a pronounced change in the profile of stream valleys across this structure especially in Devil Canyon.
2. NW trending monoclines with associated flatirons also are well delineated.
3. A large bench capped by flat lying Permian Embar limestone can be seen centering around $44^{\circ}56'$ north latitude and $108^{\circ}07'$ west longitude. There is a subtle tonal contrast between this bench and the surrounding flat areas which are developed on stratigraphically lower strata. I did not notice this feature on the ERTS imagery before I had observed it in the field, but I believe a more diligent interpreter could have. On this basis I believe that a large area of Embar exposures to the north could be delineated. This may be economically useful in uranium prospecting, since uranium has been found in the Madison Limestone which underlies the Embar (along with other rocks).

Some things could not be done on ERTS imagery in my area. These include:

1. Mapping rock units at the formational level is not practicable, in general.
2. A fair sized fault trending east-west and about 1 1/2 miles in length could not be distinguished from a monocline.

II. Ron Manley, graduate student

This project involves considerable area and can be divided into three parts with differing objectives in each. The first part involves the Cloud Peak Primitive Area itself. This was recently mapped by the United States Geological Survey as part of their primitive area studies. Numerous major faults were mapped by the USGS as were smaller faults and dikes. Since these are the types of features we expect to see on the ERTS images a direct comparison is being made. The USGS map was converted into a transparency and reduced to enlarged ERTS images, scale 1:500,000. It soon became apparent when overlaid that many of the linears seen on the ERTS image correspond to the major faults. Smaller faults and those not expressed topographically do not appear on the ERTS image. Also, as of this time, none of the dikes have been located on the imagery. Besides those corresponding to the mapped faults other linear features exist. All of these have been located on topographic maps and examined on high altitude 9X9 B&W and U-2 color infrared aerial photographs. Due to the size of the area, difficulty of access and time available most of these features were not field checked. These will be included within the thesis as postulated features and will hopefully be field checked at a later date.

Three major faults trend northward out of the primitive area. All three become buried in glacial deposits and lost. On the ERTS image there is good evidence that these faults extend considerably farther and are ultimately responsible for the stream valleys along which they appear to lie. It is difficult to come to this conclusion by looking at high altitude aerial photographs alone due to the larger scale, relief distortion and enormous amount of detail visible.

The second part of the project involves the densely forested area just north of the Cloud Peak Primitive Area. This was generally accessible with a 4-wheel drive vehicle and contains numerous short linears. Problems created by forest cover and glacial deposits were considerable although no difficulty was found in locating the features seen on the ERTS image. This was overcome by using a transparency of the Wyoming topographic map index sheet overlain on a 1:1,000,000 Scale ERTS image. The overlay was matched with the drainage pattern and since little distortion exists the matchup was quite good. The linears were then carefully located on the appropriate 7 1/2 minute quadrangles. Since most of the features seen are the result of topographic expression the linear could be located with a high degree of accuracy. Field checking was done by walking these valleys and checking available outcrops. Numerous samples were taken some of which will be microscopically examined for cataclastic material. Others are obviously fractured and this is not necessary. Since the valleys are filled with glacial debris, it was not possible to confirm existence of major faults. Also, few good outcrops could be found along the valley walls so that it was not possible to obtain evidence of movement. This set of features was very frustrating to work with although the extreme linearity and fracturing of some of the features are highly suggestive. As samples and high altitude aerial photographs are examined more information on particular features will be available.

The final part of the project involves an area known as Walker Prairie. This is a repeated section of Cambrian to Mississippian sedimentary rocks and is located on the eastern flank just west of Sheridan. Its existence was pointed out to me by the PI and as far as we know it has not been previously mapped in detail. Its relation to this project is by an approximately 12 mile curvilinear feature which runs from just south of the Big Goose Ranger Station to the west side of She Bear and Walker Mountains. The southern part of this curvilinear feature is expressed as the valley of East Fork Big Goose Creek. The curvilinear then disappears for a short distance and is re-expressed in the sedimentary units. It was at first thought that this linear was aligned with the fault causing the repeated Cambrian Section. For this reason a reconnaissance map of the area was done using aerial photographs in conjunction with field checking. It was found that the linear feature in the sedimentary sequence was the conformable outcrop of the Cambrian Flathead sandstone with the Precambrian, and that the fault causing the repeated section was on the western side of the Precambrian rocks approximately 1/2 west of the observed linear. Also there is no expression of the fault itself since it is buried and since there is no topographic or other expression.

Thus it is clear that one must be extremely careful when working with an image at this scale. Many linear or curvilinear features exist for structural reasons while others only appear to. At the same time numerous structural features are known to exist but which are not expressed on the image. ERTS imagery is a tremendous plus for the geologist working on a regional scale. It must however be used continuously and in conjunction with field work.

III. Alan Swenson, graduate student

Field checking of ERTS-1 imagery during the summer of 1973 was undertaken along the Tensleep fault in the Bighorn Mountains and in the southern Bighorn Basin.

The Tensleep fault can be traced throughout its western and central sections due to its prominent topographic expression. The eastern end is buried by high level gravels and is not detectable on the imagery. Several linear features near the Tensleep fault and a possible branch of the fault were checked. There was no evidence at the surface to indicate that there was a branch to the fault as had been suspected after examining the imagery. Other linear features adjacent to the fault were checked but couldn't be related to any geologic structures. Two linears checked out to be monoclines.

In the southern Bighorn Basin one known fault was identified on the imagery and another previously unmapped fault is detectable although it was first noted on high altitude U-2 imagery.

Several linear features in the southwestern flank of the basin held promise of being surface expressions of the western end of the speculated Tensleep lineament. Upon field checking the linears turned out to be strike valleys related to folding at the edge of the basin.

General geologic mapping on the imagery is possible over much of the area. Mapping is easiest where sedimentary units are dipping and resistant and non-resistant units are present, aiding in defining formation boundaries. Where units are more flat-lying, both tonal differences and drainage densities helped in mapping.

IV. Dan Tappmeyer, graduate student

ERTS-1 imagery is being utilized in the construction of a geologic map and in a rudimentary structural analysis of an area in the Nowood area of the Big Horn Mountains, Washakie County, Wyoming. The MSS False Color IR clearly shows previously undiscovered linear features. The most valuable information obtained from the ERTS imagery which is not apparent on the lower altitude photography (U-2 and Army Stereo-mapping photos, 65,000 Ft.) is the number, distribution, and patterns of the linear features. This past summer, the ERTS imagery was utilized to find the "straighter" features, many of which were observed on the ground as "straighter portions" along areas of topographic relief and drainage and areas of more prolific vegetation. For the majority of the linears checked on the ground, faulting was not apparent. A majority of the linears were along fracture zones which were more easily eroded than the surrounding areas.

The prominent NE-trending linear first discovered on the imagery proved to be a fault, at least at the north end. Here there is considerable disruption of Cambrian Flathead sandstone units. The southern portion of the linear appears to be a fracture zone. There appears to be a relationship between ground water distribution and the linear trace. The area along the trace has the most prolific vegetation (red on the color IR composite). Ground observation along the linear confirms that the major portion of the agriculture in the area occurs along the linear trace.

The mapping of the different geologic formations in the area has been attempted using enlarged portions of band 5, band 7, and the IR composite photographs. The delineation of the different formations from the ERTS photographs has been of limited success. In the study area the Phosphoria and Chugwater Formations can be separated from the Tensleep and Sundance Formations with some reliability

because of the contrast of color and reflectance between the red Phosphoria and Chugwater and the gray Sundance and white Tensleep Formations. Density slicing of the imagery holds some possibility of success in differentiating these formations but has not been tried because of equipment alignment problems.

V-VI. Richard Hoppin, Principal Investigator

A flight in a Piper Cub was made along area 6, over much of area 2, over the east end of area 3, most of area 4, and east to Kaycee and north to Buffalo (SE edge of Fig. 1). A number of 35 mm color photographs were taken at low altitudes along linears noted on the imagery. The NW linear in area 6 is along Rock Creek and appears to be parallel to the NW-trending, NE-dipping Kingsbury conglomerate (Eocene). Area 5 is of interest because it lies along the proposed Shell Lineament. Study of high altitude black and white and U-2 color infrared photography along with reconnaissance field observation suggests a structural discontinuity in the Big Horn basin. This area will be studied in detail next summer. ERTS imagery, along with the above photography and field reconnaissance indicates that the prominent NW-trending sharp monocline on the north side of Shell Creek at the range flank is on line with the prominent upper canyon of Shell Creek. This area, also, is to be mapped in detail next summer.

Richard Baker, co-investigator

The ground check of the vegetation verified some of the tentative findings of an earlier progress report. The target areas were the Circle Park area on the east side of the Range, and the Tensleep Valley on the west side. The distinction between steppe vegetation types (chenopod vs. sagebrush) in the Bighorn Basin is questionable. Reconnaissance work indicates that rock types seem responsible for the patterns on the ERTS images in chenopod steppe because the plants are more widely spaced. Closer spacing of sagebrush plants tends to mask the underlying rock pattern better. In areas where chenopods are closely spaced, the two steppe types may be indistinguishable. Cultivated areas, mainly along rivers, are very easily recognized. Ponderosa pine and Douglas fir forests are recognizable on underflight photos, but less distinct or not recognizable on the ERTS photos. Large stands of lodgepole pine forest and spruce-fir forest are distinct on ERTS photographs, and treeline is very distinct.

Unresolved problems include:

1. Many areas mapped by the Forest Service or by me from ERTS photographs contain substantial amounts of other trees. For example, lodgepole pine forests often contain a lot of spruce and fir, especially above 9000 ft. Mapping of these mixed forests may not be possible.
2. The size of recognizable units varies with the sharpness of the boundary. Lakes as small as 10 acres can sometimes be recognized, but most forest types must be over 100 acres to be distinguished.

In addition Baker took sediment cores and sampled pollen from several glacial lakes and bogs. As good maps of the area are available, ERTS imagery was not of direct use in locating sample sites. However, the excellent resolution of water bodies on the ERTS MSS-7 imagery, would have been extremely useful for such a study if map coverage was poor or nonexistent. Certainly ERTS imagery of similar unmapped glaciated areas would be of great use in site location for pollen studies. Color composite transparencies are the most useful for vegetation analysis; burns and clear-cut areas stand out well.

Lon Drake, co-investigator

Ground truth was checked in July for Pleistocene deposits in the southern portion of the Bighorn Mountains. On the west side of the range the glacial geology of the Tensleep watershed was delineated on 7 1/2 minute topo maps. The Clear Creek drainage on the east side was similarly outlined. Both of these drainages had been previously mapped by other workers (Nelson - Clear Creek and Palmquist - Tensleep) and some time was spent determining that the same criteria were used for mapping. I conclude that the mapping of the two areas is highly compatible.

Thirty-one photos were selected, from the four bands, which represented nearly cloud-free conditions at various times of the year to include a variety of vegetation and snow cover conditions. In most cases it was found that blowing-up the original transparency to a 9"x9" photograph was the maximum scale increase allowable. At larger scales the scan lines became excessively enhanced and interfered with observation of small Pleistocene features.

In general, large Pleistocene features could be readily discerned on most of the selected imagery. Features such as moraine groups, outwash plains and large lakes were usually well delineated by their vegetative patterns (or lack of vegetation) on most of the prints. Cirques are well marked by ridge and shadow combinations and thus south (sun) facing cirques are generally more difficult to observe. Bands 5 and 7 make bands 4 and 6 relatively useless.

The small Pleistocene features such as individual moraines, small lakes, bogs and pockets of outwash were not readily discernable on most of the imagery. Under special conditions of snow and vegetative cover a particular feature might be enhanced on one image but another identical feature in the same valley may remain hidden. The psychological factor became important for the small features. They often could not be located on the imagery until their location and shape was already known from field work.

R. A. Hoppin, PI - field checking in NW Black Hills

MSS5 and 7, and color composite, photo 1047-17175, 8 September 1972 was used along with the excellent 9x9 U-2 color infrared strips at Newcastle and Sundance. A strong E-W trending light tonal linear crossing the heavily forested area SE of Sundance was checked out. In places, charred trees suggested a burn, but the narrow band seemed odd for a burn. No geologic cause could be found either on the ground or on geologic maps. A visit to the Sundance ranger station revealed the feature to be a tornado swath! Interestingly enough this light streak is on line with a drainage linear and a known EW anticline (Cedar Ridge). A prominent drainage linear follows Inyan Kara Creek south of Belle Fourche River SSE along Mason Creek. It may or may not be continuous with another linear along Skull and Oil Creeks to the SE. There are numerous short drainage linears parallel to these trends along this flank of the Black Hills; many appear to parallel lithologic trends and hence are subsequent drainages. Others cut across lithologic trends and are probably fracture and/or fault controlled. Another EW drainage linear west of Sundance which is on line with the intrusive in Sundance Mountain was checked. The linear is in units of The Sundance Formation. There is no apparent fault along here but the only way this can be adequately checked is to carefully map on 1:24,000 topography the members of the Sundance Formation and measure fractures in the Hughlett Sandstone member. The same approach is necessary along the Inyan Kara linear.

The NE linear transverse to the structure at the NW end of the Black Hills region along the Little Missouri-Prairie Creek-Rawhide Creek drainages is striking. The Little Missouri River valley is alluvium filled but geologic maps show a number of short longitudinal faults and folds paralleling the river a short distance to the NW.

The color composite is particularly useful in that the drainage patterns are not only clear, but vegetational and lithologic contrasts are more marked than on individual MSS bands. The dark bluish-green patterns are mainly due to dark Cretaceous shales (Skull Creek, Belle Fourche, Carlisle, middle and upper Pierre). The lighter areas are sandstones (Newcastle, Niobrara, Groat member of Pierre). While some correlation can be made with mapped geologic units, one is mainly mapping tonal or color units. Some include more than one stratigraphic unit. For example the broad light tone at the NW end is a combination of the Niobara Formation and the Groat sandstone in the overlying lower Pierre.

Tracing a given color tone on the ERTS may not always keep one on the same unit. Northwest of Newcastle the Niobrara can be traced very easily on ERTS to Skull Creek. Its apparent continuation turns out to be the Greenhorn limestone while the Niobrara actually turns west a short distance as a broader light band before turning northwest. The darker tones show up best on MSS7 while the lighter tones are best on MSS5. Tonal and color contrasts are much reduced on spring imagery because of the heavy cover of green grass. Late summer and fall color composites are the best images for analysis in this region.

It is difficult to locate many known folds either because they are too small or are not outlined by resistant units. Drainage patterns are the best indication of anticlines (Oil Butte, structure west of Spearfish, another west of Belle Fourche), domes (Green Mt., Strawberry Mt.) and areas of homoclinal dips (especially well shown on Lakota-Fall River formations).

It is very evident that we have material that will provide us stimulation for years. The value of using ERTS first in an area with abundant ground truth is very apparent. We find our skills and confidence growing as we continually study and restudy the imagery, both ERTS and supporting, and compare with ground truth. Perhaps the slowest aspect and one that will continue for many man-years, is field checking. The time involved in areas where the geology is already well known suggests far greater logistical and time problems for adequately field checking lesser known areas.

One data request form is being submitted. This is to replace worn out or lost positive transparencies.

Summary of significant results (3K)

Comparisons of imagery of three seasons, late summer-fall, winter and spring indicate that for this region fall imagery is the best for overall geologic analysis. Winter scenes with light to moderate snow cover provide excellent topographic detail owing to snow enhancement, lower sun angle, and clarity of the atmosphere. Spring imagery has considerable reduction of tonal contrast owing to the low reflecting heavy green grass cover which subdues lithologic effects; heavy snow cover in the uplands masks topography.

Field checking of linears noted on imagery showed some to be along known faults, others are related to zones of more intense fracturing, and still others, though locatable in the ground, could not be correlated with any geologic feature because of heavy tree cover and lack of bedrock exposures.

Mapping of geologic formations is impractical in most cases. Separation into tonal units can provide some general clues on structure. A given tonal unit can include parts of several geologic formations and different stratigraphic units can have the same tonal signature.

Drainage patterns and anomalies provide the most consistent clues for detecting folds, monoclines, and homoclines. Vegetation only locally reflects lithology and structure. False color infrared 9X9 transparencies are the most valuable single imagery. Where these can be supplemented by U-2 color infrared for more detailed work, a tremendous amount of information is available. Adequately, field checking such a large area just in one scene is the major logistic problem even in a fairly well known region.