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A RECONNAISSANCE SPACE SENSING INVESTIGATION OF CRUSTAL STRUCTURE FOR A STRIP FROM THE EASTERN SIERRA NEVADA TO THE COLORADO PLATEAU

Argus Exploration Company
4120 Birch Street, Suite 108
Newport Beach, California 92660

January 1973
Interim Report for period: June - December 1972

Prepared for
GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland 20771

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16. Abstract

This report summarizes research progress in applications of ERTS-1 MSS imagery in study of Basin-Range tectonics. Field reconnaissance of ERTS image anomalies has resulted in recognition of previously unreported fault zones and regional structural control of volcanic and plutonic activity. NIMBUS, Apollo 9, X-15, U-2 and SLAR imagery are discussed with specific applications, and methods of image enhancement and analysis employed in the research are summarized. Areas studied and methods employed in geologic field work are outlined.

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A RECONNAISSANCE SPACE SENSING INVESTIGATION OF CRUSTAL STRUCTURE FOR A STRIP FROM THE EASTERN SIERRA NEVADA TO THE COLORADO PLATEAU

Ira C. Bechtold
Mark A. Liggett
John F. Childs
Argus Exploration Company
4120 Birch Street, Suite 108
Newport Beach, California 92660

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PREFACE

The following report summarizes research progress for the 7-month period from 15 June to 31 December 1972. This period completes the preliminary phase of an 18-month program on investigation of geologic applications of ERTS-1 satellite imagery. The scope of research is outlined in the following objectives:

1) Analyze and interpret ERTS-1 data for application to study of regional Basin-Range structure.

2) Compare and evaluate applications of selected remote sensing techniques, including NIMBUS, Apollo 9, X-15, and U-2 imagery.

3) Conduct field reconnaissance to support imagery interpretation, and evaluate earth resource applications of ERTS-1 data.

Progress toward these objectives has been favorable. Research approach, methods, and significant results summarized in this report support the following conclusions:

1) Terrain imagery with the scale, resolution and spectral range of the ERTS-1 system provides a synoptic perspective, permitting recognition of structural trends and anomalies not evident in low altitude imagery or recognized on the basis of ground-based mapping.

2) Field reconnaissance guided by ERTS imagery has proved highly efficient, especially when aided by intermediate scale imagery; a variety of sensor types aid efficient interpretation. Critical sites for detailed field mapping or geophysical study have been inferred from ERTS imagery, eliminating extensive detailed mapping conventionally required. This efficiency resulted in significant savings of time and costs for field work.

3) The ability to study structural trends and correlations over broad areas permits synthesis of data and investigation of processes at a scale not before possible. To date, such correlations show promise in understanding regional patterns of volcanism, plutonism, and related alteration, mineralization and geothermal activity. These correlations suggest potential applications to effective regional minerals and energy exploration.

CONTENTS

INTRODUCTION

The following report summarizes progress on an ERTS-1 investigation of orbital space imagery applied to Basin-Range tectonics. This study grew out of several years' research on remote sensing applications to minerals exploration, and study of geologic controls of ore distribution. The cost of finding and developing new ore bodies has increased rapidly in recent years because of the exhaustion of shallow deposits having obvious surface expression. New methods of resource exploration are clearly required to find future reserves. This need is cited in the recommendations of a special committee of the National Academy of Sciences (1969):

> "Especially needed are studies of the genesis, location, and discovery of ore bodies that have no surface manifestation - "blind" ore bodies. New methods must be employed in seeking such ores, and better methods are needed in evaluating and recovering them. Concepts of metallogenic provinces also need to be clarified and extended; for they might help greatly with the intensified geochemical census urged in Recommendation 2. Equally needed is research on the geology, exploration methods, and evaluation and recovery of marine mineral resources. The U.S. Geological Survey and the U.S. Bureau of Mines should be encouraged to expand and improve their programs dealing with such problems."

Our ERTS-1 program emphasizes study of crustal structure for an area of over 70,000 square miles in eastern California, southern Nevada, southwestern Utah, and northwestern Arizona. A map of the study area is shown in Figure 1. The area encompasses diverse geology - from the composite Sierra Nevada batholith, across the complexly block faulted Basin-Range Province, to the relatively undisturbed sedimentary terrain of the Colorado Plateau. The variation in geology recognized across this region follows a pattern transecting large mountain belts on every continent; yet the evolution and structure of these regions are poorly understood. It is within mountain belts such as the Basin-Range Province of North America, that most of the world's mineral resources have been recovered. Better understanding of the regional geology is beginning to have important applications to resource exploration.

Our research progress to date shows that the ERTS satellite provides a unique tool for regional structural investigations. The synoptic view of the earth from space platforms provides a perspective that cannot be satisfactorily achieved from aircraft. This perspective permits recognition of structurally controlled features obscured by detail in smaller fields of view. Such features have been identified as strike slip shear zones, systems of sub-parallel dikes, normal faults, elongate plutons, and concentric or radial faulting associated with domal uplifts or caldera subsidence. The investigation has coordinated ERTS-1 imagery with other sensing techniques. These include NIMBUS, Apollo 9 photography, NASA/USAF X-15 photography, USAF and NASA U-2 photography, and NASA side looking aerial radar. This multi-sensor approach provides comprehensive information, and establishes criteria for evaluation of specific applications of sensing techniques.

An important phase of the research program is ground based reconnaissance and geologic mapping to confirm and evaluate interpretation of the ERTS imagery. Specific attention is placed on correlations of structural patterns to other geologic phenomena, including age, type and distribution of plutonic and volcanic rocks, known mineral deposits, geothermal energy sources, and recorded earthquake epicenters.

Much of the information contained in the ERTS imagery is subtle and indirect. New methods for image enhancement and analysis have been required for geologic interpretation, and detailed field work is necessary to support these interpretations. This learning process is additive. We are constantly adding to our base of information and building toward a synthesis of regional geology. The analysis and interpretation methods being developed in this study will extend application of ERTS-1 data to other areas where structural reconnaissance either by air or on the ground, has not been possible.

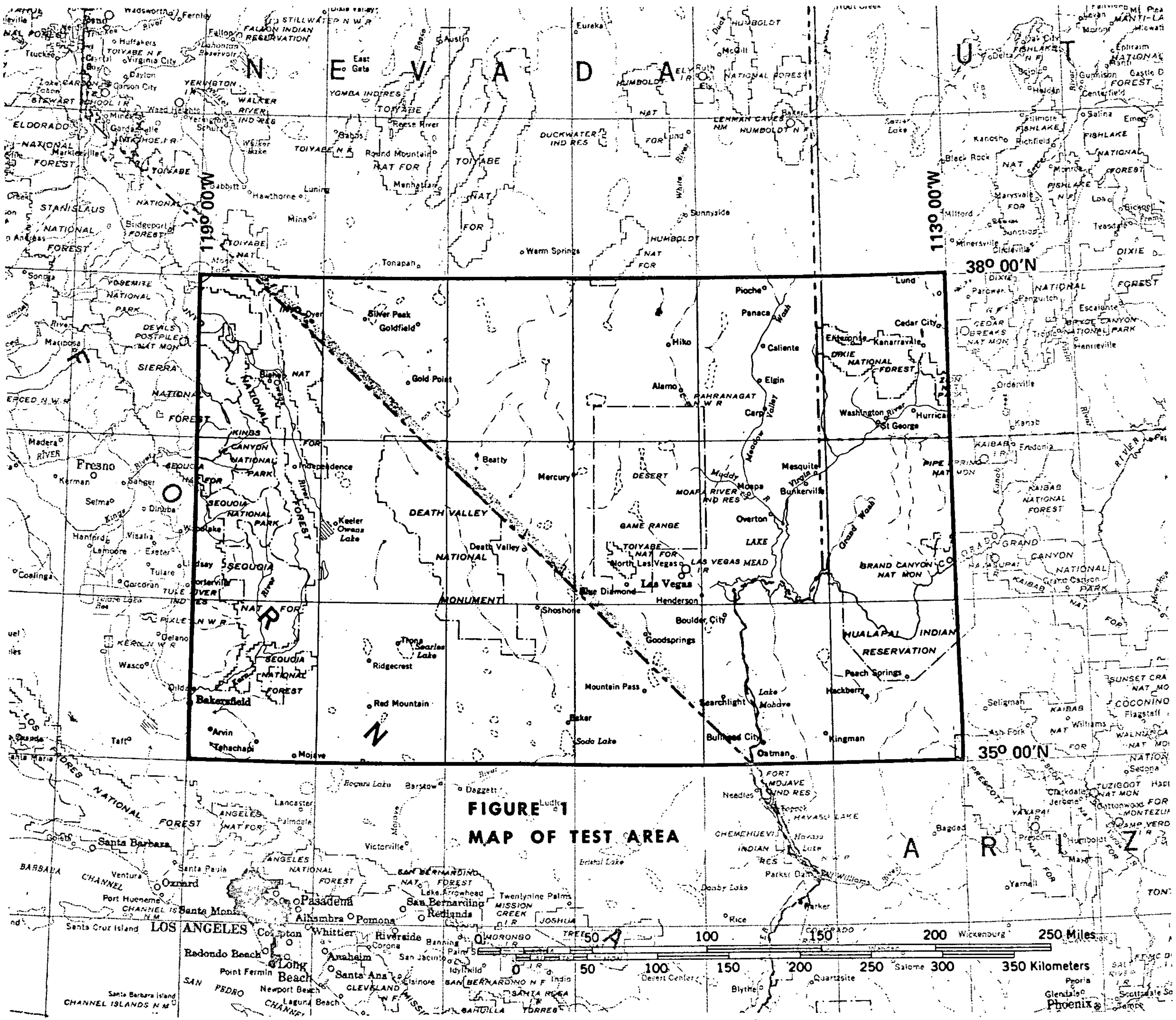

FIGURE 1

MAP OF TEST AREA

A RECONNAISSANCE SPACE SENSING INVESTIGATION OF CRUSTAL STRUCTURE FOR A STRIP FROM THE EASTERN SIERRA NEVADA TO THE COLORADO PLATEAU

Research Support:

Scientific Staff and Technical Personnel:

In conformance with the rate schedule submitted 28 April 1972, as an addendum to the referenced proposal, the following personnel are presently assigned to the ERTS-1 investigation:

Scientific Staff

Ira C. Bechtold, Principal Investigator
Mark A. Liggett, Field Geologist and Co-Investigator
John F. Childs, Field Geologist

Technical Aids

Paul L. McClay, Photographic Technician and Field Assistant
Richard L. Hutchens, Field Assistant

Backup Personnel (covered in G & A)

Secretary
Clerk-typist
Accountant

DATA HANDLING

Efficient organization and handling of ERTS-1 imagery has required design of indexing and filing systems for prints, negatives, transparencies, and processed color composites. In addition, we are analyzing and indexing available subsidiary imagery, including NIMBUS, X-15, NASA and USAF U-2, and NASA SLAR. These indexes form an important reference tool for support of ground-based geologic reconnaissance. Data research and image processing and analysis are discussed in following sections.

A comprehensive data handling and analysis plan was submitted to Goddard Space Flight Center on 4 December 1972. Procedures outlined in this plan are currently in effect.

DATA RESEARCH

Search for available published and unpublished geologic, geophysical and remote sensing data over the ERTS-1 test area is conducted as an integral part of research. This task has included plotting of imagery, and multiple reference indexing of relevant reports and maps. These materials form an excellent working library, covering geologic and geophysical studies in the test area, and applications of remote sensing techniques. Data has been researched through the following sources:

Earth Resources Research Data Facility, NASA-MSC, Houston, Texas
EROS, Sioux Falls, South Dakota
U.S. Geological Survey
Nevada Bureau of Mines, Reno, Nevada
University of Arizona, Tucson, Arizona
ARETS, Office of Arid Lands Studies, University of Arizona, Tucson, Arizona
WESRAC, University of Southern California, Los Angeles, California
Pomona College, Claremont, California
Actron, Inc., Monrovia, California
Edwards Air Force Base, California
NIMBUS Office, Goddard Space Flight Center, Greenbelt, Maryland
Review of current scientific literature, journals and proceedings
Miscellaneous personal communication and correspondence.

SCIENTIFIC COMMUNICATIONS AND CORRESPONDENCE

We have maintained close contact with NASA monitors P. D. Lowman, Jr. and E. W. Crump on all phases of research progress. Meetings were conducted at the time of the ERTS-1 Users Conference held at Goddard Space Flight Center in October 1972. This conference was attended by W. E. Hosken, President, Argus Exploration Company, and M. A. Liggett, Co-Investigator, ERTS-1 project. Additional meetings were held by I. C. Bechtold in January, 1973.

In order to facilitate acquisition and dissemination of information, we have carried on correspondence or discussions with other investigators involved in research relating to the ERTS-1 program. As appropriate, this correspondence has involved exchange of data, analytical and interpretation methods and applications. Correspondents in these categories include:

- Mr. William A. Fisher, U.S. Geological Survey, Washington, D.C.
- Mr. Charles Jennings, California Division of Mines and Geology, Sacramento, California
- Dr. R. E. Anderson, U.S. Geological Survey, Denver, Colorado
- Mr. F. C. Billingsley, Jet Propulsion Laboratory, Pasadena, California
- Mr. Robert Frazer, Jet Propulsion Laboratory, Pasadena, California
- Dr. Abdel-Gawad, North American Rockwell, Thousand Oaks, California
- Mr. Roy A. Bailey, U.S. Geological Survey, Washington, D C.
- Mr. Homer Lasitter, U S. Naval Civil Engineering Laboratory, Port Hueneme, California
- Dr. John DeNoyer, U.S. Geological Survey, Washington, D.C.
- Mr. Charles Robinove, U.S. Geological Survey, Washington, D.C.
- Lt. Commander Wayne T. Hildebrand, U.S. Naval Post Graduate School, Monterey, California
- Dr. O. T. Tobisch, University of California, Santa Cruz, California
- Dr. Chandler Swanberg, U.S. Bureau of Land Management, Boulder City, Nevada
- Dr. Alexis Volborth, Nevada Bureau of Mines, Reno, Nevada
- Mr. Jack Quade, University of Nevada, Reno, Nevada.

NASA DATA REQUESTS

24 July 1972	Request for NASA SLAR data; Earth Resources Research Data Facility, NASA-MSC. Data received.

11 September 1972	Request for duplicate color positives of Gemini and Apollo earth looking photography. Earth Resources Research Facility, NASA-MSC. Data not received.
18 October 1972	Request for ERTS-1 70 mm positive transparencies to replace damaged imagery; c/o E.W. Crump, Code 430, Goddard Space Flight Center. Data received.
26 October 1972	Request for ERTS-1 9.5 inch positive transparencies; NDPF, Goddard Space Flight Center. Portion of data recieved.
20 December 1972	Request for ERTS-1 70mm negative transparencies; NDPF, Goddard Space Flight Center. Data received.

Changes in Standing Order Forms:

A modified Standing Order Form was submitted on 18 October 1972. This modification supersedes the Form of 24 February 1972.

IMAGE PROCESSING AND ENHANCEMENT

Additive color analysis of the ERTS-1 MSS imagery is the primary enhancement tool used in investigation. This analysis is done with a modified Spectral Data Corporation Model 61 multispectral viewer. Efficient use of ERTS-1 data has required development of techniques for producing our own color composite imagery. Additional in-house photographic processing is used for duplication and enhancement of ERTS and subsidiary data. Data products include:

1) Photographic production of ERTS color composite imagery
2) Image scale adjustment for field or research data
3) Line breakdown/edge enhancement processing
4) Exposure controlled printing, such as "dodging and burning"
5) Print toning and variable contrast printing.

These procedures and specific applications to remote sensing imagery are outlined below.

1) ERTS-1 Reproduction

Production of our own ERTS color composite imagery allows complete control of filter combinations and color balance. These composites are produced by photographing off the viewing screen of a 4-channel multi-spectral viewer. A Speed Graphic 4 x 5 camera is used with an f:4.5 152mm Kodak Ektar lens. The image is framed and focused in the ground glass of the camera, light meter readings are taken from the viewing screen, and test exposures made on Polaroid type 52 B&W film (ASA 400) with a Polaroid 4 x 5 Film Holder. Adjustments in exposure are made to compensate for the speed of Kodak Ektachrome Film (Daylight ASA50-64)

Usually, one-half second to one second exposures are required at f:11 to compensate for differing emulsion characteristics. The film is processed by Producers Photo Laboratory, and custom color printing is done by MacGalliard Colorprints, Inc.

2) <u>Photographic Reproduction</u>

Black and white prints of maps, aerial photographs, SLAR and other data are made for scale adjustment or simple duplication. Copy work is done in 4 x 5 and 8 x 10 formats on Kodak Professional Copy Film and printed on standard enlarging papers.

Positive transparencies for SLAR, NIMBUS, and ERTS-1 are reproduced by enlarging or contact printing on Kodak Professional Copy Film.

The internegatives are used when duplicate transparencies are required, as in additive color viewing. The internegatives are again contact printed onto Kodak Professional Copy Film or on orthographic/lithographic film. Most black and white processing is done by Argus personnel.

3) <u>Edge Enhancement</u>

Edge Enhancement or Line Breakdown is used to subdue or remove image gray levels, enhancing the "edges" of adjacent areas having tonal contrast. In satellite and aerial imagery, this process has the effect of enhancing linear trends.

A positive image and an identical negative image, usually 8 x 10 in size, are "sandwiched" together between glass plates. Perfect registration of the "sandwich" isolates image line content. Controlled misregistration may be used to bias directional enhancement. The "sandwich" may be contact printed on standard printing paper, although long exposures are generally required.

4) <u>Dodging and Burning</u>

Photographic imagery frequently requires special printing procedures to recover detail which would otherwise be lost in areas of extreme high or low gray scale density. Two techniques used are known as "dodging" and "burning".

Dodging is used when portions of a negative are light and would result in an overly dark positive print. In dodging, a negative is projected with an enlarger onto a sheet of photographic paper. The light portion of the negative image is masked for part of the exposure time, regulating the amount of light exposing the print.

Burning is a similar procedure. A dark portion of a negative is allowed longer exposure on the photographic paper; using a mask to cover light portions of the projected image. These procedures have been used on ERTS, X-15 and U-2 imagery in which valuable detail was otherwise obscured.

5) <u>Variable Contrast and Toning Procedures</u>

Variable contrast printing and print toning are used on a variety of image data. Variable contrast printing with exposure control procedures discussed above permit extraction of maximum image detail. Sepia toned prints have proved valuable in use with black-line image overlays. Standard or variable contrast photographic papers are toned using an additional chemical bath during development.

SUMMARY OF INVESTIGATION

Imagery Comparison and Evaluation

A variety of remote sensing data has been used in conjunction with ERTS-1 data for geologic analysis and interpretation. Initial coverage of the test site with ERTS-1 MSS imagery permits preliminary comparison of ERTS and other orbital and aerial remote sensing data. Preliminary comparisons are summarized as follows:

NIMBUS

NIMBUS I imagery recorded in September, 1964 is available over much of the test area. Because of an extremely eliptical orbit, NIMBUS I was able to acquire the first low altitude space imagery available over much of the earth. Although resolution is far inferior to ERTS or Apollo, the broad synoptic coverage of the NIMBUS imagery has proved useful in study of regional structural patterns, and is currently being used to augment ERTS-1 analysis and interpretation.

Apollo 9 Photography

Apollo 9 photographs covering a portion of the test area were taken in March, 1969 - frames AS9-20-3134, 3135 and 3136. In spite of oblique look angle, this imagery contains information not found in aerial photography. Apollo 9 photography was the basis for the first four months of our ERTS-1 investigation. Apollo 9 photographs used in our studies were printed using controlled exposure and color balance. Because of oblique look angle, scale and resolution are variable from the far to the near portions of the photographs. At middle range, however, scale and effective resolution are comparable to the ERTS-1 imagery. The geometric distortion caused by the oblique look angle can be largely compensated in transferring image anomalies to base maps. However, in several instances, this distortion has resulted in incorrect interpretation of terrain alignments.

X-15 Photography

Portions of the test area are covered by earth-looking photographs taken from the experimental USAF/NASA X-15 spacecraft on 9 October 1962. Data presently available to us include 5-inch color infrared and black and white photography. This photography was taken from altitudes between 20 and 50 miles, and provides a scale intermediate between U-2 and satellite imagery. The X-15 photography has proved useful in several areas of interest in which U-2 was unavailable. Arrangements are being made with NASA Research Center, Edwards AFB, to research additional X-15 imagery available through USAF archives.

U-2 Photography

USAF/USGS and NASA U-2 imagery is currently being used in formats of 9.5-inch panchromatic black and white, 9.5-inch color infrared, 70mm color infrared, and 70mm multispectral photography. The USAF/USGS 9.5-inch black and white photography is available through the USGS for several flightlines over portions of California and southern Nevada. Photographs were taken in vertical, right oblique and left oblique modes. A limited quantity of 9.5-inch color infrared U-2 photography over the Lake Mead region of our test site was obtained from NASA-MSC. The resolution of this photography is exceptional, and has provided an important tool for studying in greater detail, geologic features recognized on the basis of the ERTS-1 imagery. Although duplication of this color imagery is costly, it has provided a valuable complement for regional structural analysis and guiding efficient field reconnaissance operations.

NASA U-2 multispectral imagery flown over portions of the test site has been generally poor. Scale variation between bands has introduced severe registration problems hindering additive color analysis.

Side Looking Radar

SLAR imagery over a portion of the test area was flown by NASA in November, 1965, using the Westinghouse APQ-97 system (mission 103). One traverse covers a strip north of Lake Mead, Nevada, a region of general interest and an area of existing U-2 photographic coverage. Like U-2 photography, SLAR has proved of value in structural interpretation at a scale intermediate between ERTS and ground-based reconnaissance. Enhancement of subtle structure is frequently superior to U-2 imagery, and SLAR is not degraded by poor haze and cloud conditions, or variation in sun angle. Although orientation of structural trends may be biased by SLAR look direction, structural anomalies are easily cross checked in other imagery or by field reconnaissance. Analysis of the SLAR imagery has included false color composite analysis of the cross polarized images.

ERTS-1 MSS scale, resolution and spectral range is providing information not available in any other remote sensing coverage over the test area. The primary advantage of the ERTS imagery is the synoptic perspective which permits recognition of alignment of terrain features, surface coloring, vegetation abundance, and other indirect evidence for structural interpretation. ERTS image resolution appears to be adequate in this application, and the spectral range of the 4 MSS bands has produced excellent color composite imagery. Additional spectral bands, however, might permit broader application for such studies as rock type discrimination. Insufficient data has been received to evaluate analysis of seasonal variation in the desert and mountain vegetation. However, enhancement of topographic features by light snow cover has been observed in the Sierra Nevada.

To date, the major problems in use of ERTS-1 imagery have risen from long delays in receipt of requested imagery, and inconsistent quality of NDPF data products.

Summary of Field Reconnaissance

Geologic field work to date has concentrated in four regions within the test area. From west to east, these are:

1) Sierra Nevada Mountains to Avawatz Mountains, California
2) Kingston Range - Ivanpah Mountains to Frenchman Mountains, California-Nevada
3) Muddy Mountains - Black Mountains - Virgin Mountains south to Hualapai Mountains, Nevada-Arizona
4) General reconnaissance.

1) Work in the western part of the study area has concentrated on the relationship of volcanism to large scale structural features recognized in satellite imagery. The Long Valley caldera near Bishop, California was studied and a number of structures related to caldera collapse were identified. Large faults such as the Garlock Fault and the Calico and Lockhart Faults in the Mojave Desert have been examined. The Garlock appears to have a number of northwest trending subsidiary faults at its western-most extension, and may extend into the Alexander Hills at its eastern end.

   Smaller faults (20-30 miles long) in the Argus Range, White Mountains and Inyo Range appear to be related to major northwest trending shear zones. These faults are associated with rhyolitic volcanic centers.

2) Field work in the central part of the test area has been predominantly in the Ivanpah, Clark, Spring, Mesquite, Kingston, Nopah, and Resting Spring Mountains in an effort to define a new right lateral strike slip fault zone recognized first on ERTS imagery. We have also worked in the Specter Range and the Funeral Mountains in order to compare deformational styles in previously recognized shear zones. This field mapping has been based on satellite imagery with more detailed information derived from U-2 and X-15 photography. We have been aided by low altitude fixed wing reconnaissance, during which hand held color

photography was taken. The combination of space and near space imagery, low altitude photography and detailed field work proved to be extremely efficient in gaining information for a large area in a minimum of time.

3) Field work in the southeast portion of our test area has centered on a 75-mile long zone of NNW extensional faults, dike swarms and epizonal plutons along the Colorado River south of Lake Mead.

This extensional region was recognized during imagery analysis and field work in the Newberry, Eldorado, and Black Mountains. Faulting and dike intrustion in this area may be continuing as indicated by numerous faults and some dikes cutting alluvium. ERTS imagery was used successfully in identifying faults in alluvium over a large area.

Field work north of the extensional area has indicated an abrupt change in volcanic rocks and tectonic style in the Muddy, Virgin and River Mountain Ranges and a possible extension of the Las Vegas Shear Zone in this area. The south end of the extensional zone appears to lie in the region of the Hualapai, Artillery, Rawhide, Buckskin, Harcuvar and Harquahala Mountains of Arizona. This southern termination appears in the ERTS imagery to be a major transverse structure and reconnaissance field work indicates it may be a fault zone similar to the Las Vegas Shear Zone.

Field work has been done in the Highland Range, Nevada where basaltic volcanism appears to be associated with fault zones. Fault zones along the western front of the Cerbat Mountains, Arizona, have been examined.

4) Four reconnaissance trips of two days each were conducted from Phoenix, Arizona to Parker Dam, Arizona/California; from Los Angeles to Death Valley to Las Vegas; from Las Vegas to Tonopah, Nevada to Pioche, Nevada to Las Vegas; and from Los Angeles to Bishop, California. The purpose of these trips was to familiarize the newer members of our staff with the test area and to spot check large scale features recognized on ERTS imagery. Some of these features are discussed below.

A large shear zone north of Phoenix, Arizona mapped in part as the Shylock Fault by C. A. Anderson (1965) was examined with the intent of recognizing similar features elsewhere. Another fault zone was identified northwest of Phoenix in the Valley of the Big Sandy River.

Rhyolitic volcanics in the Resting Spring Range, California were examined and their deformation along a northwest trending fault zone was recognized. A fault zone and associated volcanic rocks between Goldfield, Nevada and Beatty, Nevada was identified on ERTS imagery and field checked. Previously unrecognized rhyolitic volcanic centers and possible strike slip fault zones south and southwest of Caliente, Nevada were picked out on

ERTS imagery and field checked.

Arrangements to conduct field work in the AEC Nevada test site at Mercury, Nevada and Naval Weapons Test Center at Ridgecrest, California have been made.

Research in Progress

The following abstracts summarize investigations currently in progress. For both studies, additional imagery analysis, literature review and geologic field work will be required before final reports can be completed:

Preliminary Investigation of Rock Type Discrimination Near Wrightwood, California (ABS)

A large alluvial fan, 18 miles in axial dimension, near Wrightwood, California shows a pronounced dark anomaly in Apollo photography and ERTS multispectral imagery. Preliminary field work indicates that the dark coloring of the fan is caused by a sharp change in alluvial rock type from the surrounding alluvium onto the fan. The fan alluvium is composed predominantly of Pelona schist, while the surrounding alluvium is mostly granitic material. Petrography on schist boulders from the fan shows them to be high in Fe and Ca rich minerals such as epidote, tremolite-actinolite and chlorite. These minerals are known to have reflectance minimal in the near infrared portion of the spectrum and it is the near infrared bands of ERTS imagery that show the highest contrast difference between fan and surrounding alluvium.

Our reconnaissance study has indicated an increase in abundance of California Juniper and Joshua Trees on the fan, compared with surrounding alluvium. We suspect that this vegetation change is related to rock type. Vegetation on the fan is generally scarce and the effects of ground water and vegetation in producing the image anomaly are thought to be minimal. More field work is planned.

Structural Lineaments in the Eastern Sierra Nevada, California (ABS)

Several large linear anomalies have been recognized in ERTS-1 MSS false color composites of the eastern Sierra Nevada, California. We interpret these features as major fault zones generally parallel to and west of the eastern escarpment of the Sierra Nevada Mountains of California. Recently, Morgan and Rankin (1972) have published on one of these features which they interpreted as a fault zone separating rocks of Paleozoic and Mesozoic age.

Their interpretation is based on mapping in the Mt. Morrison roof pendant, from which the fault zone was extrapolated approximately 50 miles northward and 30 miles southward. Morgan suggests that the fault zone he described may be distorted by intrusion of some of the Sierran granitic plutons. This distortion may account for the variation in appearance and trend of these faults in the ERTS imagery. Another factor affecting appearance of the fault zones in space imagery may be the degree of similarity of the rocks on opposite sides of the fault zone. Further investigations are planned of these anomalous features using ERTS, Apollo 9, U-2 and available X-15 imagery to guide field reconnaissance.

References:

Morgan, B.A., Rankin, D.W., 1972. Major Structural Break between Paleozoic and Mesozoic Rocks in the Eastern Sierra Nevada, California: Geol. Soc. America Bull., v.83, p. 3739-3744

Additional imagery analysis and field reconnaissance are planned in the following areas:

1) We have recognized and are field checking new faults in the San Gabriel and Santa Monica Mountains near Los Angeles, and are corresponding with geologists familiar with the specific areas.

2) A large wedge shaped feature in alluvium east of Barstow, California has been recognized in ERTS imagery and field work is planned.

3) Field work will be conducted along the Garlock Fault zone in southern California. We have spot checked this feature and are now researching the literature. Dike swarms and faults in the ranges north and south of the Garlock Fault will also be investigated.

4) Field work is planned in dike swarms in the northern Black Mountains of Arizona, especially where camptonite dikes cutting alluvium might be expected.

5) Preliminary field work, literature research and imagery analysis have been done on a major transverse structure extending from northwest of Phoenix, Arizona WNW toward Parker, Arizona. More field work is planned in order to understand the relationship of this transverse structure and associated volcanism to a zone of crustal extension along the Colorado River south of Lake Mead.

6) Preliminary imagery analysis and field work between Beatty and Tonopah, Nevada have outlined a structural zone which will be investigated further. More field work is planned in the vicinity of Cane Springs Wash and south west of Caliente in Lincoln County, Nevada.

Significant Results

Two separate reports of investigation have been compiled and are being submitted under separate cover. Significant results are noted in the abstracts accompanying these reports:

> Evidence of a Major Fault Zone along the California-Nevada State Line, 35°30' - 36°30' N. Latitude
>
> Remote Sensing Reconnaissance of Faulting in Alluvium, Lake Mead to Lake Havasu, California, Nevada and Arizona.

The following abstracts describe two technical developments of our research we believe may have applications by other investigators. For this reason we include them in this section.

PSEUDO-RELIEF ENHANCEMENT OF COLOR IMAGERY (ABS)

I.C. Bechtold, M.A. Liggett, & J.F. Childs
Argus Exploration Company, 4120 Birch St./Suite 108
Newport Beach, California 92660, 18 Jan 1973

A planoconvex Fresnel lens can be used for pseudo-relief enhancement of composite ERTS-1 imagery. The three-dimensional perception may be due in part to chromatic aberation of the lens which causes separation of focal planes for different colors in the imagery. Because focal length is inversely proportional to wave length, red areas appear raised above yellow, green and blue areas respectively. Magnification by the lens may have an additional psychological effect on perception.

Best results are obtained viewing rear-projected color composites with red hues assigned to areas of highest topography. The projection screen is viewed from a distance of 10 to 20 inches with the Fresnel lens held 2 to 6 inches from the screen. The technique may be applied to any color imagery.

A similar pseudo-relief effect is described by McLeroy and Vaughan (1970) using a more complex optical system for viewing small color transparencies. Short (1972) discussed a related effect achieved by viewing a pair of identical ERTS images in a standard stereoscopic viewer.

A variety of inexpensive Fresnel lenses are available through Edmund Scientific Company, Barrington, New Jersey. The lens described here is an 11-inch square Fresnel lens, focal length 16 inches, Stock No. 70533.

References:

McLeroy, D.F. and Vaughan, O.H., Jr. 1970. Enhancement and Application of Space Photographs for Earth Resources Studies with Special Emphasis on Regional Geologic Investigations; NASA-ASEE Summer Faculty Fellowship, Marshall Space Flight Center, Grant No. NGT-01-003-45.

Short, N.M., (discussion): ERTS-1 Users Conference, October, 1972, NASA-Goddard Space Flight Center, Greenbelt, Maryland.

Key Words:

- Image enhancement
- Multispectral viewing
- ERTS-1 MSS Imagery

MINERAL OCCURENCE AND AGE DATE MAPS (ABS)

I. C. Bechtold and Hutchens, R. L.
Argus Exploration Company, 4120 Birch St./Suite 108
Newport Beach, California 92660 - 19 Jan 1973

Two sets of reference maps have been compiled showing the distribution of known mineral deposits and radiometric age determinations in the region between 35°-38° N Latitude and 113° - 119° W Longitude; eastern California, southern Nevada, southwestern Utah, and northwestern Arizona. Both map sets are compiled on Army Map Service 1:250,000 scale topographic quadrangles.

Mineral Occurrence Maps:

Color coded symbols are used to show the locations and types of mineralization cited. The following ore classifications are used:

lead-zinc-silver
gold
copper-molybdenum
tungsten
iron
uranium-thorium
fluorite
mercury
rare earths

Each occurrence carries a reference to the source used in compilation. No attempt has been made to indicate quantity of ore recovered or reserves for individual deposits.

Age Determination Maps:

Map symbols indicate sites of available radiometric age determinations. Each age determination is color coded to show the general rock type as follows:

granites
felsic dikes
mafic dikes
felsic volcanics
mafic volcanics
metamorphic rocks
mylonites
sedimentary rocks

Each date is referenced to a bibliography of reference sources used in compilation. Additions are being made to both compilations as new sources of data become available. Copies, in the form of 4 x 5 inch color transparencies are available to other investigators for the cost of reproduction.

Key Words:
- Minerals exploration
- Age determinations
- Basin-Range province

Authorized Reports and Presentations

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NASA REPORTS

Technical Reports:

8 September 1972
Type I Progress Report: 15 June through 31 December 1972
Ref: ERTS-1 Contract NAS5-21809

9 November 1972
Type I Progress Report, 1 Sept. through 31 Oct., 1972
Reference: ERTS-1 Contract NAS5-21809

4 December 1972

Data Analysis Plan

Ref: ERTS-1 Contract NAS5-21809

7 December 1972

Questionnaire to ERTS-1 Investigators: 16 November 1972

Ref: 1. Product Quality - System
Performance Parameters and output product quality

2. User Services - communication aids

3. Data quantities-timeliness - logistics

Financial Reports:

4 December 1972

Financial reporting of Government-owned/contractor held property other than spare hardware (Nov. 1972 NPR B.311)

NASA Form 1018

Ref: NASA ERTS-1 Contract NAS5-21809

July 31, 1972 - 31 days - June 15, July 31, 1972

Monthly Contractor Financial Management Report

Form 533M

Report for Quarter beginning July 1, 1972

Quarterly Contractor Financial Management Report,

Form 533Q

August 31, 1972 - 23 days

Monthly Contractor Financial Management Report

Form 533M

Report for quarter beginning October 1, 1972

Quarterly Contractor Financial Management Report

Form 533Q

September 30, 1972 - 20 days

Monthly Contractor Financial Management Report

Form 533M

October 31, 1972 - 22 days

Monthly Contractor Financial Management Report

Form 533M

November 30, 1972 - 20 days

Monthly Contractor Financial Management Report

Form 533M

CONCLUSIONS

The ERTS-1 MSS sensor is providing data of exceptional quality and utility in applications to regional structural geology. The value of this data is threefold, as follows:

1) The scale, effective resolution and spectral range of the ERTS-1 MSS provides synoptic perspective, permitting recognition of major structural trends or anomalies not evident in aerial imagery or in ground-based geologic mapping.

2) Field reconnaissance guided by the ERTS imagery is highly efficient; especially when aided by photography or other imagery of intermediate scale. Critical sites for detailed mapping or geophysical study of structural anomalies have been inferred from the ERTS data, eliminating extensive field work required in conventional quadrangle mapping.

3) The ability to study regional structural trends or correlations of geologic features visible in the ERTS imagery permits synthesis of data, and investigation of geologic processes at a scale not before possible. To date, such correlations show promise in understanding regional structural controls of volcanism, plutonism, and related alteration, mineralization and geothermal activity. These correlations suggest potential applications to effective regional minerals and geothermal energy exploration.

Additive color analysis of MSS imagery has on occasion enhanced the surface coloration of large areas of exposed rock. In addition, certain rock types can be inferred by analysis of gross weathering or errosional topography controlled by internal fabric, mineralogy or jointing characteristics. However, these characteristics are easily masked by vegetation, soil or alluvium. In general, detailed rock type discrimination with the ERTS data has been unsuccessful. Resolution and scale of ERTS imagery limit structural analysis of features having high local variability. These include such features as foliation, layering, folding, or jointing. Thrust faults, some with extensive areal exposure, have been difficult to distinguish. This is largely due to the irregular outcrop patterns formed by the intersection of topography with gently dipping planar surfaces. Aerial imagery, including SLAR, has had little advantage in this application.

It must be stressed that evaluation of ERTS-1 should not be based on comparisons of ERTS data with conventional geologic mapping. We must learn to recognize the new geologic phenomena visible for the first time in satellite imagery. J. M. Harrison (1963), discussing the nature and significance of geologic maps, has said:

"A geological map may be defined as one on which are shown the distribution and structural relations of rocks. As such, it is the product of research undertaken in the geologists' principal laboratory, the earth itself. And because it describes and interprets the earth, the map must, in the last analysis, be the source of geological theory."

Geologic maps are compilations of interpretation; while satellite images are compilations of fact which we must learn to interpret. In a sense, they are geologic maps, unbiased by the hand of a map maker. Recording and interpretation of these maps show promise in being a master source of geological theory.

RECOMMENDATIONS

Recommendations based on research completed to date must be tentative. Only partial seasonal coverage by the ERTS-1 MSS has been achieved and many potential applications have not been tested. For this reason, we wish to keep the following recommendations general and directed toward applications to future ERTS programs.

Data Products and User Services

It is critical that NASA provides a consistently high level of quality in data reproduction. Speed in data processing and distribution is important for support of efficient research activities. This is particularly true of studies relating to seasonal variation and other transient phenomena.

NASA should provide comprehensive indexes of available subsidiary remote sensing imagery, and facilitate exchange of data between investigators.

Spectral Range of ERTS Sensors

Spectral range extending into the thermal infrared would be a significant complement to the present MSS configuration. In addition, narrow band multispectral imaging could extend color and infrared discrimination capability for applications to rock type identification, and forestry or agricultural studies.

Stereoscopic coverage

Stereoscopic imagery would have a clear advantage in regional terrain analysis. Adequate forward framing overlap should be considered in RBV sensors of future ERTS missions.

Variable Sun Angle Illumination

ERTS applications to terrain analysis could be improved by variation in angle of solar illumination. This information would complement stereoscopic coverage.

Variable Image Scale and Resolution

Our research applications of ERTS imagery have benefited from use of intermediate scale imagery from near space, X-15 and high altitude U-2 coverage. Satellite imagery having fields of view both larger and smaller than ERTS-1 should be investigated.

Multi-Sensor Space Platforms

Multi-sensor data has proved of value in efficient analysis and interpretation of ERTS-1 imagery. The SKYLAB-EREP program will test a variety of new sensing techniques. Beyond this, space platforms employing such techniques as side looking radar, high resolution scanning spectro-radiometers, and laser imaging systems should be investigated.

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