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CR-133141

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

Argus Exploration Company
555 South Flower Street - Suite 3670
Los Angeles, California 90071

July 1973
Interim Report for period: 1 January - 30 June 1973

Prepared for
GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland 20771

E73-10774) A RECONNAISSANCE SPACE SENSING INVESTIGATION OF CRUSTAL STRUCTURE FOR A STRIP FROM THE EASTERN SIERRA NEVADA TO (Argus Exploration Co., Los Angeles, Calif.) 45 p HC $4.25 CSCL 08E G3/13 N73-27250 Unclas 00774

Approved by

W. E. Hosken
President

45 pp.

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle A Reconnaissance Space Sensing Investigation of Crustal Structure for a Strip from the Eastern Sierra Nevada to the Colorado Plateau		5. Report Date July 1973 6. Performing Organization Code
7. Author(s) Mark A. Liggett and John F. Childs		8. Performing Organization Report No.
9. Performing Organization Name and Address Argus Exploration Company 555 South Flower Street - Suite 3670 Los Angeles, California 90071		10. Work Unit No. 11. Contract or Grant No. NAS5-21809
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Goddard Space Flight Center Greenbelt, Maryland 20771		13. Type of Report and Period Covered Type II Progress Report 1 January - 30 June 1973 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

This report summarizes research progress in applications of ERTS-1 MSS imagery to 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. Field areas studied and methods employed in geologic field work are outlined.

17. Key Words (Selected by Author(s)) Tectonics Geology Basin-Range Province ERTS-1 Satellite imagery		18. Distribution Statement	
19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*

PREFACE

The following report summarizes research conducted in geologic applications of remote sensing data from the Earth Resources Technology Satellite (ERTS-1). A six month period from 1 January to 30 June 1973 is covered in this report. The preliminary phase of investigation from 15 June to 31 December 1972 is summarized in the Argus Exploration Company Interim Report of 19 January 1973.

The following objectives outline the scope of this investigation:

A. Analysis, interpretation and evaluation of ERTS-1 data for application to the study of regional crustal structure and related geologic phenomena.

B. Comparison and evaluation of selected available remote sensing techniques, including Apollo-9, X-15 and U-2 photography, SLAR, and multispectral imagery.

C. Conducting of field investigations to support imagery interpretation and to evaluate potential applications to natural resource exploration and management.

Results of investigation summarized in this report support the following conclusions:

1. The scale, resolution and spectral range of the ERTS-1 MSS imagery permits interpretation of subtle structural alignments over larger areas than feasible with conventional aerial imagery or geologic mapping. The synoptic nature of the ERTS data provides an effective filter for recognition of regional geologic features, trends or patterns obscured by detail at the scale of an outcrop or quadrangle map.

2. The ability to interpret regional structural patterns and geologic correlations from ERTS-1 data establishes a base for integration and synthesis of independent data, previously possible only with map compilations. Results of our research illustrate the value of this approach for understanding interrelationships of regional structure and volcanism, plutonism and related alteration, mineralization, and geothermal activity.

3. Field reconnaissance guided by ERTS-1 imagery is highly efficient, especially when aided by subsidiary remote sensing data of intermediate scale and resolution. Although anomalies in the ERTS imagery frequently have vague expression in the field, critical sites for detailed mapping or geophysical study can be determined, eliminating extensive ground-based reconnaissance required in conventional quadrangle mapping. This speed and efficiency are highly important in applications to mineral exploration.

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I. INTRODUCTION

The following report summarizes results of research on geologic applications of data from the Earth Resources Technology Satellite (ERTS-1). This investigation was conceived to test the application of orbital remote sensing to regional structural geology and related geothermal energy and mineral resources. It is based on a background in remote sensing applications to mineral exploration, and study of tectonic controls of ore genesis and distribution.

The area chosen for investigation occupies an area of over 70,000 square miles in the southern Basin-Range Province of eastern California, southern Nevada, southwestern Utah, and northwestern Arizona. A map of the test site is shown in Figure 1. The site was chosen for its span of diverse geology; from the Sierra Nevada batholith, across the complex block faulted Basin-Range Province, to the relatively undisturbed sedimentary terrain of the Colorado Plateau. The variation in geology across this region is similar to mountain belts of several other continents. Although it is within these mountain belts that most of the world's mineral resources have been recovered, their tectonic evolution is poorly understood. Better understanding of regional geology will have an important role in exploration for future resources.

The synoptic view of earth from space platforms provides a perspective not achieved from aircraft based sensors or conventional ground based geologic mapping. This perspective permits the recognition and mapping of structural features, and secondary, structurally controlled phenomena obscured by details in smaller fields of view.

In this investigation, analysis and interpretation of ERTS-1 imagery is being coordinated with a variety of other remote sensing data. These include NIMBUS infrared imagery, Apollo-9 photography, NASA-USAF X-15 photography, NASA and USAF U-2 photography, and Side Looking Aerial Radar (SLAR). This comparison of data over key test sites will provide a basis for evaluating the applications of different sensing techniques.

Much of the geologic information contained in the ERTS-1 data must be interpreted indirectly with the aid of image enhancement and analysis tools. We are investigating and experimenting with a variety of photographic, optical and electronic enhancement techniques.

Analysis and interpretation of the ERTS-1 and subsidiary remote sensing data is supported by an extensive program of geologic field reconnaissance and geologic mapping. This ground truth permits identification of geologic causes of data anomalies, and provides a basis for refinement of image interpretation techniques. Specific attention is placed on correlations of tectonic patterns to other geologic phenomena, including ages, types and distribution of plutonic and volcanic centers, known mineral deposits, known geothermal sources and recorded earthquake epicenters.

This progress report summarizes progress in each of the many disciplines coordinated in the overall investigation. We are confident from research results that analysis and interpretation methods being developed in this investigation will extend application of ERTS-1 data to other areas in the world where regional structural reconnaissance, either by air or on the ground, has not been possible.

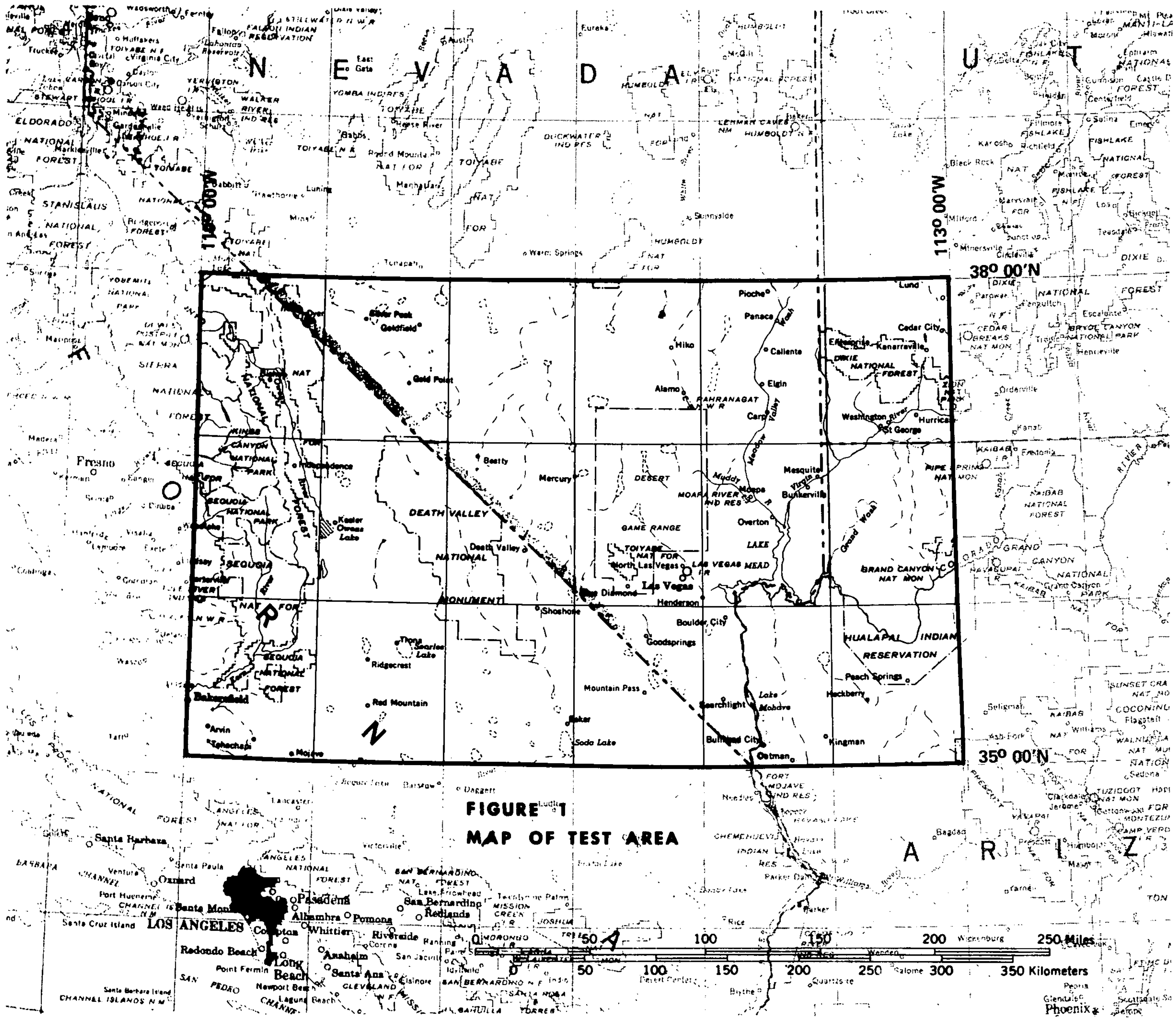

FIGURE 1

MAP OF TEST AREA

II. RESEARCH SUPPORT

A. Scientific Staff and Technical Personnel:

In conformance with the rate schedule submitted 28 April 1972, the following personnel were assigned during the six month period of this report:

Scientific Staff

Ira C. Bechtold, Principal Investigator

Mark A. Liggett, Field Geologist and Co-Investigator

John F. Childs, Field Geologist

Technical Aids

Richard L. Hutchens, Technician and Field Assistant

Jack W. Barth, Field Assistant

Paul L. McClay, Photographic Technician (part-time)

Backup Personnel (covered in G & A)

Secretary

Clerk-typist

Accountant

B. Data Handling

Organization and handling of NASA data has required design of indexing and filing systems for ERTS-1 prints, negatives, transparencies, and color composites, and subsidiary imagery including NIMBUS, X-15, NASA and USAF U-2 photography, and SLAR. These indexes form an important reference tool for support of ground-based geologic reconnaissance and data interpretation. A comprehensive data handling and analysis plan was submitted to

Goddard Space Flight Center on 4 December 1972. Procedures outlined in this plan were accepted on 16 January 1973 and are currently in effect.

C. 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-JSC, Houston, Texas
EROS, Sioux Falls, South Dakota
U. S. Geological Survey, Menlo Park, California
Nevada Bureau of Mines, Reno, Nevada
University of Arizona, Tucson, Arizona
Office of Arid Lands Studies, University of Arizona, Tucson, Arizona
WESRAC, University of Southern California, Los Angeles, California
University of 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.

D. Scientific Communications and Correspondence

Communication has been maintained on scientific progress and project administration with our principal NASA contract monitors.

Dr. Paul D. Lowman, Jr., Scientific Monitor
Mr. Edward W. Crump, Technical Monitor
Mr. Douglas Frye, Contract Specialist

In order to facilitate acquisition and dissemination of information, we have conducted correspondence or discussions with other investigators 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:

Dr. William Pratt, Department of Engineering, University of Southern California

Mr. Clinton Johnson, NASA Technology Utilization Officer, Edwards Air Force Base, California

Mr. Phil Lohman, Hughes Aircraft Company, Culver City, California

Mr. H. R. Gross, McDonnell Douglas Corp., Huntington Beach, California

Dr. Floyd Sabins, Chevron Research Corp., La Habra, California

Dr. Richard Tibby, Director, Catalina Marine Science Center, University of Southern California, Avalon, California

Mr. Robert Fox, Consulting Engineering Geologist, Fullerton, California

Dr. David Cummings, Department of Geology, Occidental College, Los Angeles, California

Dr. Lou A. Fernandez, Louisiana State University, New Orleans, Louisiana

Drs. Ernest H. Muller and Gary M. Boone, Department of Geology, Syracuse University, Syracuse, New York

Dr. Andrew V. Okulitch, Geological Survey of Canada, Vancouver, B.C., Canada

Mr. Michael Kennedy, Geologist, California Division of Mines and Geology, Los Angeles, California

Mr. Richard L. Philippone, U.S. Atomic Energy Commission, Oak Ridge, Tennessee

Dr. Alexis Volborth, Nevada Bureau of Mines and Geology, MacKay School of Mines, University of Nevada, Reno, Nevada

E. NASA Data Requests

Standing Order

No change has been made in our standing order form of 18 October 1972.

Retrospective Requests

The following retrospective requests were made to NASA Data Banks for subsidiary data in support of our ERTS-1 investigation:

11 September 1972	Request for duplicate color positives of Gemini and Apollo earth looking photography. Earth Resources Research Facility, NASA-JSC. Data not received.

12 February 1973	NDPF, Goddard Space Flight Center	
	1052-17490	N35-57/W115-06
	Banda 4, 5, 6, 7	Computer compatible tape (CCT)
	Data was requested for cooperative work with Dr. William Pratt, Department of Engineering, University of Southern California. Data received.	
8 May 1973	NDPF, Goddard Space Flight Center	
	1125-17554	N35-57/W116-37
	Bands 4, 5, 6, 7	9.5 inch positive transparencies
	Death Valley-Furnace Creek area, California. Data received.	
13 June 1973	NDPF, Goddard Space Flight Center	
	1051-17425	N37-26/W113-09
	Bands 4, 5, 6, 7	9.5 inch positive transparencies
	Colorado Plateau, N & NE of Lake Mead. Data received.	

III. SUMMARY OF INVESTIGATION

A. Sensor Comparison and Evaluation

A variety of remote sensing data has been used in conjunction with ERTS-1 data for geologic analysis and interpretation. This additional data has been coordinated with field reconnaissance, and has proved to be an important complement to the ERTS-1 data. In many instances, access to a variety of data over key field areas has provided information not apparent by any single remote sensing technique. Subsidiary remote sensing data used in the investigation and preliminary evaluation of applications are discussed in the sections below:

NIMBUS

NIMBUS 1 imagery recorded in September, 1964 is available over much of the test area. Because of an extremely eliptical orbit, NIMBUS 1 was able to acquire the first low altitude space imagery available over much of the earth. Although resolution is inferior to ERTS or Apollo, the 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 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. 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 study areas in which U-2 was unavailable or oblique.

This is especially true of coverage along the California-Nevada border used in investigation and field reconnaissance of Pahrump Valley (Liggett & Childs, 1973) where the look directions of X-15 and U-2 photographs are nearly at right angles. X-15 has also been useful in studying fault patterns in the Cody Mountains near Barstow, California.

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, 70 mm 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 has guided efficient field reconnaissance operations. (Bechtold & others, January 1973).

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. One traverse (mission 103) covers a strip north of Lake Mead, Nevada, an area of existing U-2 photographic coverage (Bechtold & others, January 1973, March 1973). 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 Imagery

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 over broad areas. ERTS-1 image resolution is sufficient for 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 and other mountain ranges and seasonal changes are apparent in the appearance of playa lakes.

Several methods of data analysis and enhancement have proved useful in effective use of ERTS-1 MSS imagery, and are discussed in a separate section of this report. To date, all our analysis of ERTS data has used NASA NDPF photographic formats for data input. Problems encountered in the use of ERTS-1 data are long delays in receipt of requested imagery, and inconsistent quality of NDPF data products.

We are investigating data processing and analysis from digital computer compatible tapes (CCT) in cooperation with Dr. William Pratt, Department of Engineering, University of Southern California. No significant results of this work are yet available.

B. Image Enhancement and Analysis Techniques

A variety of image processing and enhancement techniques is in use for analysis of ERTS-1 and subsidiary remote sensing imagery, and additional enhancement methods and applications are being investigated. These include photographic, optical, and digital processing techniques as discussed below.

Most black and white photography, photographic reproduction and special processing is done in-house by Argus Exploration Company personnel. Technical color processing is done in cooperation with Mr. Wally MacGalliard, MacGalliard Colorprints Inc., Hollywood, California.

Standard data reproduction techniques are discussed in the Type II progress report of 19 January 1973, and will not be reviewed here.

Additive Color Viewing

Additive color viewing of multispectral imagery has continued to be an important tool for analysis of ERTS-1 MSS and other available multispectral imagery. This analysis is performed on a 4-channel multispectral viewer manufactured by Spectral Data Corporation. This viewer is used for compositing of multispectral imagery with a broad range of color balance and filter/band combinations. NASA 70mm positive film chips are used as data input.

Because of the small size of the viewer screen, and degredation of image resolution, the most effective use of the viewer has proved to be in determining optimum color balance for analysis of specific geologic features or image anomalies. This choice of color balance is then used to guide production of high resolution color composite photographs, as discussed below. We have found this coordinated use of techniques to provide information frequently not evident in the use of the techniques independently.

Some experimentation has been conducted with multi-seasonal image composites, made from ERTS-1 imagery of different overpasses over key study areas. This task is facilitated by independent scale adjustment for each of the four viewer channels. The seasonal range of suitable imagery has not been sufficient to evaluate the full effectiveness of this technique.

Multispectral Ektacolor Composites

High resolution color composite photographs have proved to be the primary tool for detailed laboratory analysis and field use of ERTS-1 MSS data. Choice of color balance and filter/band combinations is guided by additive color viewing.

Initial production of composite imagery was done by photographing the viewing screen of a 4-channel multispectral viewer. This technique is discussed in our Type 1 report of 19 January 1973. Excellent duplication of color balance was achieved by this method, although resolution was not comparable to black and white prints of single bands.

To correct this problem we have developed a method for producing high resolution composites using NASA 9 x 9 positive transparencies. The positive transparencies of ERTS MSS bands are manually registered and punched for accurate locking in a printing frame. An 8 x 10 internegative film is sequentially exposed by each of the MSS bands with an appropriate tricolor filter. Both illumination intensity and exposure time may be varied for each band to control final color balance. Once a suitable internegative is produced, contact prints or enlargements are made using standard Kodak Ektacolor papers and chemicals. For detailed analysis, enlargements up to 30 x 30 inches have been made with excellent resolution and color reproduction.

This technique is discussed more fully in a report of investigation, in preparation.

Dye Transfer Color Composites

Limited experimentation has been conducted on production of color composites using the dye transfer printing technique. This technique is a three color dye process in which yellow, magenta and cyan dye images are superimposed on a paper or film printing medium. A separate, pre-registered dye transfer mat is used for each of the three dye images. These transfer mats can be precisely made from the MSS bands by contact printing of the NASA 9 x 9 positive transparencies. Dye transfer prints have high resolution and excellent color range, often superior to the range possible with photographic papers. In addition, dye transfer printing is well suited for a number of enhancement techniques, such as photographic density slicing, or variable contrast color printing. For normal purposes, dye printing is relatively expensive, and not economical for multiple image reproduction.

Further experimentation is planned on other applications of dye transfer printing for ERTS image enhancement.

Edge Enhancement Processing

A simple photographic technique known as "edge enhancement" or "line breakdown" has proven useful in pattern analysis of ERTS-1 MSS imagery. The effect of this technique is to reduce tonal variation in an image, enhancing the "edges" or peripheries of image areas having tonal contrast. In this manner, a gradual change from light to dark gray levels is reduced to a single neutral gray level; a contact of light and dark areas is enhanced to a line, separating areas of equal tone.

This technique is performed using identical positive and negative transparencies, "sandwiched" together in a printing frame. This sandwich is used to expose a photographic film or paper. Perfect registration of the "sandwich" isolates image line content while controlled misregistration may be used to bias the enhancement of linear elements having directional orientations.

A similar analysis technique can be performed digitally using equipment manufactured by Spatial Data Systems, Inc., Goleta, California, and Interpretation Systems, Inc., Lawrence, Kansas. These digital enhancement techniques have the advantage of real time variation of image orientation, contrast range, degree of tonal elimination, etc., but lack the higher resolution of a photographic process.

Optical Fourier Transform Analysis

Preliminary study has been conducted for structural analysis of ERTS-1 imagery using coherent LASER illumination in production of Fourier transforms. A Fourier transform is produced as a diffraction pattern by illumination of an image transparency with collimated LASER light. Fourier transforms are useful for precise measurement of directional orientations and spatial frequencies of linear image elements. Geologic applications of the technique are discussed by Dobrin (1968), Pincus and Dobrin (1966) and Nyberg (& others, 1971).

Fourier transform analysis of satellite imagery shows promise in the study of regional patterns controlled by a variety of geologic features. Examples include faults, folds, dike swarms, joint patterns, erosional textures and linear topographic alignments such as ridges, mountain ranges, or rivers. Such a pattern analysis can be performed for an entire image, or for separate domains within an image, providing a measure of directional variation by sub-area. A problem apparent in the application of this technique to ERTS-1 MSS imagery is the dominant expression, in the transform, of the scan lines and resolution elements which mask more subtle image features. Preliminary discussions and experimentation were performed in cooperation with:

Recognition Systems, Inc.
15531 Cabrito Road
Van Nuys, California 91406

Additional investigation and experimentation of this technique are planned.

C. Summary of Field Work

Field work conducted during this reporting period has involved regional reconnaissance as well as detailed studies of key areas in the western and northwestern parts of the test area. Some of these studies are presented as significant results in a separate section of this report and the reader is referred to them for a more comprehensive discussion. The general nature of the field work is described here with emphasis on studies which are still in progress:

Structure and Volcanism, Eastern Portion of Test Area

Field work in the southeastern and east-central part of the ERTS-1 test area has concentrated on a major north trending tectonic zone located between Blythe, California and Lake Mead, Nevada. The relationship of this feature to transverse, generally northwest trending zones of strike slip movement to the north and south has also been studied. The genetic relationship between faulting, igneous activity and mineralization in this area is discussed in our Report of Investigation (Bechtold & others, March 1973). In the northeastern part of the test area (southern Lincoln Co., Nevada) two pervasive structural trends (one set trending northwest and the other northeast) have been studied with attention to their possible structural control of igneous activity. Several small Tertiary granitic bodies are known in the vicinity and rhyolitic calderas are suspected because of the occurrence of thick welded tuft units. Faults cutting the volcanic and intrusive units have been identified by field work and are parallel to the pervasive structural trends. Further field work is planned in this area during the next reporting period.

Sierra Nevada and Inyo Mountains, California

In the eastern part of the Sierra Nevada Range of California, reconnaissance field study has been done on several large, north trending structural lineaments recognized in ERTS-1 MSS imagery. (See Abstract in Type II report of January 1973). These features appear to be a combination of geologic and geomorphologic features, including intrusive contacts, elongate intrusive masses, dikes, sills, fault zones and aligned drainage patterns. Further field work in this area awaits improvement in snow and meltwater conditions, although imagery analysis and literature research is continuing.

In Owens Valley, structural control of basaltic volcanism, recognized by earlier workers, was studied in the field and in ERTS-1 MSS imagery. This work was undertaken as part of our ongoing study of structural controls of igneous activity in the southern Basin-Range Province.

Preliminary reconnaissance was done on several components of a marked northeast trending pattern of normal faults in the Inyo Mountains, east of Owens Valley. This pattern of faulting characterizes a large region in the western part of our ERTS-1 test area, and appears to be related to large scale strike-slip faulting.

Field study of rock type discrimination using ERTS-1 MSS imagery was made in the Inyo Range. The lithologic units most easily distinguished include the marble of the Bonanza King Formation and several varieties of quartz monzonite and other granitic rocks. Where these units have been mapped in detail, a close correlation was found between the maps and distribution interpreted from ERTS-1 imagery.

Death Valley-Furnace Creek Fault Zones

Much of the field effort during the last two months has been directed toward an understanding of the Death Valley-Furnace Creek Fault Zone and adjacent structures using ERTS-1 MSS imagery as a field base. The Death Valley-Furnace Creek Fault Zone appears to form a structural boundary between a western province pervaded by northeast-trending normal faults and an eastern province of abundant north-trending normal faults. This change in fault orientation is clearly visible in ERTS-1 imagery, and is substantiated by published geologic maps and our own field work. We have studied several areas along the Death Valley-Furnace Creek Fault Zone in the hope that an understanding of this boundary will provide information on the tectonics of the areas it separates.

ERTS-1 imagery analysis and subsequent field work indicate that the northwest-trending Grandview Fault, recognized in the Ryan, California area, extends about 10 miles to the south along the west front of the Greenwater Range. Field work was also conducted northward from the Ryan area into Furnace Creek Wash at the north end of the Black Mountains. This work was undertaken to determine if some of the variation in amount of reported movement along the Death Valley-Furnace Creek Fault Zone could be the result of accommodation of movement along nearby faults, such as the break studied along the Greenwater Range.

The Ubehebe Craters, an area of basaltic volcanism in Death Valley at the northern end of the Panamint Range are thought to be controlled in part by two large north-trending faults recognized in ERTS-1 MSS imagery. A similar association of basaltic volcanism and large fault breaks is found east of Ubehebe Craters along the Death Valley-Furnace Creek Fault Zone. The Ubehebe Craters area is described separately in this report under Significant Results.

At the north end of Death Valley, a large bend in the Death Valley-Furnace Creek Fault Zone, clearly evident in ERTS-1 imagery, occurs within the Sylvania Mountains. A group of east-trending faults which may interact with the Death Valley-Furnace Creek Fault Zone was recognized in ERTS-1 imagery and confirmed by field work. This zone of faults can be traced eastward for fifteen miles along Slate Ridge to an area near Gold Point, Nevada. This is one of several east-west zones which are presently being investigated. East and north-trending sets of lineaments are prominent features in ERTS imagery of the northern part of our test area.

The Death Valley-Furnace Creek Fault Zone appears to terminate at the north end of Fish Lake Valley in an area of extensive basaltic to rhyolitic volcanism. Field reconnaissance in this volcanic terrain confirms the presence of north and northeast-trending faults recognized in ERTS-1 imagery. It is hoped that continued investigation in this region may reveal the mechanism by which the Death Valley Fault Zone is terminated, and any relationship it may have to the large volume of volcanic rock in this region.

In addition to the work along the Death Valley Fault Zone described above, individual fault strands within this zone have been studied at other localities in Fish Lake Valley and Death Valley.

Esmeralda County and Nye County, Nevada

Field reconnaissance has been done in the northwestern part of the test area in the region west of Tonopah, Nevada and Beatty, Nevada. Two major sets of structures appear to cross the area from north to south and from east to west. Two components of the north-south set have been confirmed as fault zones and one of these appears to be approximately 30 miles in length. Components of the east-west set have been identified as faults associated with elongate Mesozoic granitic plutons and Tertiary rhyolites. More field work is planned in this region during the next reporting period.

Southwestern Mojave Desert

In the western Mojave Desert, preliminary field work was conducted near Boron, California on ERTS-1 imagery-identified structures which cut both bedrock and alluvium. Investigation of a large alluvial fan near Wrightwood, California at the southern edge of the Mojave Desert has been completed and this study will form the basis for a report on the effect of alluvial sediment composition in producing a marked anomaly in the ERTS-1 MSS data.

A large, triangular anomaly was recognized in ERTS-1 imagery between Barstow, California and the Cady Mountains. This feature is believed to be controlled by northeast, northwest and north-trending faults which enclose a triangular area of unconsolidated sediments and windblown sand. The north-south fault at the eastern margin of the area was confirmed by detailed field mapping. Several of the valleys which extend eastward into the foothills of the Cady Mountains also appear to be fault controlled.

Many of the prominent structural trends within the ERTS-1 test area have been studied and differences in structural patterns within and between the various subareas are becoming apparent and more clearly understood. We believe this knowledge will be an important basis for interpreting the dynamics of faulting in the southern part of the Basin-Range Province.

D. Field Work Planned for Next Reporting Period

The addition of another field geologist to our staff will substantially increase field activity. Two areas have been assigned priority for the next field effort and we will have a team working in each simultaneously.

The first area is located in southern Lincoln Co., Nevada and includes the Delamar, and Clover Mountains and Kane Springs Wash. The area is underlain by large volumes of volcanic and intrusive rocks and is crossed by two pronounced sets of lineaments recognized in ERTS-1 imagery. This area was briefly studied earlier this year but bad weather and snow forced postponement of further field work at that time.

The second area of interest for field investigation is the extensive volcanic terrain located at the northern end of Fish Lake Valley where the Death Valley Fault Zone appears to terminate. Reconnaissance in this region may reveal the mechanism by which movement on the Death Valley Fault Zone dies out to the north, and possible relationships between the fault zone and the large volume of basaltic to rhyolitic Tertiary volcanics located in this region.

The region west of Goldfield and Tonopah, Nevada will be studied using two field teams concentrating on separate but related geologic problems in the region. This approach will permit comparison of data and ideas while in the field. This region is crossed by two large sets of lineaments, one trending north and the other east, with individual components up to thirty miles in length. Few of these features appear on published geologic maps of the area. Field work will be initiated in a large volcanic field east of Goldfield, Nevada where components of the two regional lineaments intersect. Attention will be given to possible genetic relationships between the ERTS identified regional structures and the volcanics.

E. Significant Results

The following abstracts summarize results of investigation which we feel demonstrates significant applications of ERTS-1 data.

F. ERTS-1 Applications and Benefits

Several fields of application of ERTS-1 data are suggested by the results of investigation summarized in this report. This evaluation is tentative, however, since further research is required to confirm regional correlations of geologic phenomena on which many anticipated applications are based. The current phase of our investigation is largely one of data acquisition, analysis and interpretation. A final phase of research will involve integration of data from separate research tasks and subareas.

It should be emphasized that direct comparison of ERTS data or analysis methods cannot be made with conventional geologic data or mapping techniques. Many of the data and methods used in this investigation do not have precedent, and in many cases, the ultimate value of research findings will not be immediately obvious. The following paragraphs briefly summarize fields in which satellite data may have significant operational roles.

Mineral Exploration

Regional structural control of igneous activity, associated faulting, and related gold, copper and silver mineralization is discussed in our interim report of investigation:

> Regional Tectonic Control of Tertiary Mineralization and Recent Faulting in the Southern Basin-Range Province - An Application of ERTS data. (ERTS-1 Symposium, New Carrollton, Maryland.) March 1973.

In this study, the regional patterns and structural controls of mineralization were previously unrecognized from detailed geologic mapping in areas of known mineralization. Our research was initiated by structural interpretation of Apollo-9 satellite photography, and guided by excellent ERTS-1 MSS coverage, and subsidiary remote sensing data. Knowledge of regional structural patterns and genetic controls of mineralization established in this investigation is a powerful guide for mineral exploration.

In addition to mineral exploration, trends in mineralization should be considered in governmental land-use planning. A map of the test area is being compiled which shows the geographic locations of known ore deposits (see Type II Progress Report of 19 January 1973). We plan further research to evaluate the genetic relationships of ore geneis and tectonic features in other portions of the southern Basin-Range Province.

Potential Users: U. S. Geological Survey
U. S. Bureau of Mines
State geology and mining surveys
Private exploration and mining companies
Corresponding agencies in foreign countries

Geothermal Power Exploration

A number of known geothermal springs are aligned along structural lineaments under investigation in our ERTS-1 program. In most instances, insufficient evidence has been gathered to establish a genetic relationship between these structural features and the location of geothermal springs. We are currently compiling a regional map showing known geothermal sources throughout the test area. This compilation will establish a basis for evaluating correlations of regional structural patterns, and potential application to geothermal exploration.

Potential Users: U. S. Geological Survey
Private energy resource companies
Public utility companies
Corresponding agencies in foreign countries

Geologic Hazards Research

Several of our studies of key sub-areas have illustrated the application of ERTS-1 MSS and subsidiary remote sensing data to mapping fault breaks of relatively recent age. Examples are discussed in the following reports:

"Regional Tectonic Control of Tertiary Mineralization and Recent Faulting in the Southern Basin-Range Province - An Application of ERTS-1 Data.": ERTS-1 Symposium, New Carrollton, Maryland, March 1973.

Structurally Controlled Dike Swarms Along the Colorado River, Northwestern Arizona and Southern Nevada (ABS): NASA-CR-128290, E72-10192, 1972.

Evidence of a Major Fault Zone Along the California-Nevada State Line, 35°30'-36°30' N Latitude: NASA Report of Investigation, 1973.

These studies have demonstrated the use of ERTS-1 data for reconnaissance of active faulting. This capability can have important applications to a variety of land use planning roles, including the design and location of engineering projects, such as dams, nuclear generating plants, bridges and highway systems.

We are continuing to compile a regional map of known epicenters which will provide a basis for studying correlations of late Quaternary faulting and historic earthquakes. A positive correlation of these phenomena has not been established in our investigation to date.

Potential Users:

- U. S. Bureau of Land Management
- U. S. Bureau of Reclamation
- U. S. Atomic Energy Commission
- U. S. Department of Transportation
- Federal, state, and county land-use planning agencies
- U. S. Geological Survey
- Public utility companies

Hydrology

Applications of our research findings to ground-water geology have not been fully evaluated. Late Quaternary faults discussed above under "Geologic Hazards Research" are significant to sedimentary basin development and may affect related hydrology.

The effect of faults as possible ground water traps is suggested by the alignment of springs found along portions of the Pahrump Fault Zone (Liggett & Childs, 1973), and similar alignments observed along the Death Valley-Furnace Creek Fault Zone. Application of ERTS-1 imagery analysis to ground water exploration will be pursued in future reports.

Potential Users:

- U. S. Geological Survey
- U. S. Department of Agriculture
- State and county water resource agencies
- Public utility companies
- Corresponding agencies in foreign countries

G. Authorized Reports and Presentations

Orbital Remote Sensing for Mineral Resources Exploration (ABS).
By: I. C. Bechtold and M. A. Liggett
Presented at the Ninth Annual Meeting of the American Institute of Aeronautics and Astronautics, Washington, D. C., 8 January 1973

Remote Sensing of Faulting in Alluvium, Lake Mead to Lake Havasu, California, Nevada and Arizona - An Application of ERTS-1 Satellite Imagery.
By: I. C. Bechtold, M. A. Liggett, & J. F. Childs
NASA Report of Investigation, January 1973

Regional Tectonic Control of Tertiary Mineralization and Recent Faulting in the Southern Basin-Range Province - An Application of ERTS data.
By: I. C. Bechtold, M. A. Liggett & J. F. Childs
Presented at the ERTS-1 Symposium, New Carrollton, Maryland, 6 March 1973

Orbital Remote Sensing for Mineral Resources Exploration (ABS).
By: I. C. Bechtold
Presented at Section Meeting of the American Institute of Aeronautics and Astronautics, Edwards Air Force Base, 17 April 1973

Significant Geological Results from ERTS-1 Applicable to Regional Planning.
By: I. C. Bechtold
Presented at ERTS Views of Southern California - Reviews of Multidisplinary Results Relating to Regional Planning and Resource Management, Los Angeles County Regional Planning Commission, Los Angeles, California, 4 May 1973

Evidence of a Major Fault Zone along the California-Nevada State Line, $35^{o}30'$ - $36^{o}30'$ N Latitude.
By: M. A. Liggett and J. F. Childs
NASA Report of Investigation, July 1973

NASA Reports

Technical Reports:

15 March 1973
Type I Progress Report: 1 January through 28 February 1973
Ref: ERTS-1 Contract NAS5-21809

11 May 1973
Type I Progress Report: 1 March through 30 April 1973
Ref: ERTS-1 Contract NAS5-21809

Financial Reports

15 January 1973
Monthly Contractor Financial Management Report for period ending 31 December 1972
Form 533M

Quarterly Contractor Financial Management Report for period ending 31 December 1972
Form 533Q

14 February 1973
Monthly Contractor Financial Management Report for period ending 31 January 1973
Form 533M

28 February 1973
Argus Exploration Company billing:
NASA contract NAS5-21809
Form No. 1034

14 March 1973
Monthly Contractor Financial Management Report for period ending 28 February 1973
Form 533M

15 March 1973
Argus Exploration Company billing:
NASA contract NAS5-21809
Form No. 1034

16 April 1973
Monthly Contractor Financial Management Report for period ending 31 March 1973
Form 533M

Quarterly Contractor Financial Management Report for period ending 31 March 1973
Form 533Q

20 April 1973
Argus Exploration Company billing:
NASA contract NAS5-21809
Form No. 1034

16 May 1973

Monthly Contractor Financial Management Report for period ending
30 April 1973
Form 533M

25 May 1973

Argus Exploration Company billing:
NASA contract NAS5-21809
Form No. 1034

12 June 1973

Argus Exploration Company billing:
NASA contract NAS5-21809
Form No. 1034

15 June 1973

Monthly Contractor Financial Management Report for period ending
31 May 1973
Form 533M

13 July 1973

Argus Exploration Company billing:
NASA contract NAS5-21809
Form No. 1034

IV. CONCLUSIONS

The ERTS-1 MSS system is providing data of a unique nature to geologic research. The investigation results discussed in this report emphasize three primary aspects of the ERTS data that have proved most valuable:

1. The scale, resolution and spectral range of the ERTS-1 MSS imagery permits interpretation of subtle structural alignments over much larger areas than feasible with conventional aerial imagery or geologic mapping. In this sense, the synoptic nature of the ERTS data provides an effective filter for recognition of regional geologic features, trends or patterns obscurred by detail at the scale of an outcrop or quadrangle map.

2. The ability to interpret regional structural patterns and geologic correlations from ERTS-1 data establishes a base for integration and synthesis of independent data, previously possible only with highly subjective map compilations. Results of our research illustrate the value of this approach for understanding interrelationships of regional structure and volcanism, plutonism and related alteration, mineralization, and geothermal activity.

3. Field reconnaissance guided by ERTS-1 imagery is highly efficient, especially when aided by subsidiary remote sensing data of intermediate scale and resolution. Although anomalies in the ERTS imagery frequently have vague expression in the field, critical sites for detailed mapping or geophysical study can be determined, eliminating extensive ground-based reconnaissance required in conventional quadrangle mapping.

Further research is needed to test and evaluate the value of ERTS-1 data in other geologic applications. High resolution color composites of ERTS-1 MSS imagery have permitted excellent rock type descrimination in several field areas. Additional interpretation of rock type has been done with ERTS-1 data by analysis of gross weathering and erosional morphology controlled by the rocks internal fabric, mineralogy or jointing characteristics. Although the color and textural expression of rock types is easily masked by vegetation, soil or alluvium, research in imagery enhancement and analysis techniques shows promise in improving this application.

The coarse resolution and snyoptic scale of ERTS-1 data do not permit analysis of structural features having high local variability. Such features as thrust faults, some with extensive exposure, have proved difficult to distinguish. This is due to the irregular outcrop patterns formed by the intersection of thrust surfaces with uneven topography. Aerial imagery, including SLAR have shown little improvement of this task.

The use of satellite remote sensing does not outmode methods of classical field geology. Many of our investigation results have relied heavily on data of previous studies which have involved laborious geologic or structural mapping, geochemical sampling and analysis, petrography or geochronology. ERTS-1 data does not replace these techniques, but provides new complimentary information critical in regional reconnaissance mapping or exploration. Refinements in data analysis and interpretation methods show promise for applications of satellite remote sensing to a broad range of geologic research problems, including operational resource exploration and management.

D

V. RECOMMENDATIONS

The recommendations summarized below are tentative suggestions of technical or operational deficiencies or modifications for consideration in future ERTS programs.

The recommendations are biased toward research in regional geologic and structural reconnaissance, and applications to energy and mineral resource exploration. We have not considered technical modifications optimum for other disciplinary studies.

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 especially in studies relating to seasonal variation and other transient phenomena.

To the maximum extent feasible, NASA or EROS should compile and provide comprehensive indexes of available subsidiary remote sensing data.

Stereoscopic Coverage

Stereoscopic imagery would have a strong advantage in applications involving terrain analysis, especially structural geology. Increased ERTS-MSS sidelap or RBV forward overlap should be considered in future missions.

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.

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 spectroradiometers, and laser imaging systems should be investigated.

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Bechtold, I. C., & Liggett, M. A., January 1973, Orbital Remote Sensing for Mineral Resources Exploration (ABS): Ninth Annual Meeting of the AIAA, Washington, D. C.

Bechtold, I. C., Liggett, M. A., & Childs, J. F., January 1973, Remote Sensing of Faulting in Alluvium, Lake Mead to Lake Havasu, California, Nevada and Arizona; An Application of ERTS-1 Satellite Imagery: NASA Report of Investigation, 8 pp.

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Liggett, M. A., 4 December 1972, Data Analysis Plan; A Reconnaissance Space Sensing Investigation of Crustal Structure for a Strip from the Eastern Sierra Nevada to the Colorado Plateau (contract NAS5-21809): Submitted to Mr. Henry Arista, NASA Goddard Space Flight Center, Greenbelt, Maryland.

Liggett, M. A. & Childs, J. F., July 1973, Evidence of a Major Fault Zone along the California-Nevada State Line, 35°30' - 36°30' N Latitude. NASA Report of Investigation.

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THE SALT CREEK FAULT, DEATH VALLEY, CALIFORNIA (ABS.)

By John F. Childs

In the central part of Death Valley, California, (Figure 1) several subtle linear anomalies, trending about N 15°E, were recognized in ERTS-1 MSS imagery. The most prominent of these features (see Figure 2) was singled out for study because it appears to extend undeflected across several strands of the Death Valley-Furnace Creek Fault Zone. Subsequent field work, using high altitude U-2 photography, confirmed this feature as a high-angle, oblique-slip fault, referred to as the Salt Creek Fault (Figure 3). Along its northern end, the Salt Creek Fault cuts Recent travertine deposits and has uplifted Miocene (?) and Oligocene (?) sediments on its southeast side. Southward, it crosses the Death Valley-Furnace Creek Fault Zone at an angle of approximately 60°. Near its southern end, the fault bifurcates and appears to terminate in the Paleozoic bedrock of Tucki Mountain. In a study of the geology of Death Valley, Hunt & Mabey (1966) infer a 2-1/2 mile segment of the Salt Creek Fault, but they show it terminating against strands of the Death Valley Fault Zone. (Hunt & Mabey, 1966, Geologic Map).

Structural measurements taken at the localities shown in Figure 3 are plotted on equal area nets in Figure 4. The scatter in fault plane orientation (Figure 4A) is probably due to interference of northwest trending faults, possibly related to the Death Valley-Furnace Creek Fault Zone, with the predominant northeast trends of the Salt Creek Fault.

The data in Figure 4B suggests that some of the faults measured have essentially down dip movement, but most have a strong component, of strike slip. Although the data shows considerable scatter, over half of the low plunging slickensides trend northeast. This northeast plunge, combined with field evidence that the east side of the fault is uplifted indicates a possible component of right lateral slip.

Burchfiel and Stewart (1966) proposed a "pull apart" origin for the central part of Death Valley by which the valley opened between two northwest trending strike slip faults; the Death Valley-Furnace Creek Fault Zone on the north and the Death Valley Fault Zone on the south. The lack of apparent offset of the Salt Creek Fault where it crosses the Death Valley-Furnace Creek Fault Zone may be explained as the result of synchronous movement on the two faults or a temporary transfer of active movement to the Salt Creek Fault. Some of the discrepancies in estimates of displacement across the Death Valley-Furnace Creek Fault Zone (Wright and Troxel, 1967; Stewart and others, 1968) may be explained by taking into account the movement on northeast trending oblique slip faults such as the Salt Creek Fault.

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Wright, L. A., and Troxel, B. W., 1967, Limitations on Right-Lateral, Strike-slip Displacement, Death Valley and Furnace Creek Fault Zones, California: Geol. Soc. Amer. Bull., v. 78, p. 933-950.

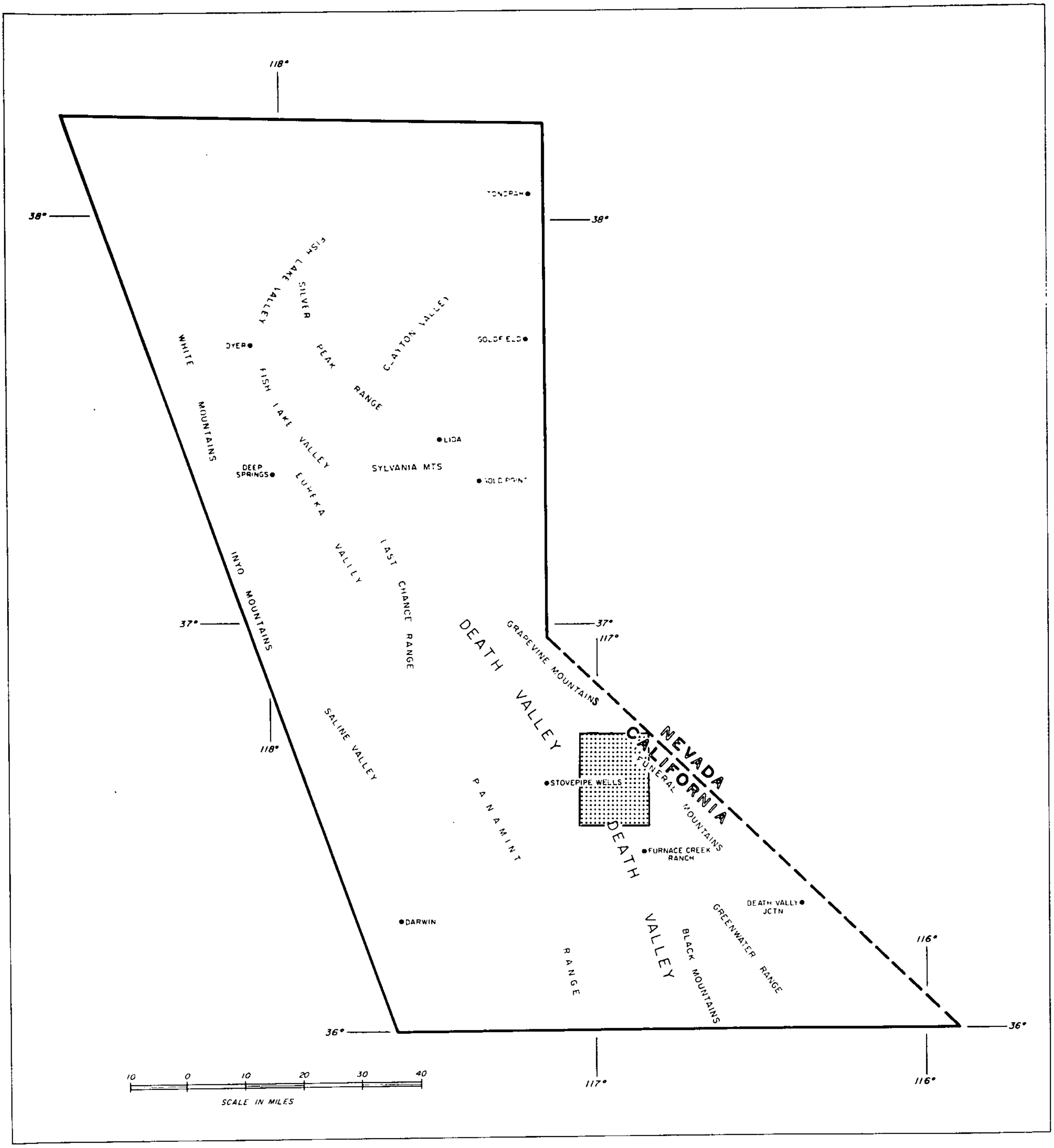

Figure 1 - Index map showing location of study area (shaded) in the central part of Death Valley, California

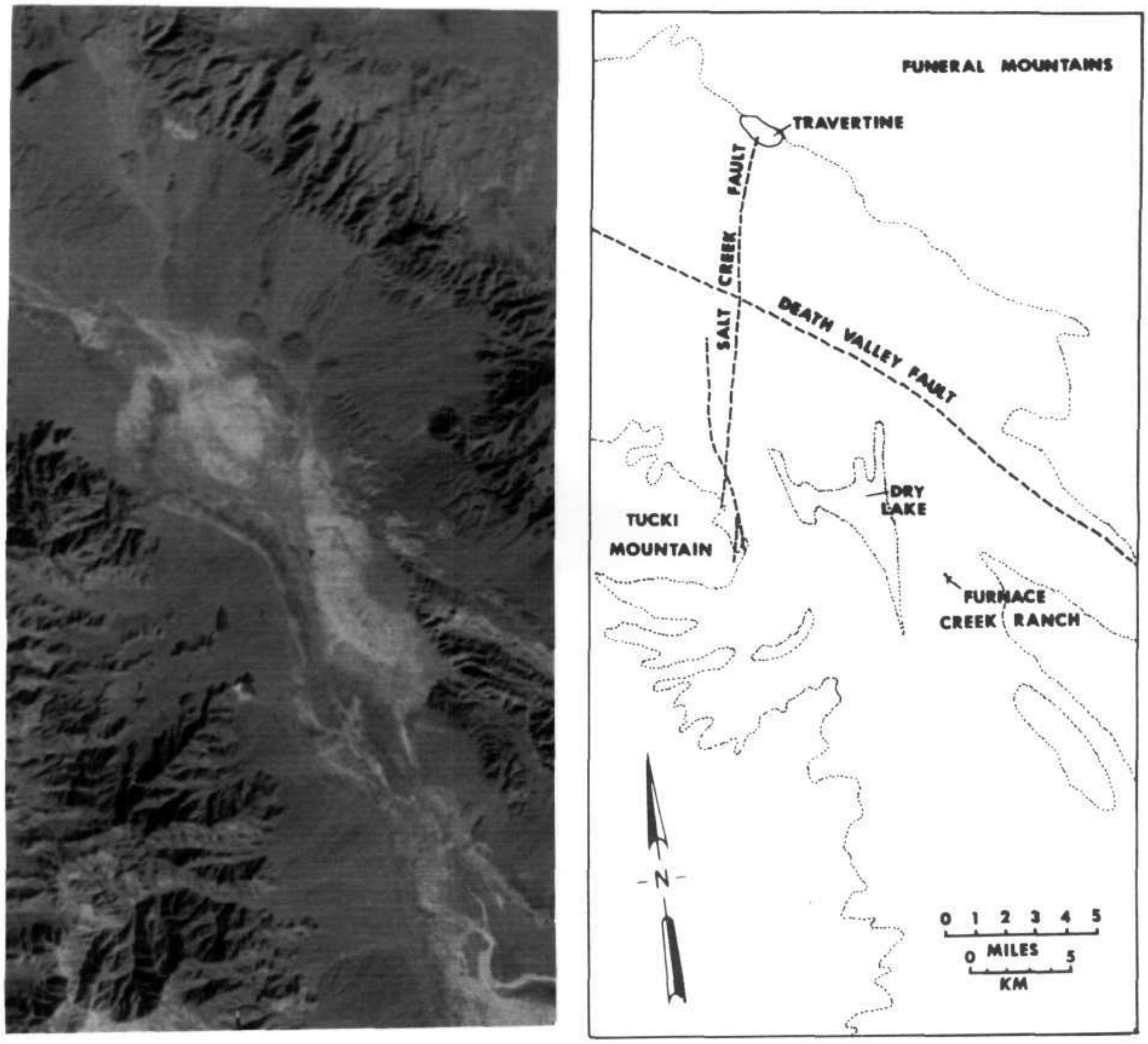

Figure 2 - Enlarged portion of ERTS-1 MSS Frame 1125-17554, 25 Nov. 1972 and corresponding index map. The Salt Creek Fault, described in the text, is shown in relation to the most prominent of several strands of the Death Valley-Furnace Creek Fault Zone.

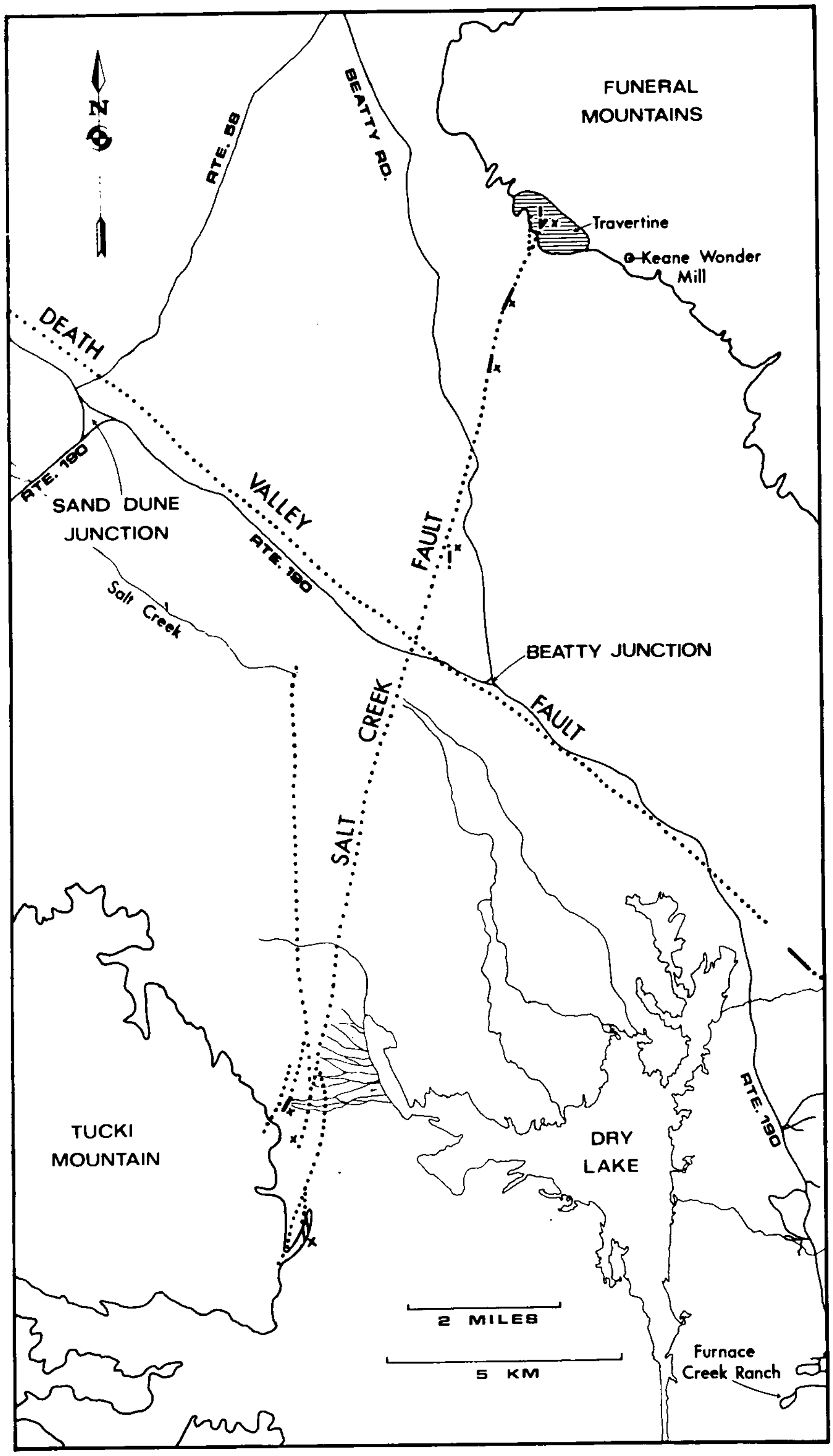

Figure 3 - Map showing the Salt Creek Fault and a prominent strand of the Death Valley-Furnace Creek Fault Zone. Topographic base maps used are the Chloride Cliff, Emigrant Canyon, Furnace Creek and Stovepipe Wells 15' Quadrangles. Localities where structural measurements were made are shown as Xs.

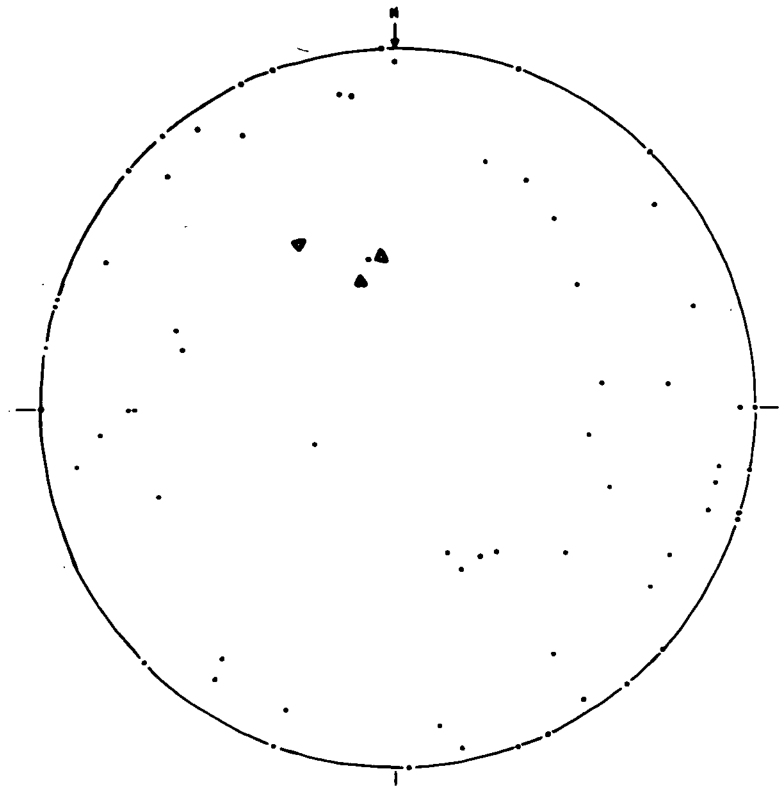

Figure 4 A -

Lower hemisphere equal area projection of 55 poles to fault planes (dots) and three poles to bedding (triangles) from localities shown in Figure 3 along the Salt Creek Fault.

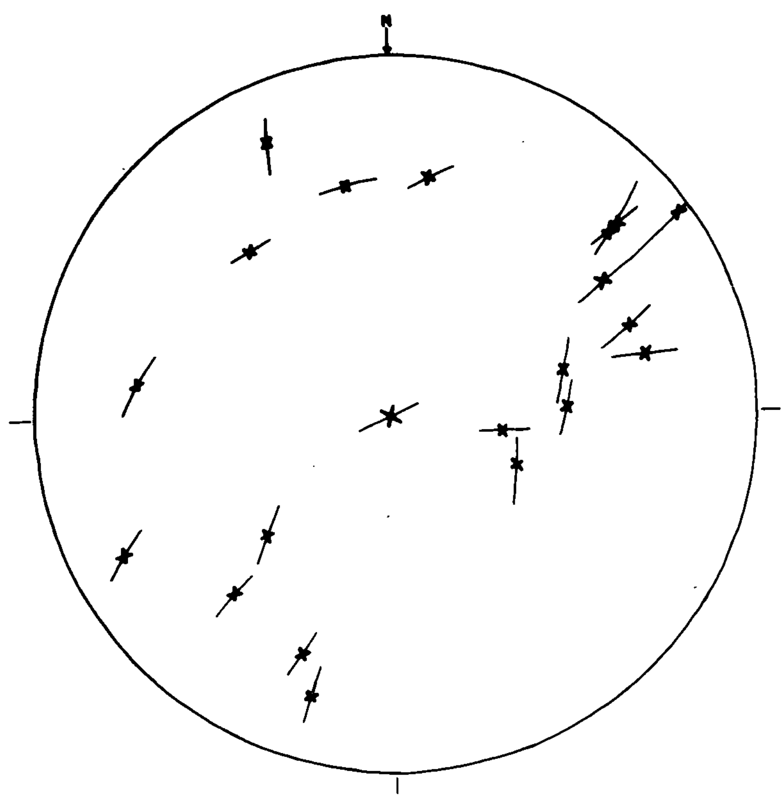

Figure 4 B -

Equal area projection of slickensides (crosses) and the fault planes on which they lie (arcs). Localities same as in Figure 4 A.

C

STRUCTURE AND VOLCANISM, UBEHEBE CRATERS, DEATH VALLEY, CALIFORNIA

John F. Childs and Mark A. Liggett

ABSTRACT

The Ubehebe Craters in northern Death Valley, California, are a cluster of Pleistocene or Recent (?) maar volcanoes located at the intersection of two faults recognized as major lineaments in ERTS-1 imagery. These north trending faults have not been previously mapped in the craters area. Field reconnaissance and mapping suggest an alignment of structural trends with volcanic features in the Ubehebe Craters area. Similar alignments of basaltic vents along subparallel faults in the vicinity suggest that northerly trending faults may have served as conduits for basaltic magma.

The Ubehebe Craters (Figure 1) are a cluster of shallow volcanoes of Pleistocene or Recent (?) age (Crowe and Fisher, 1973) which are aligned on north-south and east-west trends (Figures 2 and 3). In a study of the sedimentary structures of the volcanic ejecta, Crowe and Fisher (1973) concluded that the craters are maar volcanoes formed primarily by phreatic eruptions of basaltic magma.

The Ubehebe Craters appear to be located at the intersection of two prominent lineaments in ERTS-1 imagery (see Figure 2). The purpose of this study was twofold; to document the nature of the ERTS-1 lineaments in the craters area, and to investigate possible correlation of tectonic and volcanic features.

The intersecting ERTS-1 lineaments were confirmed as normal faults at several localities and are referred to here as the East and West Faults (see Figure 3). The East Fault can be followed in ERTS-1 imagery from north of the craters southward into the Panamint Range, a distance of 25 miles. The West Fault extends from just south of the craters for at least 20 miles along the west side of the Panamint Range. Displacement on the East Fault is probably on the order of tens or hundreds of feet, based on offset of lithologic units. Several thousand feet of displacement on the West Fault is suggested by the relief of the steep western face of the Panamint Range. The faults are thought to be Pleistocene to Recent in age since they cut Pliocene-Pleistocene (?) fanglomerates and possibly Recent alluvium. Although segments of both faults appear on the newly revised Death Valley Geologic Sheet (Streitz, 1973, written communication), and parts of the East Fault were mapped by McAllister (1952), these faults have not been previously mapped into the vicinity of the craters.

An alignment of volcanic features and faults is suggested by evidence from our field work, imagery analysis and previous geologic studies (Crowe and Fisher, 1973; Von Engeln, 1932). Faults in and adjacent to the Ubehebe Craters have trends similar to the East and West Faults in addition to a less pronounced east-west trend. The East Fault can be traced through the crater area except where it is deeply buried by volcanic debris near the eruptive center. The West Fault can be traced to within half a mile of the craters. Several north trending faults are mapped near the craters and others are inferred from topographic expression where the maar deposits have obscured the underlying geology (Figure 3).

The outline of the main Ubehebe crater is nearly circular except for a straight, slumped section along the western side. The slumping and asymmetry may be fault controlled. Von Engeln (1932) describes a fault which cuts through the center of the main crater and continues to the north but unfortunately his report does not include a map.

Basalt dikes found in the craters area, although few in number, have orientations similar to the north-trending faults. Dikes are thought to have fed basalt flows and spatter cones which preceded the main phreatic eruptive activity.

Pleistocene or Recent (?) basalt flows found along the Death Valley-Furnace Creek Fault Zone five miles to the east of Ubehebe Craters were erupted along fissures parallel to and within the fault zone, and are nearly identical petrographically to the basalts at Ubehebe Craters (Crowe, 1973, personal communication).

The frequent occurrence of basaltic volcanism along north trending faults in the Death Valley area suggests possible regional structural controls of basaltic magma sources. If faults in the Ubehebe Craters area acted to localize ground water as well as serving as conduits for rising basaltic magma, phreatic eruptions such as those which produced the craters may have occurred as the magma and water came into contact at shallow depth.

Acknowledgements

Bruce Crowe, University of California at Santa Barbara, generously made available a number of oblique and enlarged low altitude aerial photos for use in this study. He also gave freely of his time and of his detailed knowledge of the Ubehebe Craters area, making many helpful suggestions. However, the authors are fully responsible for the contents of this study.

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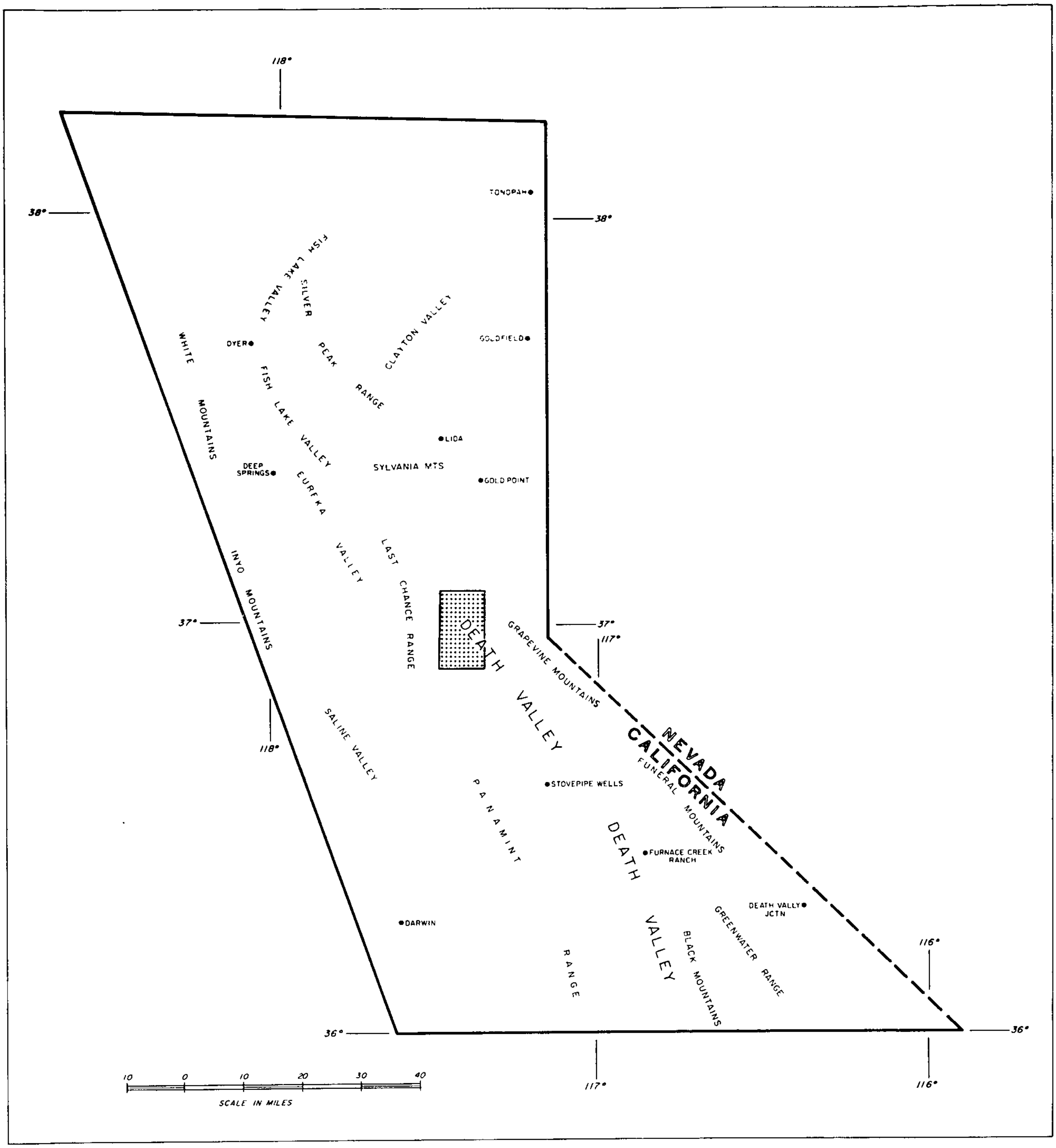

Figure 1 - Index map showing location of study area (shaded) in north-central Death Valley, California.

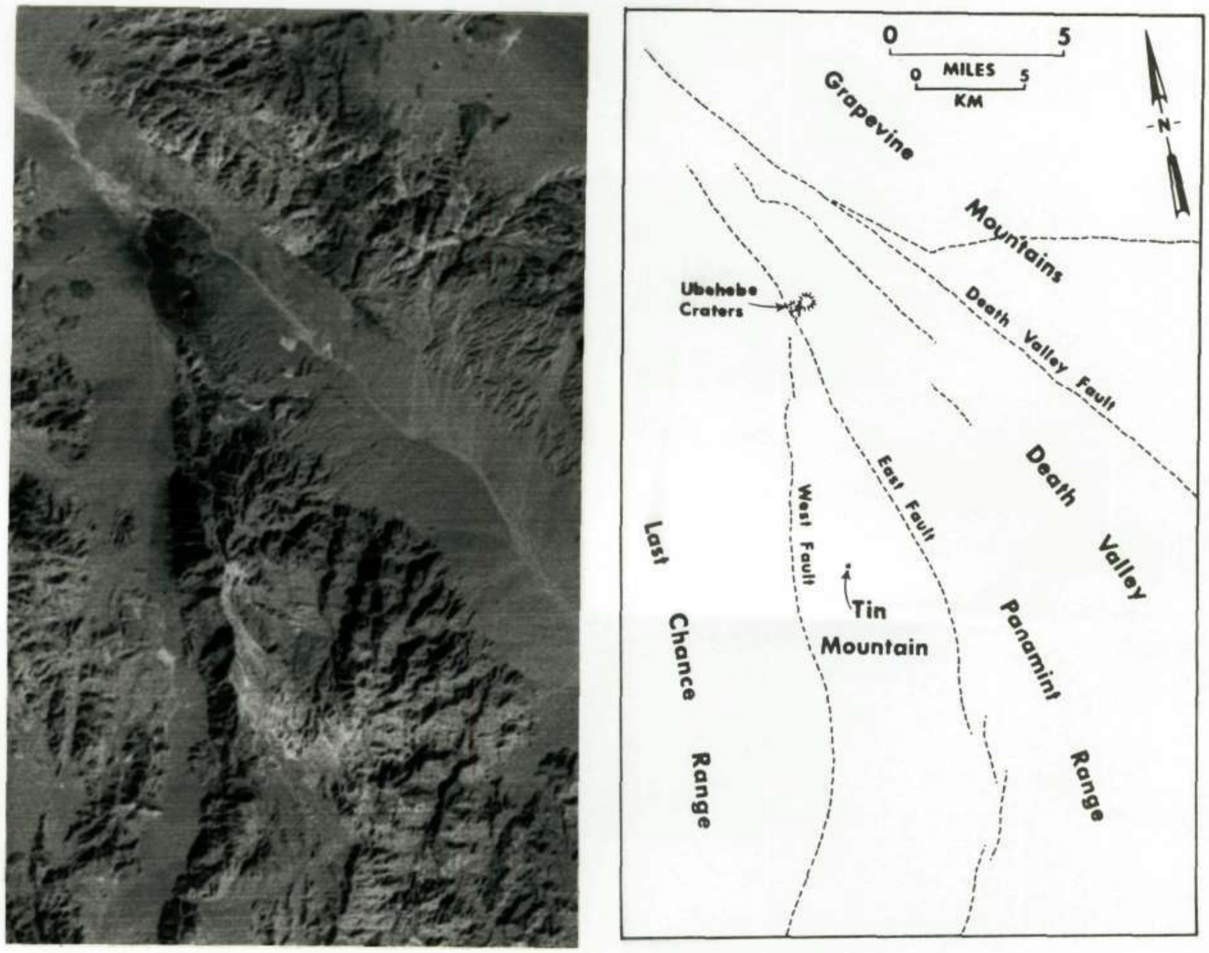

Figure 2 - Enlarged portion of ERTS-1 MSS Frame 1126-18010, 26 Nov. 1972, Band 7 and corresponding index map. The main structural features discussed in the text are shown in relation to Ubehebe Craters. The maar deposits surrounding Ubehebe Craters appear dark in the ERTS image. Basalts along the Death Valley-Furnace Creek Fault Zone appear dark grey.

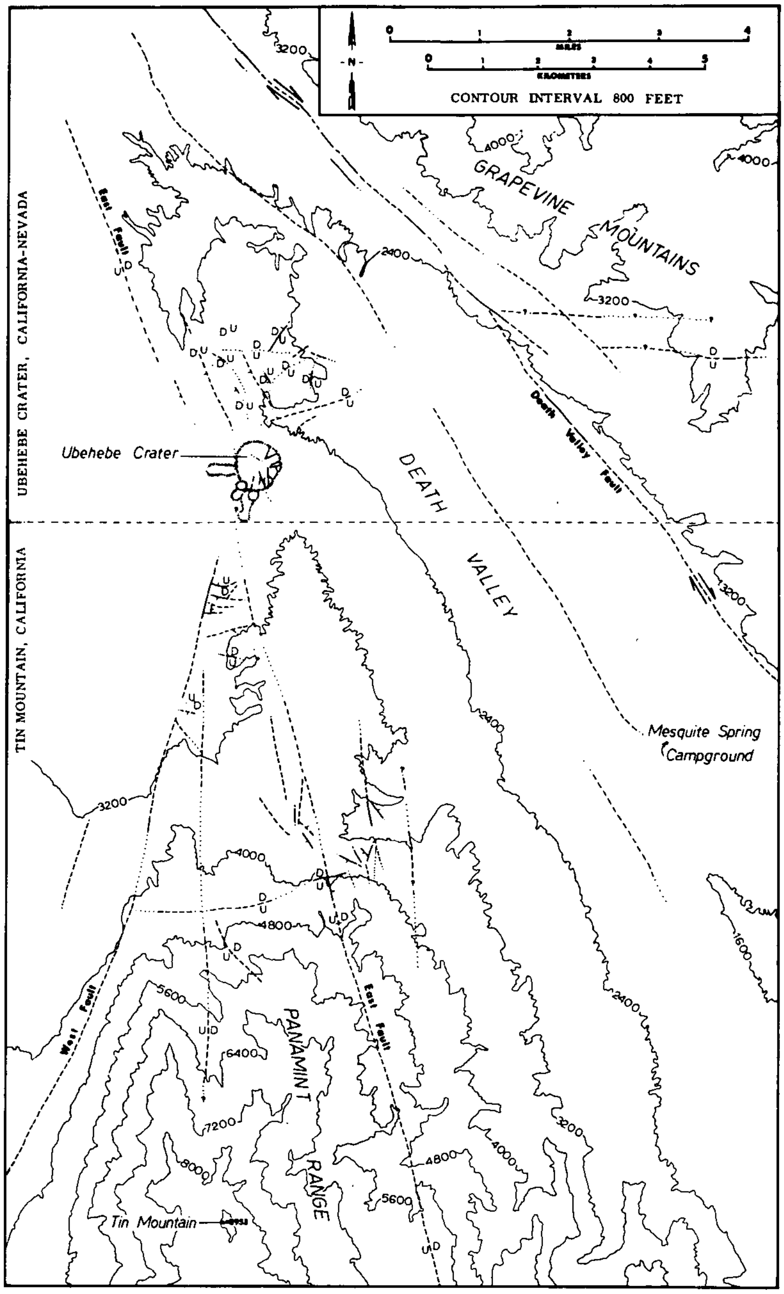

Figure 3 - Structural map of the Ubehebe Craters area based upon field work and analysis of ERTS-1 imagery and low altitude aerial photographs. Topographic base maps used are the Ubehebe Craters and the Tin Mountain Quadrangles. Faults dashed where approximate and dotted where inferred.