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ROY M. BRECKENRIDGE

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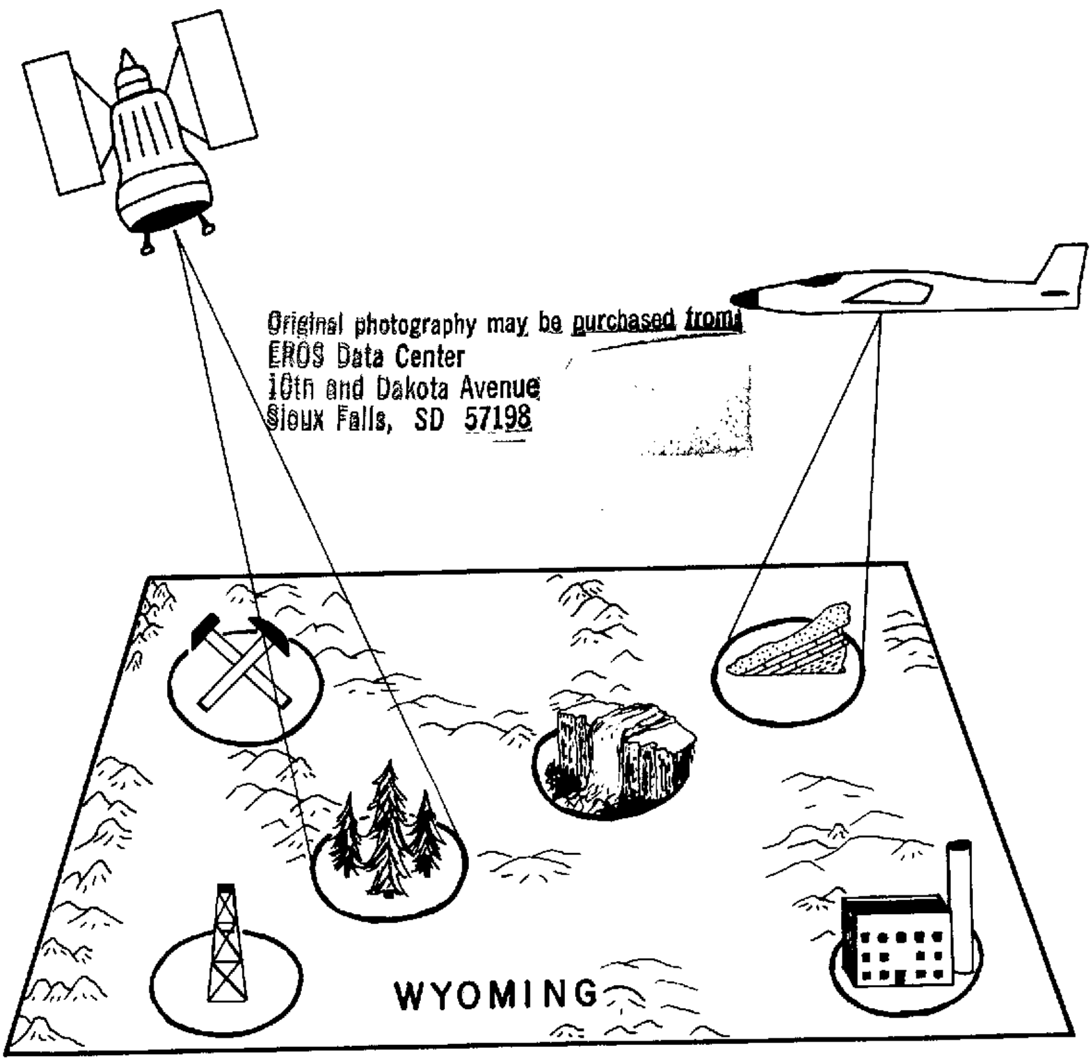

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16. Abstract

ERTS-1 image interpretations in the Yellowstone/Absaroka volcanic province indicate that the ERTS-1 imagery can be successfully employed in mapping large-scale structures and gross lithologic differences within the volcanic rocks. The volcanic rocks are readily separable from the sedimentary and crystalline rocks but the various volcanic units are seldom distinguishable unless they exhibit a characteristic morphology. Color anomalies were detected on the ERTS imagery and found to be related to zones of alteration and mineralization. High-altitude aircraft imagery provided a means of checking and improving the interpretations.

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Figure 2. Technical Report Standard Title Page

APPLICATION OF ERTS IMAGERY TO GEOLOGIC MAPPING IN THE VOLCANIC TERRANE OF NORTHWEST WYOMING

Roy M. Breckenridge

Department of Geology

University of Wyoming

Laramie, Wyoming 82071

December, 1973

Prepared for

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND 20771

INTRODUCTION

Two of the largest volcanic provinces in the United States are located in northwestern Wyoming; the Absaroka volcanic field and the Yellowstone Plateau. The Absaroka Range forms the southern part of the Absaroka field which extends north into the Gallatin Range of Montana (figure 1). Generally the Absaroka Range consists of a large dissected plateau of layered Eocene volcanic flows, breccias and conglomerates, most of which are andesitic in composition. The Quaternary Yellowstone volcanics adjoin and cover the Absaroka field on the west. Unlike the Eocene eruptions, the Yellowstone volcanism was not violently explosive and accumulated as lava flows and ash flow tuffs. Together the two provinces provide an excellent test area of varied volcanic features.

PURPOSE AND METHOD OF INVESTIGATION

The purpose of this study was to evaluate ERTS-1 imagery in interpretation of various geologic features common to this region. Volcanic rocks are notoriously difficult to map. They generally lack sufficient stratigraphic markers and are characterized by rapid facies changes over short distances. Also much of the section is mineralogically homogeneous.

Although parts of the region are well-traveled and familiar to anyone who has visited Yellowstone National Park, most is wilderness area and extremely rugged. For a general discussion of the regional geology, the reader is referred to Keefer (1972); or, for a more detailed discussion, to Smedes and Prostka (1972) and Christiansen and Blank (1972). An ERTS interpretation of the glacial history of this same area was presented in an earlier report, Breckenridge (1973). A first-look analysis of the area from ERTS was reported

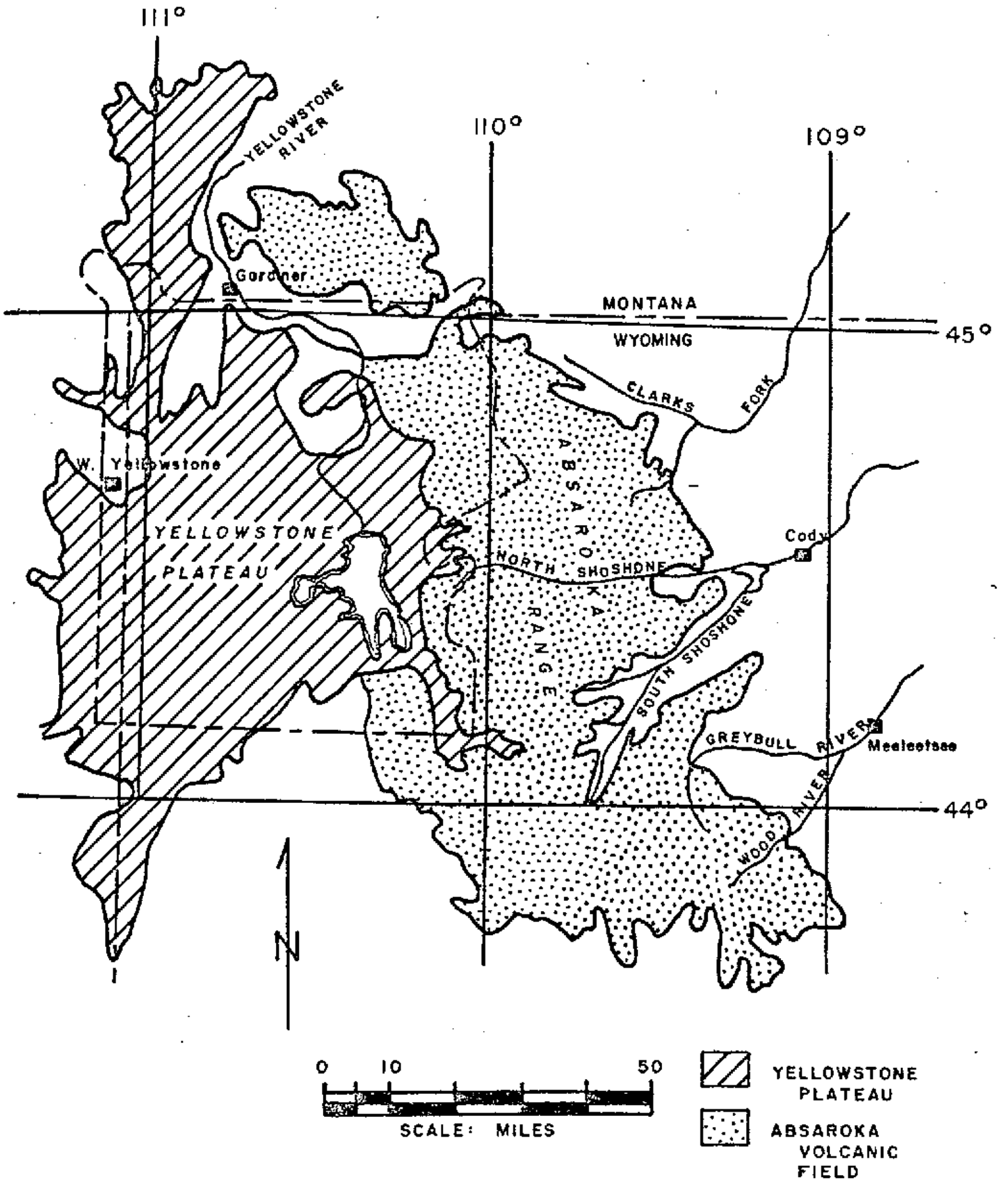


Figure 1. Index map of volcanics in northwestern Wyoming.
(After A.A.P.G. Northern Rockies Highway Map)

in Houston, Short and others (1973). Subsequent receipt of color composites and application of other interpretive techniques has resulted in improved geologic interpretation.

Laboratory interpretations of the ERTS imagery were made using standard photogeologic techniques augmented by color-additive viewing and isodensity contouring. Several small areas within the main test site were checked in the field in order to confirm the image interpretations. Spectral reflectances of representative rock outcrops were obtained with a multi-channel filtered photometer. Each channel was calibrated by reading a reference grey card at the outcrop. Data were collected in spectral bands corresponding to ERTS bands 4, 5, 6, and 7. Limited time and accessibility permitted field checks of only a small portion of the study area, but it seems reasonable to assume that the interpretation has approximately the same reliability for the entire area as was demonstrated in the areas that were field checked. In some areas aircraft imagery was available as an additional check.

At first an effort was made to restrict the map interpretations to features which any trained photogeologist could recognize, but the author's familiarity with the area precluded an unbiased judgment. However, it is apparent that much extremely useful information could be derived from the ERTS imagery by an interpreter who is more than casually familiar with the area under investigation. For the purpose of this study, all existing knowledge of the region was used to benefit the conclusions.

STRUCTURE

An ERTS band -7 mosaic was constructed for the area to facilitate a uniform regional geologic interpretation of the area (figure 2). Several major structural features and numerous smaller structures were mapped in the ERTS image

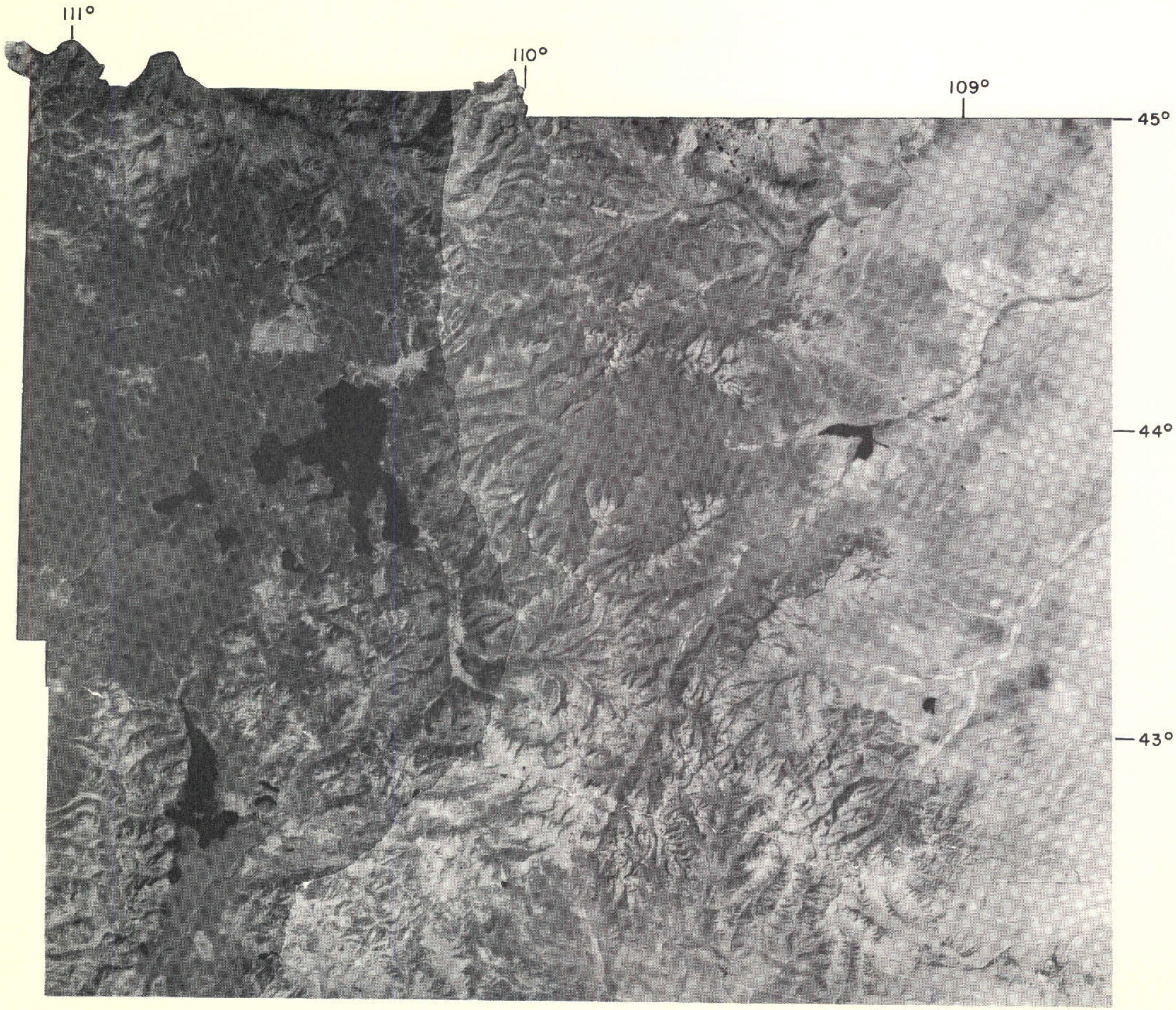


Figure 2. ERTS-1 MSS-7 Mosaic of northwestern Wyoming

interpretation. Most of the obvious structural features are in the sedimentary units along the margin of the Bighorn Basin. The largest structural feature noticeable on the imagery is the Yellowstone caldera (figure 3). The caldera is so large and ill-defined that it cannot be recognized from the ground and, in fact, was not known until the late 1950's (Keefer, p. 34-42). Recognition of the feature on the imagery is possible primarily because of the series of topographically expressed ring fracture zones outlining the perimeter of the structure and hot-spring deposits which are concentrated in the old caldera. Also, the flooding of the caldera floor by late rhyolites resulted in a conspicuously flat basin.

A number of fault zones mapped in the Yellowstone Park have been described by Love (1961) as Quaternary fault zones, many of which are exposed as recent fault scarps. Other fault zones shown only on the newer map of Yellowstone (U.S.G.S., 1972) were also mapped from ERTS. Direction of movement could not be determined from the ERTS imagery. In several places, glacial streaming and flow features were confused with faulting.

Nearly all of the linear elements previously discerned from radar imagery (see Christianson, Pierce, Prostka and Ruppel, 1966) were distinguished on the ERTS imagery.

Faulting in the Absaroka Field is not as obvious as in the younger plateau volcanics. The extreme dissection of the mountains in a dendritic pattern produces a complex topography and shaded slopes which combine to mask most linear elements. However, some major structural features appear to exert control on topography and can be observed on the ERTS imagery.

The trace of the Wood River fault (Wilson, 1964) was extended beyond the original strike on the basis of the ERTS-image interpretation. The valley of

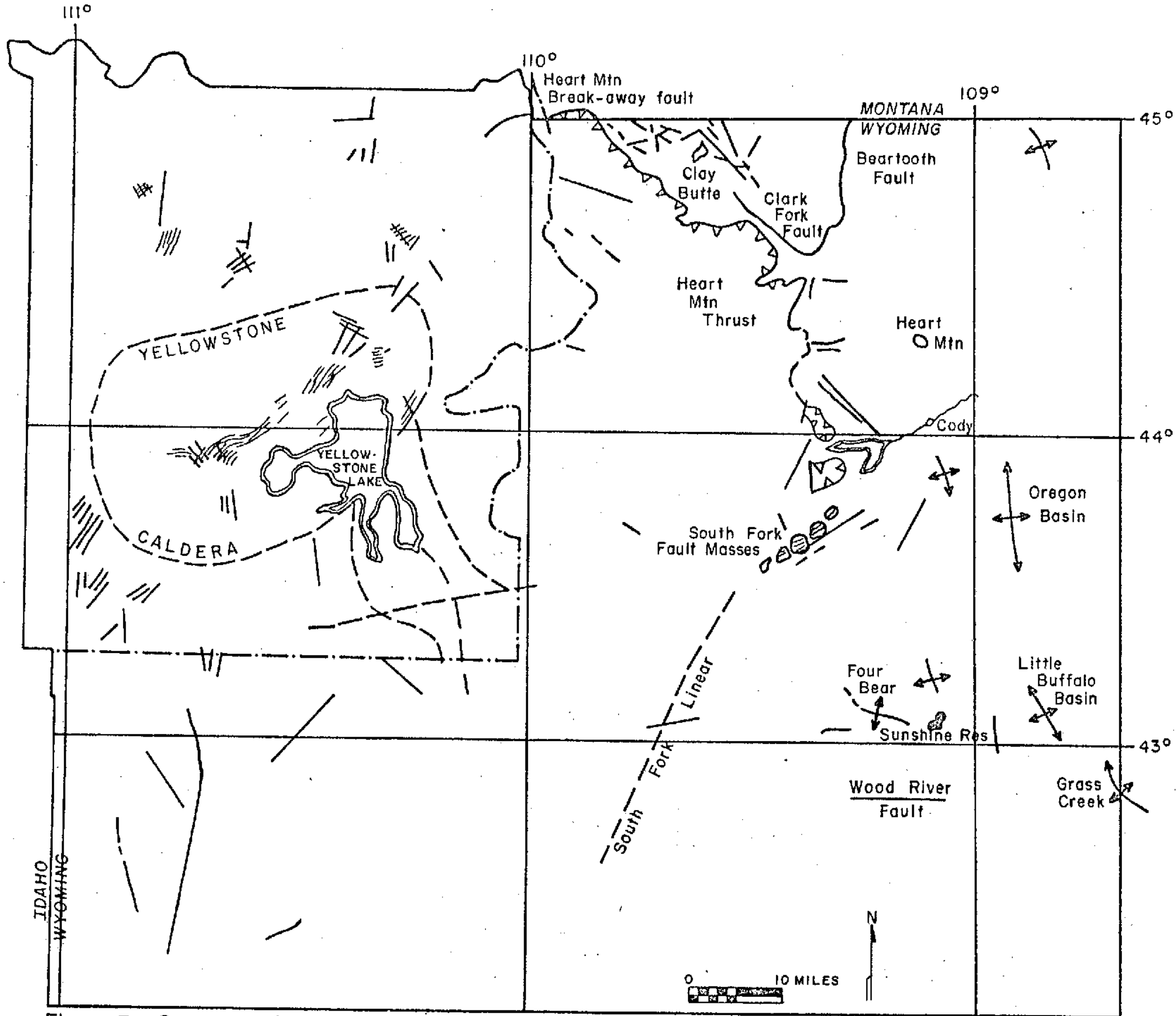


Figure 3. Structural features interpreted from ERTS-1 Imagery

the South Fork of the Shoshone River is distinctly linear and probably structurally controlled. Alluvial fans on the north wall coalesce in a straight line which probably represents the fault trace. Landslides characterized by hummocky topography dominate the south side of the valley obscuring possible structural elements. Both the Heart Mountain and South Fork thrusts (Pierce, 1957) were easily mapped from the color composite imagery. The thrust sheets are distinguished because of the high reflectance of the Bighorn Dolomite, Jefferson and Madison Limestones in the upper plate.

A number of other "linears", or linear elements suggestive of faulting were recognized and are shown on the map, but were not checked this field season because of difficult access and time limitation.

LITHOLOGIC DISTINCTIONS

As previously mentioned, the Absaroka volcanic field is a highly dissected plateau of vent and alluvial volcanic facies. Although compositions vary from andesite to basalt, most rocks are andesitic. A wide range of textures occur in the volanic pile. The stratigraphic nomenclature of the region has a long and complicated history which is treated by Smedes and Prostka (1972).

The stratigraphy of the Yellowstone Plateau volcanics has been recently summarized by Christianson and Blank (1972). The more subdued topography and heavy vegetation of the plateau area combine to limit exposures of the Yellowstone volcanic sequence, but some recent flows can be mapped by recognition of flow-lines, fronts, topographic position, and pressure-ridges.

Differentiation of volcanic, sedimentary, igneous and metamorphic lithologies was best accomplished by using a standard color-composite ERTS image. The Absaroka volcanics have a distinctly dark-brown color and appear much as they do in outcrop. The more mafic units have a characteristic dark blue tone on the color composite ERTS image. Similar drab colors identify the Yellowstone volcanic rocks when they are not obscured by vegetation. The plateau volcanics are most easily differentiated by their flow features, such as pressure ridges and steep fronts. Older crystalline rocks in the Beartooth and Teton Ranges have high reflectance in band 7 and exhibit numerous joints. The crystalline blocks are often bounded by large faults. Sedimentary rocks in the Bighorn Basin are characterized by bedding, structure, and light tone. Figure 4 shows the distribution of major rock types in the area. In some cases, the eastern contact of the volcanic rocks was difficult to define because large volcanic-covered pediments lap out over the sedimentary units of the basin.

Lithologic distinctions within the volcanic sequence were best accomplished with band 7 images used in conjunction with a corresponding color composite. Initial field examinations were somewhat disappointing. Units readily recognized in the field could not be distinguished on the imagery. Careful examination of the problem revealed that most of the units were differentiated in the field on the basis of mineralogic texture and outcrop form. For example, some breccias were coarse and massive while others were fine and thinly bedded, and some were chaotic with interbedded lenses while others were uniform. Yet all of the mappable units are similar in composition and spectral response. In addition, many of the better exposures occur in near-vertical walls and are not imaged by vertical-looking sensors. The small scale textural differences could not be resolved at ERTS scale. However, the cumulative effect of frequent ledges, "hoodoos", lenses, flows, etc. results in large changes that are detectable on the ERTS imagery. After the initial field check the meaningful distinctions reflecting different formation surface textures could be more confidently identified on the imagery and the interpretations improved accordingly.

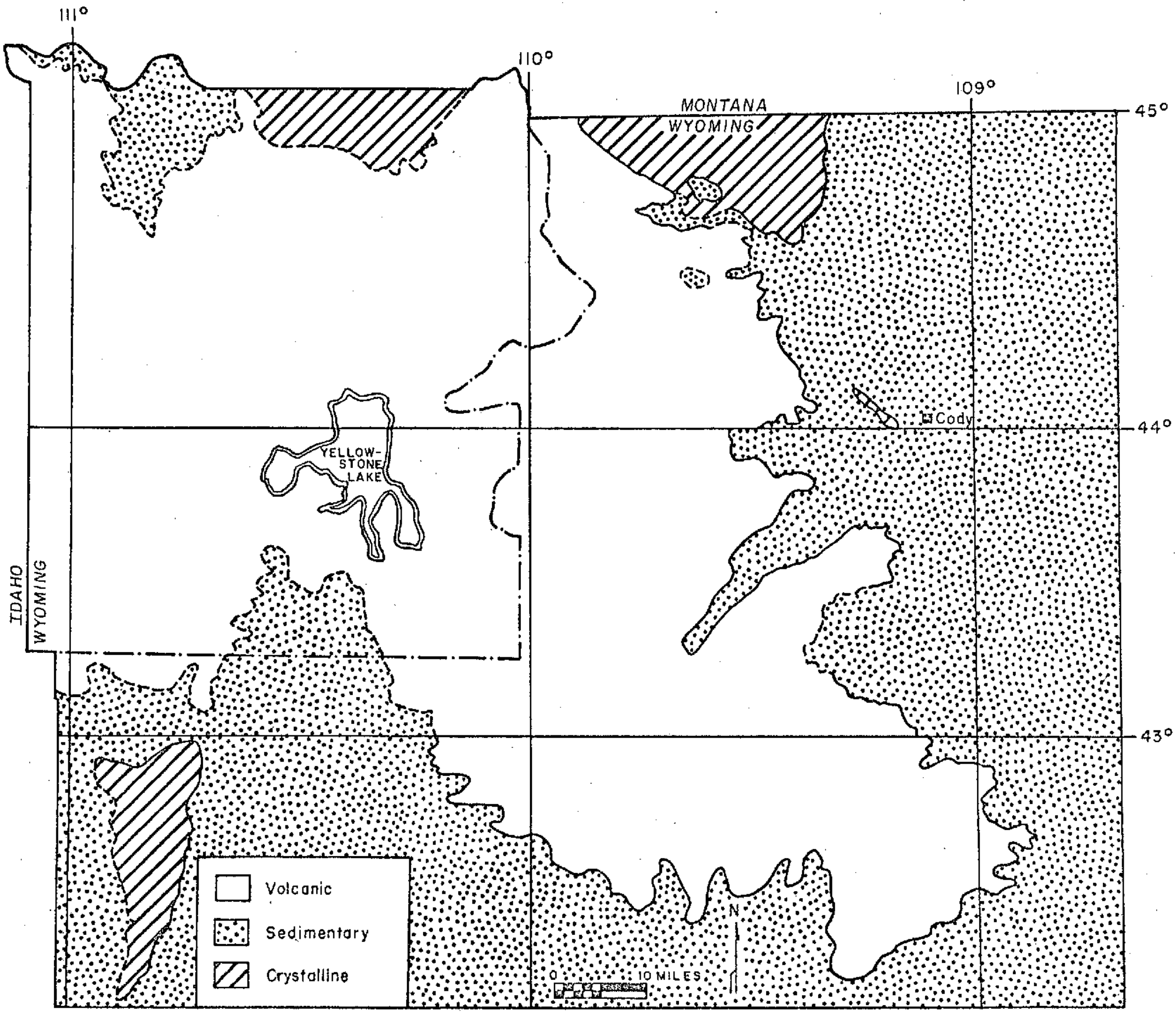
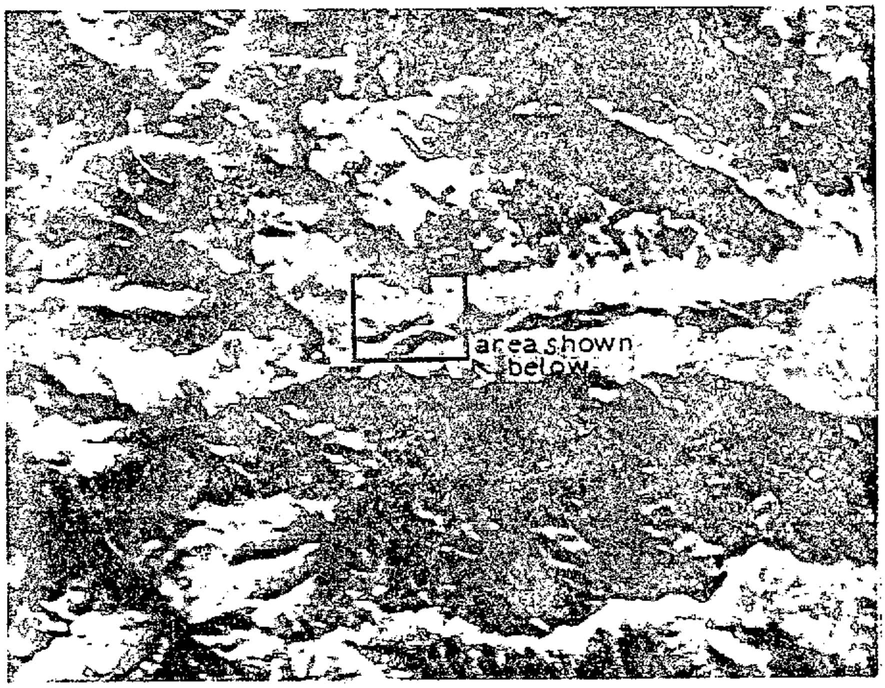


Figure 4. Major rock types mapped from ERTS-1 Imagery

At the SouthFork test site the Wapiti Formation was successfully subdivided into three units similar to those mapped by Pierce and Nelson (1969): 1) An upper series of flows and flow breccias, 2) a middle mafic breccia, and 3) a lower, light-colored volcanic sandstone, siltstone, and conglomerate. Figure 5 shows the different units on ERTS and low-level aircraft imagery. Again, the major difference between the flows and breccias is textured or topographic, but the fine-grained volcanic sandstone and siltstone has an anomalously high reflectance and appears light on the image. Spectral response of each rock type was measured in the field for the ERTS and EREP bands (Figure 6). All of the values represent an average of at least 5 readings over a large outcrop. Since the field of view was small (100 sq. ft. or less), these values cannot reflect the overall effect of ledge-shadowing or vegetation. Consequently, the field-measurements minimize the weathering characteristics of particular rock types and probably maximize the compositional similarities. They also demonstrate that these rocks have a relatively flat spectral response.

Multiband photography was taken at the outcrop to further evaluate possible enhancement of volcanic lithologic units. Figure 7 shows a section of pyroclastic rocks in the Wood River test site. To the right of each image is a densitometric curve for that image. As can be seen from the curves, all of the rock units have a relatively uniform reflectance through this part of the spectrum. Consequently, multiband enhancement of the pyroclastic rocks is limited.



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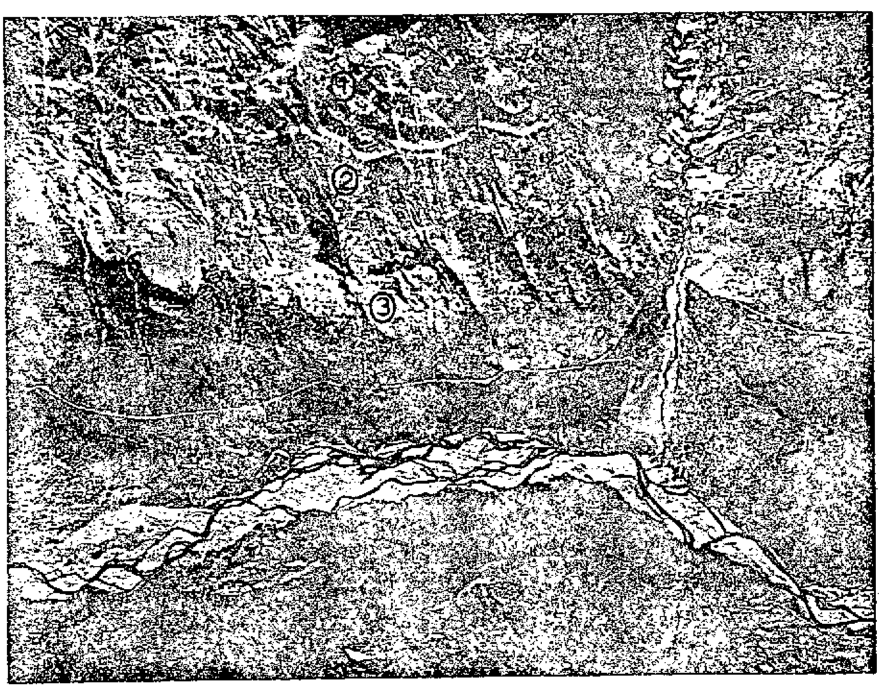

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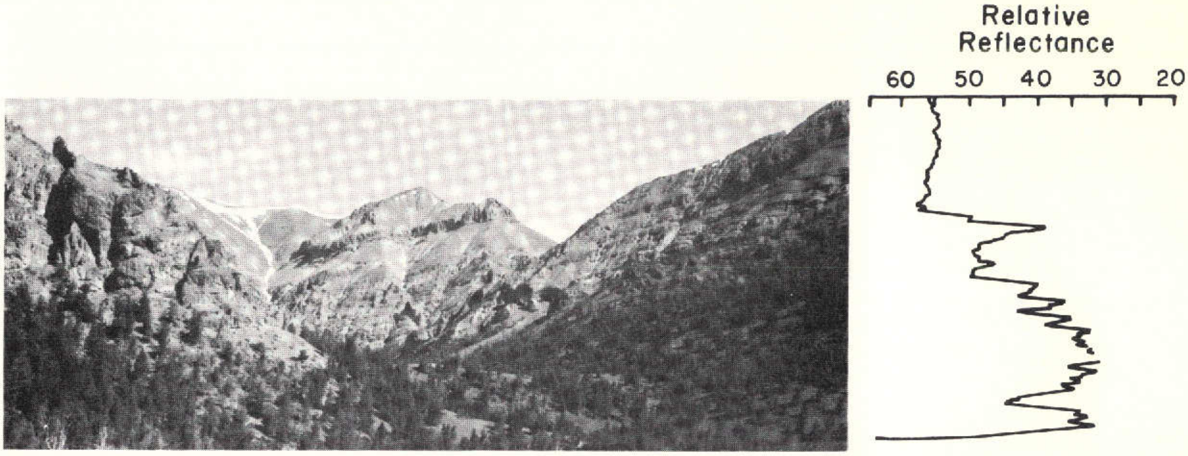
Figure 5. South Fork Test Area

	ERTS				EREP		
	4	5	6	7	OO	PP	QQ
INTRUSIVES							
Latite dike (Wood R.)	17.0	18.0	17.5	20.0	17.5	16.5	19.0
Latite dike (N. Fork)	13.0	20.0	20.0	21.0	20.0	21.0	19.0
dike (S. Fork)	21.0	25.0	24.0	22.0	21.0	24.0	23.0
Andesite (Funnel Mtn.)	12.0	9.0	11.0	15.0	11.0	8.0	9.5
BRECCIAS AND FLOWS							
Early Basic Breccia	17.5	18.5	21.0	19.0	20.0	20.5	20.0
Wiggins Fm.	12.0	11.0	11.0	10.0	13.0	13.0	12.0
Crosby Breccia	17.0	18.0	19.0	21.0	18.0	19.5	20.0
Crosby Breccia (green facies)	19.0	21.0	22.0	16.0	24.0	21.0	28.0
Wapiti Fm. (Twb) "breccia"	18.0	20.0	20.0	20.0	16.0	19.0	21.0
Wapiti Fm. (Tws) "flows"	21.5	27.0	26.0	22.0	21.0	25.0	24.0
Wapiti Fm. (Twj) Jim Mtn.	20.0	24.0	22.0	21.0	19.0	21.0	21.0
Member - Trachyandesite							

Figure 6

Filtered Photometer Readings
From Major Lithologies of the Yellowstone-Absaroka Test Site

Note: Values represent uncorrected photometer readings rather than absolute reflectances. Consequently they reflect only qualitative differences between the measured units.



Skylight Filter (2A)

Yellow Filter (12)

Green Filter (57)

Red Filter (25)

Figure 7. Multiband photography of Wood River test site

INTRUSIVE ROCKS

The volcanic flows, breccias and tuffs of the region are intruded by numerous intrusives, ranging from dikes a few feet thick to large plutons. In general, the larger intrusive bodies are much lighter in tone on all ERTS bands than the surrounding pyroclastics. Parsons (1963) recognized seven major vent areas in the Absaroka Range. Figure 8 shows the intrusives mapped from ERTS. Since some of the intrusions are covered with vegetation or occur on shadowed north slopes, they were not recognized. A number of intrusions not mapped on black-and-white ERTS images (Houston, Short and others, 1972) were readily distinguished on the color-composites.

Most of the major vents are centers of extensive dike swarms. Unfortunately, most of the dikes could not be resolved at ERTS scale. Several of the larger dikes in the North Fork Valley were mappable.

MINERALIZED ZONES

Several mining districts in the Absarokas are associated with intrusive activity. The Kirwin-Wood River area was chosen as a test site for ERTS imagery interpretation. The Kirwin area is one of the major vent centers in the volcanic field. Numerous intrusive bodies are exposed in the immediate area (figure 8). Several of these are mineralized. Recognition of the mineralized intrusions on ERTS imagery was possible because of reddish alteration zones which appear yellow on the color-composites. After targets of possible mineralization were picked from the ERTS imagery, high altitude aircraft imagery was employed in checking the interpretation at a larger scale.

Color-infrared photography (Mission 72-138) was extremely valuable in locating color-anomalies associated with alteration zones. Most alteration was

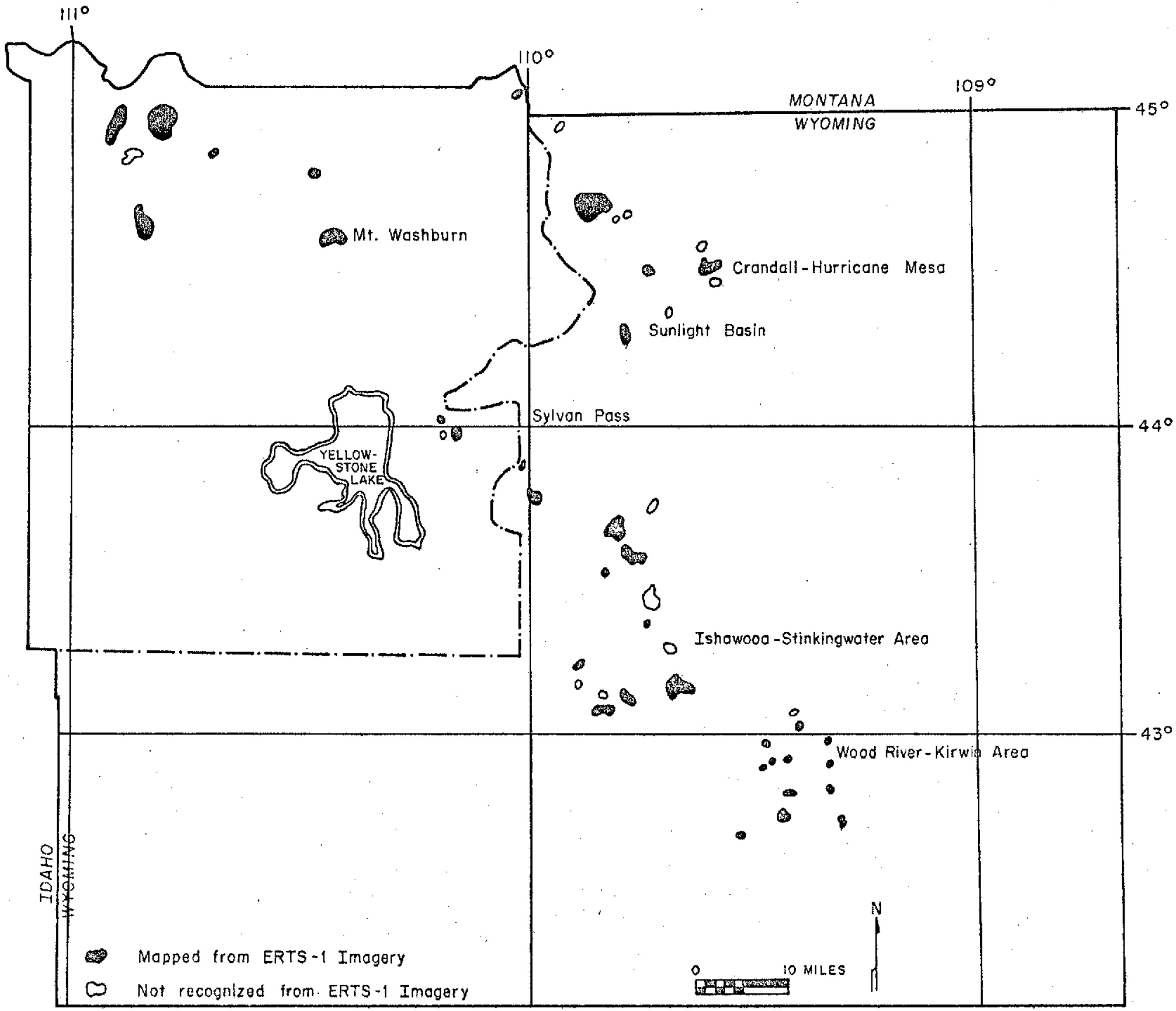


Figure 8. Intrusives in the Yellowstone - Absaroka Provinces

enhanced as yellow on the photography. Figure 9 is a map of the Kirwin test area from the high-level color-infrared photography. Alteration zones, intrusions and dikes were easily mapped at this scale. The distribution of altered areas and intrusives appears linear with a N 15° W trend and also coincides with the local dike trend. The dike swarm is splay-like in pattern, apparently radiating from a source near Bald Mountain.

The mapped alteration and fracture pattern appears to represent a zone of weakness nearly 10 miles in length and 1 to 2 miles in width along which intrusive activity and mineralization has been concentrated. Field evidence seems to support this interpretation. Nearly all of the mining and exploration activity in the district has been concentrated along this trend. In addition, geochemistry of intrusions at opposite ends of the zone are similar, suggesting a common source.

Chadwick (1970) proposed that the intrusive activity in the Absaroka-Gallatin volcanic province was centered along two subparallel belts. Although the Wood River center is included in the western belt which trends N 40° W no further alignment was noted in that direction from the imagery.

After the alteration zones were recognized on the high-level aircraft imagery a check with the ERTS color composite appeared to show subtle color anomalies in the same areas. Figure 10 is a comparison of the "alteration zones" interpreted from ERTS by: a) an interpreter unfamiliar with the area, b) an interpreter familiar with the area and c) the known alteration zones or "ground truth". Although the outlines of the zones identified varied there was close agreement on the target areas.

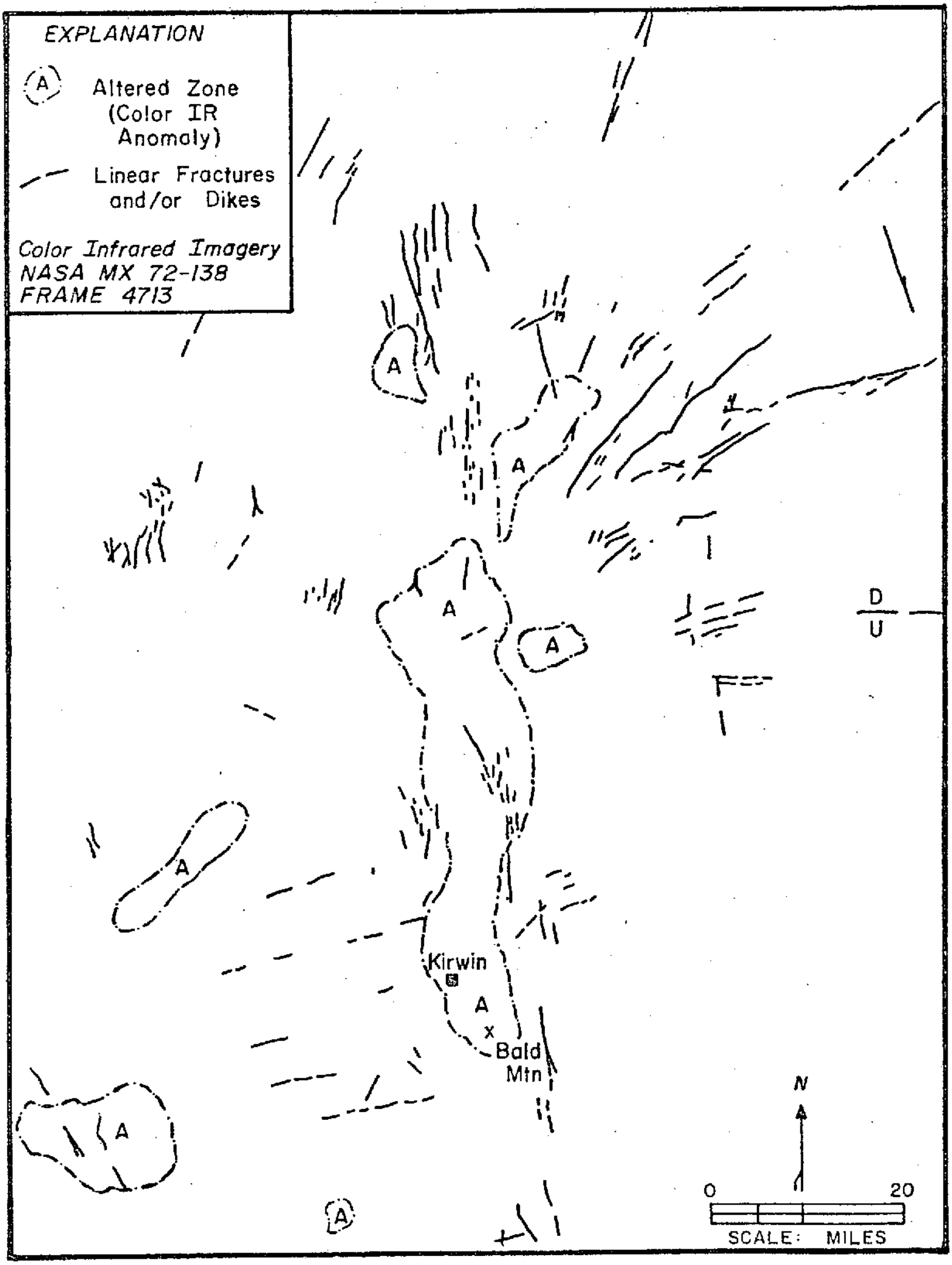
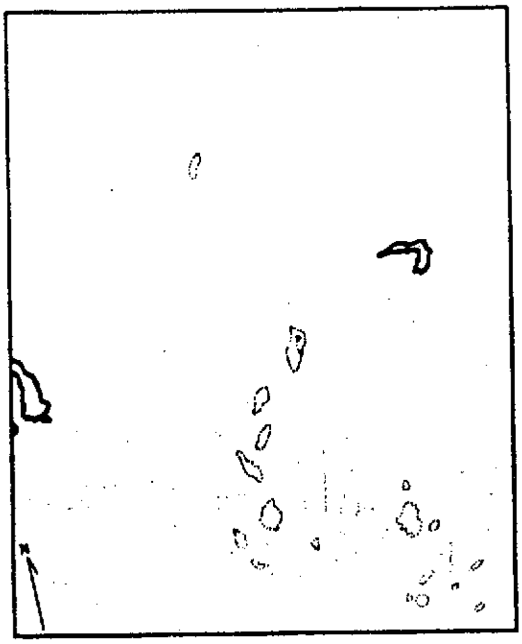
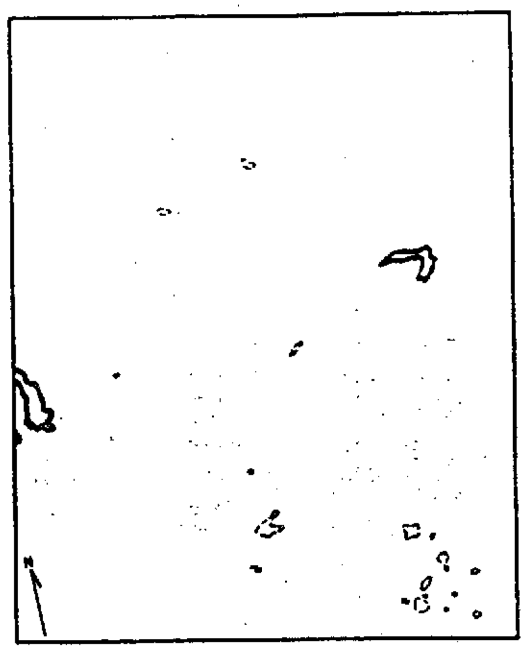


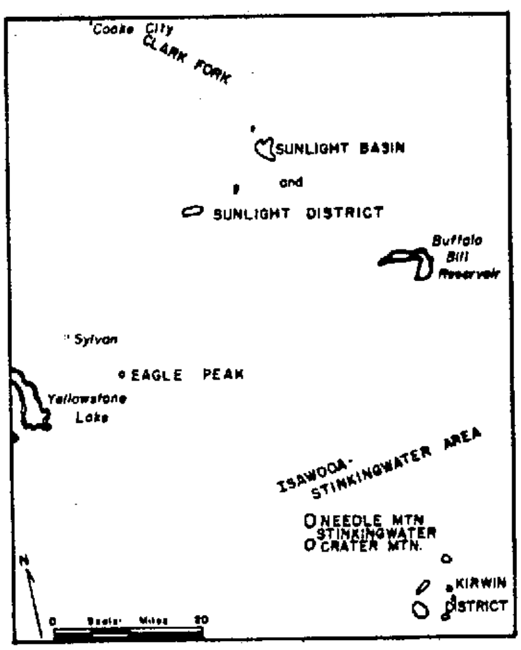
Figure 9. Dikes and alteration zones in the Kirwin area



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



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



10-c. Map of previously known areas of alteration.

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

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

An attempt to outline the mineralized zone on the ERTS imagery using an isodensitracer was not successful. Only two of the eight known alteration zones in the immediate Kirwin area were distinguished. Machine recognition could be improved by better training sets and combined analysis of all bands.

SUMMARY OF LITHOLOGIC DISTINCTIONS

Volcanic rocks were easily separated from crystalline and sedimentary terrain. Although some inter-formational contacts could be consistently recognized, it is apparent that most of the volcanic section is very uniform in its mineralogy and exhibits indistinctive spectral signatures. Differentiation of pyroclastics (volcanic breccias, tuff breccias, tuffs, lava flows, and derived sediments) by image interpretation is primarily based on mineralogic and large-scale surface textural differences. Topography and shading is a major factor in tracing the outcrop of some units. Most of the best exposures are in steep topography not suitably imaged by high-altitude aircraft or satellites. Some highly reflectant units, such as rhyolites, alteration zones, and hot springs deposits, are easily delineated.

Possible targets for mineral exploration were picked from ERTS imagery using color anomalies as a guide to "alteration zones", but high altitude aircraft imagery was better suited to this task because of the increased resolution and possibility of recognition of the smaller associated fractures. In all tests recognition of alteration zones was restricted to areas where bedrock was exposed, such as steep cliffs, valley walls, road cuts, slide scars or areas above timberline.

CONCLUSIONS

ERTS imagery can be used to distinguish structural features in volcanics. Many large-scale features not discernible from the ground are mappable from the imagery. In spite of problems with indistinct lithologies in the volcanic rocks, gross lithologic subdivisions can be made on the basis of gross textural features and patterns. False-color composites are the most useful image products for lithologic mapping. Further subdivision of the volcanic units is possible with greater image resolution. Color anomalies mapped from the ERTS color composite images are related to alteration and mineralization. Such anomalies can be detected only in areas of exposed bedrock or talus.

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