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ABSTRACT

The ERTS* program has been designed as a research and development tool to demonstrate that remote sensing from orbital altitudes is a feasible and practical approach to efficient management of earth resources. From this synoptic view and repetitive coverage provided by ERTS imagery of the Great Salt Lake area, large geological and structural features, trends, and patterns have been identified and mapped. A comparative analysis of lineaments observed in September and December data was conducted, existing mineral locations were plotted, and areas considered prospective for mineralization based on apparent structure-mineralization relationships were defined. The additional information obtained using ERTS data provides an added source of information to aid in the development of more effective mineral exploration programs.

*ERTS—Earth Resources Technology Satellite now designated as LANDSAT (Land Satellite)

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INTRODUCTION

The Earth Resources Technology Satellite (ERTS-1) was launched by NASA in July 1972. Since that time, the considerable data that have been acquired provide scientists with a new perspective and a new source of information for large regions of the world. These data have practical applications in many areas including agriculture, hydrology, and geology. The Great Salt Lake area has been chosen to illustrate the application of the satellite imagery to geologically-oriented programs of local, regional, and national concern.

This paper seeks to illustrate that geologists can use ERTS data to expedite efforts of identifying and further extending the knowledge of previously unrecognized or poorly known geologic features. The results presented here also illustrate that new techniques using space imagery can be applied to both geologic mapping and mineral exploration.

THE ERTS-1 SATELLITE

The Earth Resources Technology Satellite operates from an altitude of 920 km (570 miles) in a near-polar orbit, circles the earth every 103 minutes, and completes 14 orbits per day. The orbital characteristics are such that any given point on the earth's surface can be imaged by ERTS-1 every 18 days, with each ERTS scene covering an area of 185 by 185 km (115 by 115 statute miles) or 13,000 square miles. The satellite contains two multispectral imaging systems: a three-camera Return Beam Vidicon (RBV) and a four-channel Multispectral Scanner System (MSS). The two systems record images in three nearly identical bands, green, red, and near-infrared, and the fourth band of the MSS is further in the near-infrared. Radiances from the earth's surface detected by these sensors are converted to electronic signals, transmitted to ground stations, and are then reconverted by video signals to produce black and white images at NASA/Goddard Space Flight Center in Greenbelt, Maryland. False-color composites can subsequently be made by combining two or more of these black and white images using color filters.

Because the RBV system malfunctioned soon after launch, the vast majority of observations have been acquired by the MSS sensor. The ability of the MSS to resolve objects on the earth's surface varies somewhat, depending on the geometric characteristics of an object and its contrast with the surrounding features. Generally, however, the spatial resolution capability of nearly 80 meters is achieved.

GEOLOGICAL SETTING

The wide variety of geological and physiographic features in the Great Salt Lake area provides an attractive setting for study. As can be seen in Figure 1, three major landform features exist: (1) the Great Salt Lake and Utah Lake Basins, remnants of the once expansive Pleistocene glacial lake known as Lake Bonneville; (2) the rugged and forested Wasatch Mountains, the highest peaks of which tower to an altitude of 18,000 feet above a base which has an altitude of 5,000 feet; and (3) the sparsely vegetated mountains and basins of the desert region west of the Lake which are characterized by abrupt north-south trending mountain ridges bounded by desert plains. The great diversity of landforms attests to the complexity of geological features in the Great Salt area. Geologically the area falls within two major physiographic provinces of the United States: namely, the Basin and Range province to the west, and the Middle Rocky Mountain province to the east. The two provinces intersect topographically along the western edge of the Wasatch Mountains. Structurally, a transition area exists between these zones. (Thornbury, 1965.) The Middle Rocky Mountain province is dominated by thrust faulting, while the Basin and Range province is a complex of normal fault blocks. The Wasatch Range contrasts both topographically and in areal extent to the Basin and Range mountains. The latter mountains generally have altitudes of less than 5,000 feet, while the Wasatch Mountains reach altitudes of over 13,000 feet.

GEOLOGICAL MAPPING

The geology of the Great Salt Lake area as interpreted from ERTS-1 MSS imagery compares favorably with the published geological maps and demonstrates the feasibility of using satellite data for geological mapping. The primary data used for interpretation in this study have been ERTS black and white bands 5 and 7 color transparencies and prints, at scales from 1:1,000,000 to 1:500,000. ERTS data acquired in September and December 1972 were selected for use in this analysis from all ERTS imagery over the area. The major geological features of the region are evident in the imagery and numerous seasonal comparisons have been made.

In general, the rocks of the area are of four major geologic ages: (1) Pre-Cambrian schist, gneiss, and pegmatites; (2) Paleozoic sedimentary units; (3) Tertiary igneous intrusives; and (4) Quarternary alluvium. Contacts between the lithologic units that make up these age groups are evident in the ERTS-1 MSS imagery, and the rock units conform in general to the published geological maps. For example, in the Wasatch Range east of Ogden shown in Figure 2, the Pre-Cambrian Farmington complex (schist and gneiss) area number (1) trending north-south is clearly distinguishable by tonal and textural differences from the

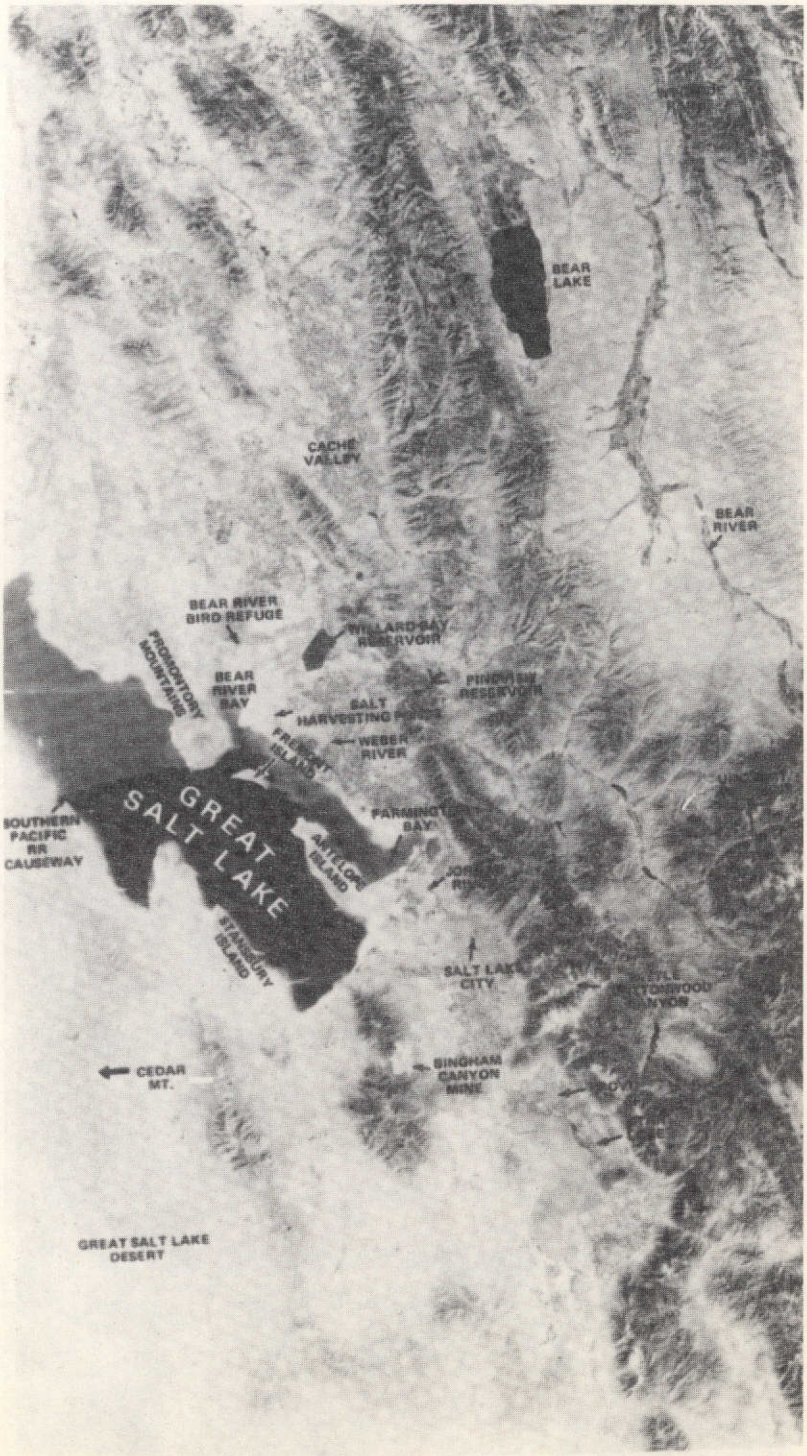


Figure 1. Two image mosaic of the Great Salt Lake area showing the major landform and cultural features. ERTS images 1051 - 17414, 20 of September 12, 1972.

Figure 2. The Great Salt Lake region as viewed from ERTS-1 on September 12, 1972, showing geological formations and structures.

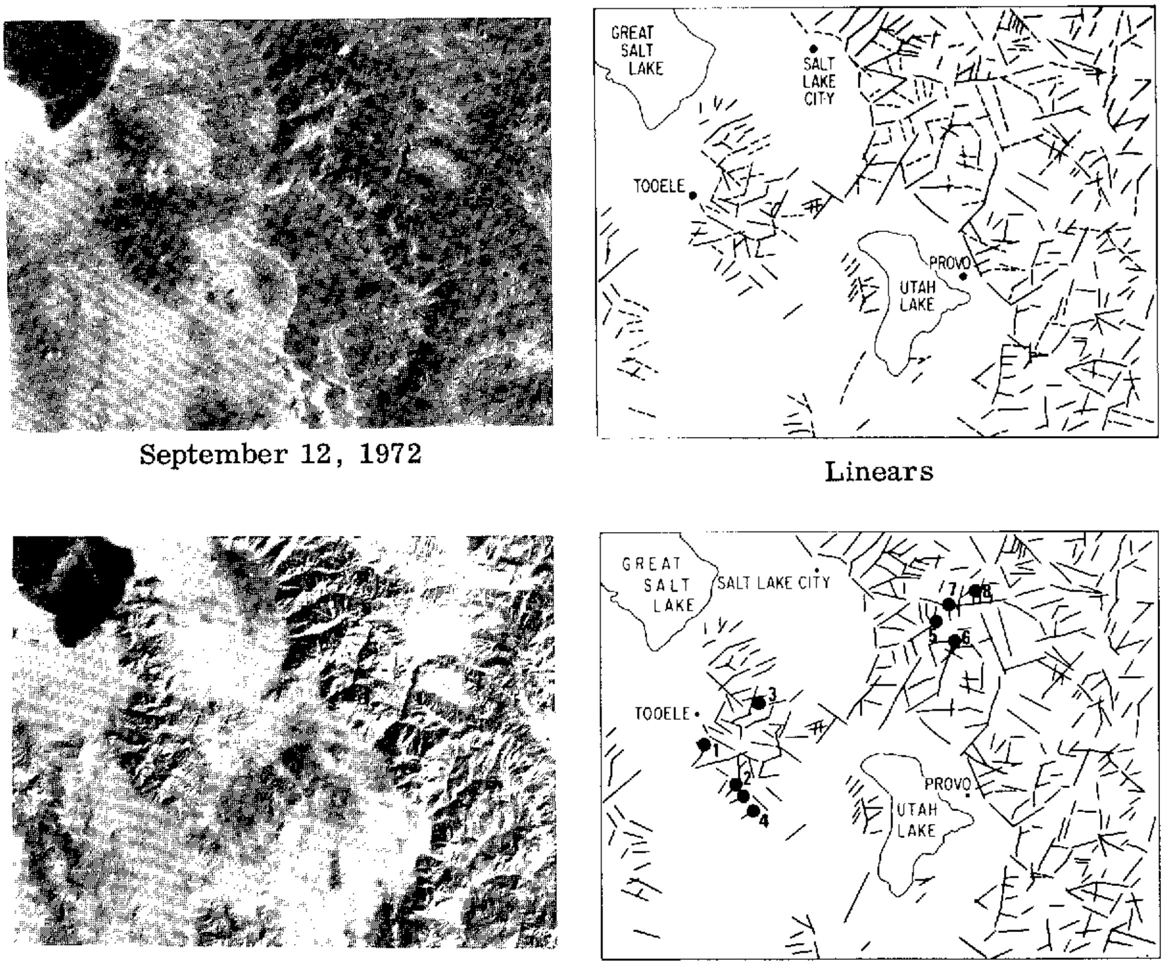
northeast-southwest trending younger Paleozoic sedimentary units immediately to the south (2). The Little Cottonwood stock, a Tertiary intrusive (3), is well defined by a semiradial drainage pattern that tends to accentuate its inherently more massive and monolithic character. The early Tertiary dacite-trachyte lava flows to the south of the Cedar Mountain area are readily evident (4). They are particularly evident in the false-color imagery by the distinct dark grayish blue color of this rock. On the other hand, the Park City (5) (Pennsylvanian) and Oquirrh (6) (Paleozoic) groups that make up the Cedar Mountain structure do not appear significantly different in color imagery, but the Oquirrh group (6) does have a darker tone in the black and white imagery. Finally, the Tertiary intrusive (7) south of Utah Lake has a distinctive darker gray/blue shade in the false color imagery, and on Antelope Island tonal contrasts between the Pre-Cambrian schist and gneiss group (8) to the south, and the Pre-Cambrian units (chiefly quartzite) (9) on the northern third of the island, are quite distinct, particularly on the color images.

STRUCTURAL MAPPING

One of the most useful parameters in structural geology is the analysis of the number, distribution, and magnitude of linear features (lineaments) of a prospective mineralized area. Lineaments can be readily identified on the ERTS imagery. Geologists have long recognized the presence of these straight to slightly curved linear features on the earth's surface that vary in length from hundreds of feet to hundreds of miles. Lineaments may have no direct field expression, but are often revealed as straight valley segments, abrupt changes in valley alignments, and localized vegetation differences. Lineaments are commonly straight, unaffected by topography, and are typically considered to be surface manifestations of vertical to near-vertical zones of subsurface fractures or faults. Many appear to be independent of the regional structural trend. Dr. Mead L. Jensen, an ERTS-1 principal investigator at the University of Utah, is conducting research in the area and has found that the continuity of a lineament "is frequently traceable through ranges and across adjoining sedimentary basins where changes in drainage, erosion pattern, soil cover, or vegetation suggest that the basin sediments are extremely sensitive to underlying structure" (Jensen, 1973a). Lineament analysis provides this important structural data to geologists for local and regional mineral and ground water surveys by providing a new view of the earth's geological structure. Another virtue of ERTS-1 imagery is that it provides in map form this regional tectonic pattern of the earth's crust as expressed at the surface.

The ability to distinguish lineament patterns was greatly enhanced by images obtained after an early December snow fall. The lineaments for a portion of an ERTS scene in the Wasatch Mountains area were plotted using both the September

12 and the December 11, 1972, images to demonstrate the value of repetitive imagery and particularly of snow covered imagery for structural analysis (Figure 3). The results of this comparative lineament interpretation revealed that the combination of snow cover and lower winter solar angle greatly enhanced lineament recognition; in fact, detection of major lineaments increased by approximately 30 percent in the winter scene. It is apparent that this contrasting surface medium, snow cover, increases the tonal contrasts of surface features



September 12, 1972 — Linears

December 11, 1972 — Mining Areas

Figure 3. Comparative linears analysis and correlation of major metallic mining areas of the Wasatch Range area using both snow-free (September) and snow-covered (December) images. The linears analysis includes the September (solid lines) and December (dash lines) while the mining areas contains a composite of both. Mining areas of this region and their mineral resource include; (1) Stockton (Cu), (2) Ophir (Cu, Pb, Zn, Ag), (3) Bingham (Cu, Pb, Zn, Ag), (4) Camp Floyd (Pb, Zn, Ag), (5) Little Cottonwood, (6) American Fork, (7) Big Cottonwood, and (8) Park City contain (Cu, Pb, Zn, Ag).

and hence can be useful in the detection of many of the more subtle bedrock fractures. The low-angle solar illumination present during the winter months further complements the imagery by emphasizing the many topographic expressions not as apparent on imagery acquired with a higher sun angle during other seasons of the year.

A second comparison was then made with the lineaments observed on the imagery versus the faults plotted on a geological map published by the U.S. Geological Survey (1972). The results of this analysis indicate that not only do many of the observed lineaments coincide with the location of known faults, but quite possibly additional but less well expressed faults have been observed for the first time. These apparent faulted areas will require extensive field surveys to verify or deny their existence. In time, however, area geologists will be able to update geological maps based on ERTS image analysis when substantiated by field surveys.

An additional task, to determine which types of faults (thrust, normal, etc.) were more readily distinguishable in the imagery, revealed that while most of the major normal and cross-cutting faults indicated on the map are evident in the imagery (and are mapped as lineaments), many thrust faults that are particularly prominent in the Wasatch Mountains are not detected. For example, in Figure 2 the Willard overthrust fault east of Ogden and west of the Pineview Reservoir area (a) is a specific case where the fault traces are not evident. The normal northwest-southwest trending fault (b) is readily evident. However, a continuation of this fault, or a lineament (c) associated with it, extends to the southeast for at least 20 miles and terminates in the vicinity of Echo Reservoir. Also evident in the imagery are such major faults as the Wasatch fault (d), the Bannock overthrust (e) (north-south fault just east of Bear Lake), the Crawford fault (f) (east of Bear River), the thrust fault (g) on the western edge and the normal fault (h) on the eastern edge of the Cedar Mountains, and the transverse faults (j) east of Willard Bay Reservoir in the Wellsville Mountains. Faults with little or no vertical displacement and parallel to the strike are usually difficult to detect with ERTS imagery, although in some cases changes in drainage patterns or vegetation patterns along an escarpment are indicators of anomalous and perhaps faulted zones. Finally, the lineament map prepared from field data by Cohenour and Thompson (1966) also compares to within 75 per cent of the ERTS lineament map in the Oquirrh Mountains and Wasatch Range.

ECONOMIC APPLICATIONS

One of the most important economic aspects of a geological lineament map is its application to the exploration for new prospective mineral deposits. Given the proper geological setting such as in the Great Salt Lake area, ore deposits are particularly likely to occur along or at intersections of zones of weakness in the crustal material. Fractures, faults and joints represent these zones of weakness, and these zones can be manifested in the ERTS imagery as lineaments. Since many of these important lineament zones are not visible at or near ground level, ERTS data are readily applicable to isolating the potentially significant structural zones.

Within the mining districts of the Great Salt Lake are mineral deposits of several genetic types: disseminated porphyry deposits, contact deposits, replacement deposits, and fissure veins. The major mineralization is associated with a Tertiary quartz monzonite and granitoid stocks intruded as vein alterations into bedded formations along zones of weakness. The primary oxides of lead, zinc, copper, and silver of the Bingham, Stockton, and Ophir mining areas are genetically related to this stock. The faults which control mineral distribution often appear to be visible in the ERTS imagery as lineaments. The relationship between the ERTS imagery and the major mineral districts (with greater than 1000 tons production) in the Great Salt Lake area were analyzed for any geologic correlations (Figure 3). The purpose was to identify possible structural trends of known mineral locations and to determine where further ERTS-identified extensions of fractures within both the Basin and Range and the Wasatch Range provinces may identify additional localities prospective for mineralization. The lineament map of the December 11 scene was used for this task. The first step was to plot the major mining areas, most of which contain ores of copper, zinc, lead, silver and gold, onto the map. Due to the small scale of the imagery, only the most productive mining areas were plotted. These include the Bingham copper mine, the world's largest open pit copper mine, Big and Little Cottonwood, American Fork, Park City, and three other mining areas as shown on Figure 3.

The results of this analysis reveal other areas that may be prospective for mineralization. These were located by extending the major mineralization trends recognized in the areas. Linear trends, along which the known mineral deposits are located, appear to be more extensive than previously mapped. Other lineaments trending in a similar direction, lineaments crossing an existing mineral area, and areas containing a concentration of linears may also be potential mineral areas if they are genetically related to the fractures that control known mineralization. The Bingham area on Figure 3 has trends in a north-northeast-southwest direction, the Big Cottonwood district may extend both east and northwest of its known extent, and both Park City and Big Cottonwood appear to be located on the same linear fracture zone. Similar conclusions can be drawn for lineament extensions along American Fork that appear to connect with Big Cottonwood. The Stockton, Ophir, and Camp Floyd mining areas trend in a northeast-southwest direction, and all may be associated with a lineament zone. Similar analyses in the several mining districts, plus verification of the lineaments, could lead to the location of mineral deposits with economic potential. For example, the new Carr Fork Mine (Mining Engineering, November 1974) in the Oquirrh Mountains east of Tooele in Pine Canyon which will commence in 1979, could have been focused in on by this regional tool. ERTS data can be used in this manner to shorten the time involved in selecting possible mineral sites. This method can also be particularly valuable in remote or poorly mapped areas of the world.

CONCLUSIONS

The synoptic view provided by ERTS imagery has permitted recognition of large geological features, trends, and patterns which are often obscured by detail at the scale of aerial photography or conventional geologic field mapping. These geological features are recognized in the ERTS-1 imagery by a characteristic surface tone, topography, texture, shape, and vegetation patterns. ERTS-1 imagery provides pertinent data for analyzing the geomorphology and geology as demonstrated in the Great Salt Lake area. Geologically, the lineaments, prospective mineral locations and contacts between rock units are distinguishable in the imagery. The identification of previously unidentified lineaments using the snow covered imagery provided complementary data that may lead to the identification of additional mineral deposits.

Within the geologic and climatic terrain of the test site, the use of ERTS-1 MSS imagery has afforded the opportunity to quickly and effectively plot and analyze the various regional geological features of the Salt Lake area more rapidly than would have been possible with conventional photogeologic techniques. The conventional approach would require aerial photography, photo mosaics, airborne geophysical and gravity data along with ground verifications. This method is considerably more costly than a regional photo geologic analysis using the ERTS data. Although no cost-benefit estimates can be made in this particular study, estimates of cost savings of approximately 10 to 1 over conventional reconnaissance techniques has been stated by one geological investigator (Liggett) conducting a similar but more in-depth regional mineral exploration project using ERTS imagery.

These findings are useful to the Great Salt Lake area and can be extended to other areas as well. Further study will provide additional concepts for the use of ERTS-1 data to benefit a greater number of people in the State of Utah, as well as throughout the Rocky Mountain and other areas.

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