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# APPLICATION OF ERTS AND EREP IMAGES TO GEOLOGIC INVESTIGATIONS OF THE BASIN AND RANGE - COLORADO PLATEAU BOUNDARY IN NORTHWESTERN AND NORTH-CENTRAL ARIZONA



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## Problems

We continue to have difficulties with the computer compatible tapes. Striping, which we understand to be a general problem, well understood by GSFC, is strikingly evident on any frame which is computer enhanced. This artifact must be removed as soon as possible. Intermittent banding is also severe and would appear to be the result of a problem in transcribing the master tape to the CCTs, since only portions of a frame are affected.

## Accomplishments and Plans

### Shivwitz Plateau and Environs

ERTS-1 photographs have revealed a possible circular structure located in southeastern Nevada. The structure is about 90 km in diameter and well defined topographically. According to published geologic maps, it is defined structurally as well, and contrasts markedly with the linear basin-range structures that characterize the region.

A subcircular mountain range, about 25 km in diameter, is located near the center of the structure. According to the literature, this central mountain is basically a dome composed of Lower to Middle Paleozoic rocks.

The depression, or "moat" surrounding the central range is topographically low, and largely filled with basin deposits of Cenozoic age. In places, older rocks protrude through the basin fill and include, notably, upper Paleozoic and Mesozoic rocks.

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The rim of the structure is particularly well defined on the east side, where it forms a segment of arc subtending an angle of about 90°. In this segment, Precambrian rocks are exposed on the side of the rim that faces the center of the structure, and are overlain by Paleozoic and Mesozoic rocks that dip radially outward. The rim is cut by high-angle faults, many of which are concentric with respect to the structure. The western part of the rim is complicated by high-angle faults and folds and includes rocks of Paleozoic, but not Precambrian or Mesozoic age. The southern part of the structure is rimless and no boundary can be defined. The northern part shows a ragged and diffuse rim developed in volcanic rocks of Tertiary age that include silicic ash flow tuffs. The symmetry of the structure is modified in part by several relatively minor features, the most conspicuous of which is a fault-block range trending through the structure in a north-northeast direction. It is probable that the structure has been modified by basin-range faulting that postdates the structure itself.

Three explanations can be advanced for the structure:

(1) It is a fortuitous combination of basin-range faulting. This seems unlikely in view of its uniqueness and symmetry of shape, the structure of the eastern rim, and the structural as well as topographic nature of the "moat".

(2) It is an ancient impact structure with a central peak. The structure would be post-Mesozoic in age, and probably younger than the Tertiary volcanic rocks exposed on the north side. Although this hypothesis cannot be dismissed entirely, it is unlikely because (a) a crater of the diameter in question would have penetrated more deeply than the rocks now exposed within the structure; (b) the crater would have been eroded completely in spite of its relatively young age; and (c) no mesoscopic or microscopic features typical of impact structures have been described for the area.

(3) The structure is a volcano-tectonic collapse feature related to effusion of volcanic rocks - especially ignimbrites - of Tertiary age. No vent-like features have been recognized within the structure, but the abundance of silicic volcanic rocks at and near the north rim is suggestive: regional considerations indicate that, before basin-range faulting, the overall topographic slope in the Lake Mead region was to the north and northwest, so that volcanic rocks would flow in that direction from the source areas. Ever since it has been recognized that ignimbrite sheets in the eastern Great Basin represent a volume of thousands of cubic miles, the question has arisen of how so much material can be extracted from the crust without attendant collapse over source areas. Yet, no large-collapse structures have been found. Perhaps, features such as the one described here merit close study in this context.

If the volcano-tectonic hypothesis is correct, the inferred geologic history of the area would be (a) updoming over an active magma chamber; (b) effusion of lavas and ignimbrites; (c) collapse; (d) renewed updoming of the central part of the structure to form a resurgent dome, perhaps accompanied by further eruptions; (e) basin-range faulting; and (f) erosion.

Current work includes compiling geologic cross sections and simplified maps from the literature, in order to test the various hypotheses.

ERTS images are excellent for seeking and detecting other structures that may be volcano-tectonic depressions.

## Interior Basin Deposits

The fill of many tectonic basins in the western United States is composed of interior-basin deposits. Not uncommonly, the deposits of individual basins have been correlated over wide areas, and assigned formational status. Yet, the correlations cannot be made on the basis of lithologic characteristics or stratigraphic position, but only on genetic, and thus interpretative grounds. For this reason, the "formations" comprising the basin deposits are not objective rock-stratigraphic units. This is particularly well illustrated by the Muddy Creek "Formation" of Cenozoic age, which crops out widely in western Arizona, southern Nevada, and southwestern Utah. The Muddy Creek includes the fill of several separate basins, comprises many different lithologies, and can only be defined as an interior-basin deposit postdating basin-range faulting and predating establishment of the Colorado River.

The problem cannot be solved by revising the stratigraphic rank of the Muddy Creek and its component units; although basic units could be defined that would be objective and mappable, and thus rock-stratigraphic units, units of higher rank would remain in part genetic and interpretative.

The solution proposed hinges on recognizing that units such as the Muddy Creek are in part objective and in part interpretative. The proposed classification comprises objective mappable units based on composition and texture, which are used to produce objective and reproducible maps that are free from interpretation. These units are then put together into units of higher rank that are progressively more interpretative, and allow correlation on the basis of genesis, which, in this case, is the only criterion that can be used. By means of this classification, observation and interpretation are separated explicitly, but both recognized as essential.

The need for clarifying and systematizing the approach to deposits such as the Muddy Creek has been made urgent by the advent of earth-orbiting satellites such as ERTS-1. The small scale of the images provided by these satellites encourages mapping and correlation of regional extent. In addition, the synoptic view now available clarifies the relation of deposits to the basin in which they were laid down, as well as the relations between the various basins of deposition.

## Cataract Creek

Work in this area has been limited to some computer image enhancement discussed below. The unusually heavy snowfall in this area will probably postpone field work until after May 1.

Central Arizona

Work was concentrated in this area since it was so readily accessible for field checking and because of the impending March 5-9 ERTS conference presentations.

The simple color composites of bands 4, 5 and 7, computer stretched to increase contrast, show remarkably good correlation with the generalized geologic map we have constructed from literature sources. Areas not covered by Ponderosa pine exhibit color tones diagnostic of the individual geologic units, in spite of moderate vegetation cover in the form of Juniper bushes, sagebrush and grass. In the areas of sparse vegetation all major geologic units are identifiable. Areas mapped as Qg, gravel and sediment deposits, cannot be differentiated from the units from which they were derived. For instance in the northern Verde Valley the deposits derived from the Paleozoic Supai Formation have the same characteristic color as the original unit.

The major copper workings, as well as the tailings leach ponds, are highly visible down to one resolution element in size, because of the characteristic low sulfide reflectivity in the near IR compared to the visible. These areas appear bright blue on a false-color IR composite.

Well-developed regional structural patterns are strikingly visible on the ERTS images, particularly where Precambrian metasedimentary and metavolcanic rocks are at the surface. The ancient structural grain trends predominantly northeast and north, and includes subordinate widely spaced east-trending lineations. Northwest-trending structures and lineations reflect comparatively recent structural adjustments and the development of the present geomorphologic form of the region. The northwest-trending linear features, for the most part, are less conspicuous than the north and northeast-trending lineations. ERTS images show that most of the eruptive centers for the basaltic volcanism on the Colorado Plateau are clearly localized along northeast and north-trending lineaments. This suggests that Precambrian structures were responsible for the localization of the eruptive centers, and that structural adjustments along the ancient trends occurred during the Tertiary volcanism. The Oak Creek Fault, for example, is inferred to overlie a north-trending fault system in the basement that is en echelon to the Shylock Fault Zone north of Humboldt.

The lineaments mapped photogeologically from the ERTS images locally supplement, and generally complement, the pattern of known mapped faults. In unmapped areas, the lineaments constitute the only structural information, information which provides an overall sense as to the nature of the crackling of the crust. The lineaments range from very strongly developed sets of joints, to vaguely developed, almost indefinite groups of short linear features which together portray a possible structural grain. In some cases, the well defined lineations reflect stratification in metamorphosed rocks (south of Humboldt); in other cases, they reflect strong zones of fracture (in Paleozoic rocks near Sedona). It should be noted that northwest-trending fractures in the Sedona area are extremely abundant and closely spaced, and in images from low altitude are the overriding structural characteristic. The ERTS images of this area, however, display some very strongly developed northeast- and east-trending lineations which previously were unrecognized. Similarly, a strong north-trending lineament which parallels and lies east of the Oak Creek Fault was recognized as an element of the Oak Creek Fault system in light of the ERTS images. The ERTS images appear to provide a method for "seeing" important structural grain in sedimentary rocks beneath the basalt cap in the Flagstaff area. Structural discontinuities in the basement also may be traced even where concealed by thick valley-fill deposits. An example occurs in the Chino Valley where one or more lineations may be traced northwestward from Humboldt to past Stewart Ranch.

Directional filtering to remove horizontal banding and enhance small oriented features has been attempted. Several orientations of structural grain are visible over a wide area of the image. Such enhancements are useful to attract the attention of the viewer to subtle, oriented features. However, the subjective evaluation of the mapper is necessary to exclude possible artifacts.

## APPLICATION TO GROUND WATER RESOURCE PROBLEMS

The City of Flagstaff is presently in the process of developing a source of subsurface water from the Coconino Sandstone at two localities; (1) in the Woody Mountain area, where several wells have been drilled, and (2) in the lower Lake Mary area where one well has been drilled. The Coconino Sandstone appears to be saturated at these places and reliable producing wells depend on fractured ground. Areas marked by the intersection of differently oriented sets of fractures will be important for guiding the location of wells that are to be drilled this summer into the Coconino Sandstone, and the location of a planned deep well that is to test the stratigraphically much lower Redwall Limestone. Long range plans for the development of a large supply of water will require the structural evaluation of ground extending some 60 miles southeast of Flagstaff.

An area immediately southwest of Woody Mountain may be structurally favorable for subsurface water. Strongly developed northwest-trending lineaments impinge and appear to intersect north-trending lineaments of the Oak Creek Fault system. The utility of the minor lineaments and their relation to a regional fracture pattern remains to be demonstrated. A lineament map is to be made employing normal aerial photographs in an analytic stereo plotter to supplement the lineaments derived from ERTS images. RB-57 photography has been ordered to allow the the compilation of lineaments for a more extended area at a scale of 1:62,500, which is compatible with anticipated drilling target areas. The latter will cover the area of intermediate and long range planning for the development of Flagstaff's water resources.

<u>Sedona area</u>: The State Geologist of Arizona and Water Resources Division of the U. S. Geological Survey, are concerned with discovering a new and extensive supply of water to serve the scenic and rapidly developing Sedona area of the Verde Valley. The potential aquifer is the Redwall Limestone, which underlies Sedona and the cliffs of Supai Formation and Coconino Limestone that bound Sedona on the north and east. Information needed includes elevation control on key horizons in exposed beds, which will provide data on the structural attitude and spatial position of the potential aquifer. Also needed is the distribution of fracture zones that would permit the interconnection of karst or cavernous ground anticipated in the lower part of the Redwall. In such cases, one can encounter virtual underground "rivers".

Existing ERTS images and high altitude RB-57 color photographs display the character of fracturing in the Sedona area. A few very will developed east-west-trending lineaments transect the more common NE-, NW- and north-trending sets of lineaments. We interpret that the scenic embayment in the Colorado Plateau margin in which Sedona is located resulted from erosion in an area that is somewhat more fractured than adjoining areas. The greater fracturing presumably reflects the existence of the fourth (E-W) set of fractures. Development of water resources will depend on the location of a favorable structural position for the potential aquifer and the existence of suitably fractured ground. We have begun discussions which may lead to the establishment of a cooperative effort toward the solution of this problem.

Chino Valley, Stewart Ranch area: Another area of interest to the State Hydrologist and Water Resources Division is in Chino Valley, near the Stewart Ranch. Here, substantial quantities of ground water occur near the surface, and flowing wells have been drilled. Control, source, and recharge areas for the water are not really known, although the existence of outcrops of Precambrian Mazatzal Quartzite in low hills nearby suggests some form of structural control on the aquifer (Redwall Limestone).

The ERTS images have revealed the existence of lineaments of Chino Valley which extend northwestward from Humboldt. These can be traced to and well beyond the Stewart Ranch area. They are provisionally interpreted to reflect structure in bedrock beneath the valley fill. Their existence suggests that the near-surface ground water is controlled by the existence of a heretofore unrecognized "dam" in the subsurface.

A structural evaluation of this area is needed to allow the proper development of ground water resources. ERTS images, and high altitude photographs, need to be analyzed for the distribution and character of lineaments. These, interpreted in light of structure to be obtained from surface and subsurface studies, should shed light on water resources in this part of the Chino Valley. We tentatively plan to carry out the required structural studies as part of a cooperative investigation with the appropriate federal and state agencies.

## Computer Image Processing

A standard procedure for handling CCTs under VICAR, the JPL image processing system, has evolved. Each tape is logged and processed by the ERTSFIX program to clear up errors. The ERTSFIX program detects each picture line which deviates more in average value from its two neighbors than a preset tolerance. These bad lines are eliminated and the average of the neighboring lines is substituted. This produces a fairly clean picture but reduces the vertical resolution at these points. Errors over small parts of lines which are not detected by the ERTSFIX thresholding are located manually and averaged out.

The original MSS data have not been skewed to compensate for earth rotation. Although for the majority of the processing this would make no difference, skew correction for registration to maps appreciably aids the field investigator and so is routinely done. A skew correction is applied using a program which laterally shifts the data in each picture line by a progressively changing amount as required to produce the desired output skew. Following this, flexible rubber sheet stretching may be applied if desired for precise overlay matching or for registration to maps.

Final adjustment for aspect ratio is accomplished by film recording at differing horizontal and vertical pixel spacings.

The images as received are relatively low contrast and it has been found useful to stretch the contrast before presenting the data for visual inspection. Stretching to the limits of the available digital number (DN) range has been used for black and white presentation. This produces stretches which vary for the different colors and vary between pictures. Stretching in the digital domain has the particular advantage that it is under precise control, can be linear or non-linear, and does not suffer from the toe and shoulder saturations encountered with photographic stretching. For color presentation it is desirable to have uniform color presentation throughout a series of pictures. A fixed predetermined stretch is therefore used. Comparison of the stretched pictures with the original GSFC color prints reveals considerable additional detail not visible in the original.

A second presentation which has been found useful is obtained by forming the ratios of pictures, the two most useful of which have been the ratios of each of the bands to red and each of the bands to an average of all four colors. This ratioing process largely eliminates the brightness components of the original pictures and produces a color display whose color variations are more indicative of material variations than the simple pseudo color displays.

A program FUNC has been written which allows the function

$$DN_{out} = \left(\frac{Ax + By + C}{Dx + Ey + F}\right) (Gx + H)^{I} + J$$

to be performed on two pictures where x is the input DN of one picture and y is the input DN of the second. By suitable manipulation of the coefficients this program may be used to perform the ratioing, picture averaging, picture differences, offset and gain change, and exponentiating. A two dimensional table is first built up to 8 bit precision using the coefficients entered as parameters. The two input pictures are then read in parallel and an output picture assembled in synchronism by reference to the table at a location determined by the DN's of the two input pictures, pixel-by-pixel. Rapid processing speed is afforded by the table lookup method.

High frequency detail may be contrast stretched to enhance its visibility or anisotropically filtered to emphasize geologic structures with differing orientations. Spatial filtering by convolution (our normal method) has two important practical advantages: For the large pictures and the reasonable size filters used for ERTS it is faster than doing the required two-dimensional FFT, and since filtering is in the real domain the effects may be easily visualized and to some extent the filters may therefore be designed heuristically. Filtering in the Fourier domain has been advantageous primarily where the filter function in frequency space is fairly complex. This process has not been necessary for the ERTS images.

Clustering and classification is accomplished using an extension of the techniques previously described for the Apollo S-158 experiment. Training samples are chosen by the analyst to represent the various materials for which classification is desired, and their average value and deviation for the four bands are found by a program CLSTRN and tabulated. The four-dimensional decision volume is defined using three two-dimensional decision spaces of 128 x 128 locations each. Within each space rectangular areas based on the previously determined average and deviation for each material are delineated. A subsequency rule is used to eliminate the effects of overlap. Alternatively, the defined areas may be of any shape desired by manual delineation.

A two-dimensional cluster diagram in which increasing darkness represents increasing quantity of pixels at a given DN intersection may be presented to the analyst for inspection, either in image form or on a line printer. For better visualization this cluster picture may be contrast stretched and contoured. The analyst manually defines in the two-dimensional cluster spaces the areas corresponding to the various materials based on the CLSTRN parameters.

Four dimensional classification using these two-dimensional spaces is done in three passes using the two-dimensional classifier HSTLOC2, first using two bands, then the output of the first pass with the third band, and finally the output of the second pass with the fourth band. Because of the way the VICAR system is organized this multiple pass approach is quite simple to apply. While not as sophisticated as the LARS approach, it has provided a useful interim capability.

Registration is normally accomplished in two steps. First, translational offsets are simply accomplished utilizing the truncating capabilities of VICAR. The required translations of small areas used for pass points are then obtained by cross correlation. One of several rubber-sheet stretching programs may then use these parameters to distort the picture to accomplish the desired overlay match. The basic operation of these programs is to systematically generate a uniform-grid output picture, obtaining the required data by weighted interpolation from the four nearest neighbors surrounding the precise calculated location in the input picture. It has not been found satisfactory to use simply the nearest neighbor to the calculated location for the output data, as this reduces the resolution. The location in the input picture is calculated from the array of distortion parameters, using linear interpolation between. We have considered higher-order generating functions for the location calculations, but have not found them necessary.

After registration, any inter-picture operation, such as DIFFPIC to detect temporal changes by picture differencing, may be applied. VICAR is designed to handle multiple input and output pictures where appropriate to the required tasks.

Of the 200+ executable programs available on VICAR, about half are of general purpose interest, the remainder being written around pecularities of various projects, such as specialized programs for processing pictures from the Mariner spacecraft camera. Of the group of general interest, a moderate number have been used in ERTS processing, supplemented by some ERTS special programs such as ERTSFIX. Table I lists some of these, with typical execution times for a 1600 x 1700 pixel ERTS picture (i.e., two of the four strips comprising one ERTS frame). As a general rule, processing time is linearly proportional to the picture area, so small portions of the pictures - easily extracted by VICAR - are generally used for experimentation.

TABLE I

ERTS MSS PROCESSING TIMES
4 bands, two strips (1620 x 1620)

| | | Min. |
|---|---|---|
| VMSS | GSFC format to VICAR format on disk, 1 strip | $6\frac{1}{2}$ |
| CONCAT | Join two strips to form 1620x1620, 4 colors | 18 |
| STRETCH | Expand to 8-bit range, 4 colors | $4\frac{1}{2}$ |
| ERTSFIX | Cleanup bad lines, 1 color (depend on severity of problem) | $3\frac{1}{2}$-7 |
| SKEW | Skew, 4 colors | $7\frac{1}{2}$ |
| PICAVE | Average four bands | 8 |
| FUNC | Ratio band to average | $5\frac{1}{2}$/ratio |
| HISTOGRAM | Generate histograms, 4 colors | 8 |
| DIFFPIC | Difference picture, one pair | 4 |
| STRETCH | Contrast stretch, 4 colors | 16 |
| FILTER | Spatial frequency filter, 1 color | $12\frac{1}{2}$ |
| AFILTER | Asymmetric filter, 1 color | $31\frac{1}{2}$ |
| FASTIL2 | Suppress low frequency, 1 color | 8 |
| CLSTRN | Calculate x, up to 150 areas, 4 colors | 3 |
| HISTLOC2 | 2-dimensional classifier (1000x1200) | 10 |
| HISTLOCN | N-dimensional classifier (N=4) | 30 |
| TAPE | Generate save tape, 5 pix. | 6 |
| SAR | Read/Write 4-frames to tape | 5 |
| FOTO | Quick look Polaroid picture, 1000x1000 | $1\frac{1}{2}$ |
| REGISTER/ CROSS | Generate registration parameters by cross correlation | 15 |
| GEOM | Rubber sheet stretch for registration | 5-20, typ |

## Publications

Two abstracts were prepared for the March 5-9 ERTS Investigators Meeting.

1. Preliminary Geologic Investigations in the Colorado Plateau Using Enhanced ERTS Images, A.F.H. Goetz, F.C. Billingsley, E.P. Elston, I. Lucchitta and E. Shoemaker.

2. Computer Techniques Used for Some Enhancements of ERTS Images, F.C. Billingsley and A.F.H. Goetz.

## Change in Emphasis

The discovery of the possible use of ERTS images in the search for ground water resources in central Arizona calls for a redirection of our effort to fully exploit this application. Our manpower is limited, however, we will be able to lend our expertise to the proper agencies, namely the City of Flagstaff and the Arizona State Hydrologist and help them in their use of the ERTS and U-2 data. We are also anticipating using part of our Skylab program resources in this application. As a result the previously proposed Hackberry Mountain mapping task will have to be dropped or at least continued only at a low level.

## Data Request Forms

No Data Request Forms were submitted in this reporting period.